APPENDIX C
(English only)

MANUAL ON THE IMPLEMENTATION OF THE
VERY HIGH FREQUENCY (VHF) DIGITAL LINK MODE 3
(VDL MODE 3)

Abstract

This document contains guidance material for the Very High Frequency (VHF) Digital Link (VDL) Mode 3 Standards and Recommended Practices (SARPs) and provides implementation-related information. This document includes material related to system description, concept of operations, and various message formats and protocols of the VDL Mode 3. The document also includes characterization of the overall system performance based on extended simulation of the VDL Mode 3 system during the course of the VDL Mode 3 SARPs development. Concentration of the protocol is on the Data Link Service (DLS) sublayer and Media Access Control (MAC) sublayer based on the Open Systems Interconnection (OSI) 7-layer model, although for the sake of clarity some information on other layers is also included.

KEYWORDS: Aloha, Connection-less Network Protocol (CLNP) compression, Data Link Service (DLS), downlink, Ground Network Interface (GNI), ISO-8208 compression, Media Access Control (MAC), MAC cycle, Management (M) burst, message end-to-end delay, priority, Random Access, burst, Reed Solomon (RS) code, simulation, squelch, Standards and Recommended practices (SARPs), TDMA, throughput, Timing State, uplink, traffic model, VDL, VDL Mode 3, Vocoder, Voice/Data (V/D).
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SECTION 1

1. INTRODUCTION

This document contains guidance material relating to the implementation of the SARPs and detailed technical specifications for the Very High Frequency (VHF) Digital Link (VDL) Mode 3 and will be updated to reflect necessary changes as more backup information as a result of implementation of VDL Mode 3 becomes available. This document includes material related to system description, concept of operations, and detailed description of formats and protocols for the VDL Mode 3. The document also includes characterization of the overall system performance based on extended simulation of the VDL Mode 3 system during the course of SARPs development. Concentration of the protocol is on the Data Link Service (DLS) sublayer and Media Access Control (MAC) sublayer based on the Open Systems Interconnection (OSI) 7-layer model, although for the sake of clarity some information on other layers is also included. This document is organized as follows. Section 1 presents the general information about the VDL Mode 3 system. Section 2 describes the concept of operations for the system. Section 3 lists the message formats, and Section 4 describes the message processing protocols. Section 5 describes the details of the MAC-DLS operations in a possible implementation of the DLS and MAC protocol to support priority queuing. Sections 3 and 4 focus primarily on the VDL Mode 3 configurations other than the 3T and 3S configurations. The special properties of 3T and 3S configurations are described in Sections 6 and 7. Information on special timing states is presented in Section 8. Some miscellaneous additional items are found in Section 9. Section 10 provides simulation-related information including simulation models and performance. Section 11 discusses some of the ground system implementation issues. Section 12 provides examples for implementing data bursts in the system. Section 13 provides an example of state transitions and the associated state diagrams.

1.1 System Time Structure

1.1.1 VDL Mode 3 is a time-slotted system. It is assumed that in normal operation all participants in the system interoperate in an environment where time is distributed from the ground radios to the airborne radios using radio beacon signals described below. In certain circumstances it may be desirable that ground stations have their time coordinated. In that case they are synchronized to an absolute time source related to Universal Coordinated Time (UTC). At times, airborne radios may lose ground/air time coordination. When this happens, special procedures must be followed. These are described in Section 8.

1.1.2 There is a hierarchy of time scales associated with VDL Mode 3. The important concepts include:

   (1) TDMA Frame. The basic unit of time is a TDMA frame, which is 120 milliseconds (ms). In any voice communication, a radio will transmit digitized voice bits periodically once per frame.

   (2) Time Slot. Frames are divided into time slots. There are two classes of VDL Mode 3 configurations which are based on two different time slot sizes. For the 4-slot configurations, the frames are divided into 4 30 ms time slots. For the 3-slot configurations, the frames are divided into 3 40 ms time slots.
(3) Subslot. For most configurations (except 3T) each time slot is divided into two subslots. The first subslot is devoted to Management (M) channel transmissions and the second subslot is devoted to voice or data (V/D) transmissions.

(4) MAC Cycle. A MAC cycle consists of two TDMA frames, an even frame followed by an odd frame. For each TDMA net, in any configuration, there is exactly one uplink M channel beacon per MAC cycle.

(5) Epoch. An epoch consists of 25 MAC cycles, or 6 seconds. The concept of an epoch is used to define how to synchronize a ground radio with an “absolute” time source which provides time update signals at a rate of one per second. This concept is developed more completely in Section 8.

1.2 Configurations

1.2.1 The VDL Mode 3 system provides for a variety of different system configurations. The various configurations differ in the way that the different time slot resources are allocated to different user groups. (Throughout this description a user group will consist of a ground radio and a number of airborne radios which are all interconnected by voice and/or data communications. In some cases a user group is also called a net.) At any given time different user groups can be in different configurations. An airborne radio does not need to know configuration information prior to net initialization. This information is provided by the ground station. There are 4-slot configurations and 3-slot configurations. The 4-slot configurations provide guard time sufficient to allow interference-free communication up to a range of 200 nautical miles (nmi). For long range scenarios, the 3-slot configurations provide for 600 nmi.

1.2.2 The 4-slot configurations include the following:

(1) 4V. Provides 4 voice channels (no data) in one 25 kilohertz (kHz) channel. This mode may, as an option, include downlink M channel transmissions and features such as urgent/priority access, semiautomatic frequency change, and caller ID.

(2) 2V2D. Provides 2 voice and 2 data channels in one 25 kHz channel. These are paired so that one user group uses one voice and data time slot pair and a second, independent, group uses the other voice and data pair.

(3) 3V1D. Provides 3 voice and 1 data channel in one 25 kHz channel. The three voice channels are completely independent; however, the single data channel is shared by the three user groups.

(4) 3T. Provides a trunked capability shared by all users in one 25 kHz channel in which 1 out of 4 time slots is available for voice or data and 2 out of 4 time slots are available exclusively for data. The fourth time slot is used exclusively for channel management functions.
1.2.3 The 3-slot configurations include the following:

1. 3V. Provides 3 voice channels (no data) in one 25 kHz channel. This mode is analogous to 4V, but provides more propagation guard time.

2. 2V1D. Provides 2 voice and 1 data channel in one 25 kHz channel. This mode is analogous to 3V1D, but provides more propagation guard time.

3. 3S. Provides a single voice channel in one 25 kHz channel. The same digital voice bit-stream can be transported on each of 3 time slots used by 3 separate ground sites to provide coverage over an area larger than that which could be provided by a single ground site.

4. 2V1X. Provides 1 wide area voice channel for 2 separate ground stations and reserves another independent channel in one 25 kHz channel. The independent channel is defined separately in its own beacon.

1.2.4 The timing of the 4-slot configurations is shown in Figure 1-1. The 4 time slots contained in each frame are labeled A through D. The timing of the 3-slot configurations is illustrated in Figure 1-2. Whether a slot is used for voice or data is indicated by V or D in each slot. The direction of the arrow indicates whether the M channel in a slot is used for uplinks or downlinks.

1.3 Definitions

1.3.1 To clarify the later descriptions, some system concepts are defined in this introductory section.

1.3.2 ID Numbers

1.3.2.1 There are three types of ID numbers that may seem quite similar in some contexts, but should be differentiated.
Figure 1.1. Four-slot configuration timing diagrams
(1) Slot Number. As described in Section 1.2, the time slots in each TDMA frame are labeled A through D. The field “Slot Number” appears in the uplink M channel message. The Slot Number identifies the slot in which the burst is transmitted. The Slot Number allows entering aircraft to correctly initialize their internal timing to the local time reference.

(2) User Group ID. A user group refers to a ground controller and a group of aircraft who share voice connectivity. A TDMA net is defined by a Frequency and a User Group ID.
(and sometimes a Ground Station Code (GSC)). The range of User Group IDs is (at most) A through D. (The term User Group ID is synonymous with the term Group ID.)

(3) Local ID. The Local ID is an 8-bit number that is used by the participants in a net to take the place (temporarily) of the much longer International Civil Aviation Organization’s (ICAO) address. The Local ID consists of a 2-bit prefix that ranges from A through D and a 6-bit numerical suffix. The prefix is the user’s Group ID; and the suffix, when used separately, is called the Aircraft ID. An important function of the Local ID is the coordination of the polling responses of the airborne radios. (The Local ID is sometimes referred to as the Local User ID.)

In the simplest configuration (4V), the Slot Number, the Group ID, and the Local ID prefix are all the same on a given net. However, this unique relationship is not necessarily true in other configurations. For example, in the 3T configuration an airborne radio may have a Local ID prefix B but will transmit a voice message in time slots labeled D.

Note.— that the Slot Number, the Group ID, and the Local ID prefix are all coded the same way, with A = 00, B = 01, C = 10, and D = 11.

1.3.3 Random Access (RA) Opportunities

1.3.3.1 The downlink M channel slots are divided into two types: those that are scheduled for use by a particular airborne user, and those that support random access (RA) opportunities. Scheduled events include downlink acknowledgments of uplink data addressed to a particular user and poll responses. Acknowledgments are scheduled by the presence of an end-of-message (EOM) indication at the end of an uplink data burst sequence with Message ID = 100 (see Section 3.2). Poll responses are scheduled by uplink M channel poll messages.

1.3.3.2 All nonscheduled downlink M channel slots are available for RA opportunities. These opportunities are used by a number of message types including Net Entry Request, Leaving Net, and Reservation Request messages. The process of choosing a RA slot in which to transmit is described in Section 4.10.

1.3.4 Frames

1.3.4.1 Within the VDL Mode 3 literature there are three types of “frames” defined.

(1) TDMA frame. A TDMA frame defines the period between time slots used for a particular voice message. As described in Section 1.1, a TDMA frame is 120 ms.

(2) Data frame. A data frame is a block of data with a specific address which is generated by the Data Link Service (DLS) sublayer. Each data frame includes a single 24-bit Cyclic Redundancy Check (CRC) code for error detection and a variety of other overhead bits for functions such as “bit-stuffing,” addressing, etc. The DLS will ensure that the largest possible data frame consists of 7440 bits, which exactly fill 15 V/D (data)
bursts. In some cases, the DLS can combine multiple data frames to create a “frame group.” Frame groups must conform to certain size restrictions (especially the 15 burst maximum limit). Grouping is explained in more detail in Sections 4.7.1 and 4.8.1.

(3) Vocoder frame. Normal voice transmissions will consist of a digital bit stream of 4800 bps. A typical vocoder will generate this bit stream as a periodic sequence of data blocks, which are called vocoder frames. An integral number of whole vocoder frames will be transmitted in each time slot. Thus, the vocoder frames must have a length given by $120/n$ ms, where $n$ is a relatively small integer. For the particular vocoder chosen, the value of $n$ is 6 for the normal voice mode (see Section 3.2) and is 5 for the truncated voice mode (see Section 8.2.4).

1.3.5 Golay Word

1.3.5.1 In VDL Mode 3 the V/D headers and the contents of the M channel messages are protected by a Golay (24, 12) code. This is a half-rate code, where 12 information bits are augmented by 12 parity bits. This powerful code will correct any 3-error pattern and detect any 4-error pattern. Each Golay word is transmitted as a contiguous stream of 24 bits (8 symbols) with the parity bits preceding the information bits.

1.3.6 Timing States

1.3.6.1 An airborne VDL Mode 3 radio can be in one of a number of different timing states. The timing state controls the way the airborne radio receives timing information and the types of messages it can and cannot transmit. Which state it is in depends on how well it can guarantee that its internal time is within the accuracy required of a fully-compliant radio. Perfect timing for an airborne radio corresponds to the time of its associated ground radio adjusted by the propagation delay between the ground and the airborne radios. The expected accuracy is within $\pm 1$ symbol period of this time. The timing states include:

(1) TS0. This state primarily describes a radio prior to link initialization. A radio in this state cannot transmit and must search for an appropriate M channel signal, as described in Section 4.1. As described in Sections 6 and 8, TS0 also applies to the 3T configuration in certain scenarios when airborne radios lose contact with the ground.

(2) TS1. After a radio has determined its correct timing by receiving a valid beacon signal from the correct ground station and verifying that beacon by receiving another, it can enter TS1. Only then can an airborne radio proceed to net entry. A radio in TS1 which has also completed net entry can participate in all activities requiring discrete addressing, including data communication. An airborne radio in TS1 which has not completed net entry can communicate by voice only (as described in Section 4.5). A radio can remain in TS1 as long as it can “guarantee” that it is within $\pm 1$ symbol period (95 ms) of its “correct” time.

(3) TS2. If an airborne radio cannot receive beacon signals, it cannot guarantee correct timing. In such a case the airborne radio may be able to receive time from alternate sources. Such timing will normally be degraded from the time received directly from
beacon signals; and an airborne radio in TS2 will transmit “truncated voice” signals (as described in Section 8). A radio in TS2 cannot transmit downlink M channel messages and, hence, cannot transmit data messages.

(4) TS3. An airborne radio which has not received a beacon signal nor any Poll Responses for a specified period of time will assume that it is operating in an area where no ground station is currently providing time. It will then enter TS3 and begin transmitting full-length voice messages in the so-called “free-running” mode as described in Section 8.

1.3.7 Logical Burst Access Channels

1.3.7.1 The concept of a Logical Burst Access Channel (LBAC) has been introduced in the SARPs [1] to help enumerate all of the possible burst transmission opportunities which occur during a MAC cycle on a particular net (or user group) in a particular configuration. The number of LBACs in a configuration is equivalent to the number of arrows plus letters listed for each row in Figures 1-1 and 1-2. Thus, 4V and 3V have 4 LBACs; 2V2D, 3V1D, and 2V1D have 8 LBACs; 3T has 18 LBACs; 3S has 12 LBACs, and 2V1X has 7 LBACs. These LBACs are typically numbered sequentially from left to right. For historical reasons the configurations 4V and 3V violate this rule, and their LBACs are numbered 1, 2, 5, 6.
SECTION 2

2. OPERATING CONCEPTS

2.1 Overview

2.1.1 The VDL Mode 3 system provides functionally simultaneous voice and data communications between airborne and ground-based users. VDL Mode 3 is based on the TDMA technology and is primarily sector-based with dedicated circuits for each user group. The network control concept is based on a centralized net system with the ground station as the network controller. The network controller controls the network configuration, network timing, net entry and exit, and user access for data link.

2.2 System Description

2.2.1 Physical Layer

2.2.1.1 At the physical layer, the VDL Mode 3 system architecture is completely consistent with that of the ICAO VDL Mode 2. This offers the dual benefit of:

a) simplifying the VDL Mode 3 system standardization process since part of an existing standard will apply; and

b) providing a path by which initial implementation of the VDL Mode 2 capability can be upgraded to the integrated voice and data link standard of VDL Mode 3.

2.2.2 Timing Structure

2.2.2.1 The VDL Mode 3 system operation is based on 120 millisecond (ms) TDMA frames. Each VDL Mode 3 TDMA frame contains either four 30 ms slots for normal range operations or three 40 ms slots for long range operations. Each of these slots forms the basis for an independent two-way air ground simplex circuit capable of supporting two way real-time voice or data link applications. Each slot can be independently accessed with two separate bursts. The first of these is a management (M) burst that carries system data for signalling and circuit initialization functions. The second is the V/D burst that carries user information.

2.2.3 System Configurations

2.2.3.1 The VDL Mode 3 system architecture offers a degree of flexibility to accommodate a wide range of operational requirements through a set of predefined system configurations.

2.2.3.2 In the Air Traffic Control (ATC) environment, distinct user groups exist based on ATC positions or sectors. Each user group includes the ground user (usually an air traffic controller) and the

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1 Two types of M bursts are provided: the uplink M burst is used by the ground station for timing and network management and the downlink M burst is used by the airborne users for downlink management functions.
“client” aircraft of that ground user. A fundamental objective of the VDL Mode 3 system is to provide voice circuit resources to each user group on a dedicated basis while simultaneously providing access to data link with a single airborne radio transceiver. To accommodate this functional requirement, a pre-defined set of system configurations is established. Each system configuration corresponds to a specific pre-configured static allocation of the resources (i.e., individual time slots) of each 25 kHz channel to the user groups.

2.2.3.3 To provide additional flexibility, a VDL Mode 3 system can be configured where resource allocations for both voice and data are made strictly on a demand basis within a 25 kHz channel. This configuration could also be used to support a high capacity data-only service if desired.

2.2.3.4 The system configuration established for a ground radio is communicated to the aircraft radios through a beacon signal continually broadcast by the ground station. Aircraft radios acquire this beacon and adapt to the system configuration of the ground radio with which communications will be established. This adaptation to the proper system configuration is completely transparent to the users.

2.2.3.5 3T (Trunked)

2.2.3.5.1 From the standpoint of voice and data access there is only one user group in 3T. The single user group is divided into three groups (designated B, C, and D) for managing the use of the downlink M bursts for poll response more efficiently. Dividing users of a 3T net into three separate user groups B, C, and D allows each group to have a dedicated downlink M burst opportunity to transmit its poll response. Each of the three groups can accommodate up to 60 users for a total of 180 maximal users in 3T.

2.2.3.5.2 Due to the sharing of voice and data in time slot D, the voice transmission over slot D needs to be controlled just like the data slot in order to avoid collision in slot D between voice and data access. Due to this sharing of slot D between data and voice, voice access may be delayed due to ongoing data transmissions. The 3T configuration is suitable in situations where the traffic is predominantly data with relatively light voice traffic.

2.2.4 System Timing State

2.2.4.1 In VDL Mode 3 the ground station establishes the TDMA timing reference for the aircraft users in the user group by periodically broadcast a beacon signal. The aircraft users extract the system timing information from the ground beacon. There are three distinct timing states of the aircraft radios, designated as TS1, TS2, and TS3, which depend upon how accurate an aircraft radio can maintain time relative to the system timing reference derived from the ground beacon.

2.2.4.2 In timing state TS1 an aircraft radio receives periodic timing updates from its ground beacon to maintain accurate time relative to the network time reference. In TS1 the aircraft can access both voice and data services.

2.2.4.3 In timing state TS2 the aircraft radio does not receive its ground radio beacon and its time is being updated by less accurate Alternate Timing Signals from other aircraft or ground sources.
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2.2.4.4 In timing state TS2 the aircraft radios does not have the necessary timing accuracy to operate in data and the normal voice mode to guarantee TDMA timing boundaries, but will be able to operate in a voice mode with reduced vocoder data rate.

2.2.4.5 In timing state TS3 the ground radios are absent and the aircraft radios’ clocks are free running. The aircraft radio will eventually drift to the point that TDMA timing structure can longer be maintained. In TS3 all user groups in a given 25 kHz channel will collapse into a single user group and non-TDMA free-running voice operation based on LBPTT discipline can be supported.

2.2.5 Vocoder Operations

2.2.5.1 Low bit rate digital voice coding (vocoding) is the key enabling technology that gives digital mobile radios high spectrum efficiency for voice operation. Digital voice operation in the VDL Mode 3 system is based on a low bit rate voice coder (vocoder) operating at 4.8 kilobits per second (kbps) in TS1 and TS3 timing states. In timing state TS2, the aircraft vocoder date rate is reduced to output voice at 4.0 kbps (truncated voice) to compensate for its less accurate timing.

2.2.6 Discrete Addressing

2.2.6.1 The VDL Mode 3 system supports voice and data functionality requiring discrete addressing. Discrete addressing in the VDL Mode 3 system is coupled to the user group. A local user ID is established for each new airborne user that enters the group (or net). A process known as net entry serves to automatically “log in” a new arrival to the group. Basic voice operation involving only the “listen-before-push-to-talk” protocol is available without discrete addressing or the net entry process.

2.2.7 Media Access Protocol

2.2.7.1 For voice operation, the media access protocol is based strictly on a “listen-before-push-to-talk” protocol (competition limited only to users within the group) with the added ability for voice signalling as described in Section 2.4.3.3.

2.2.7.2 For data operation, media access employs a centrally managed reservation protocol for all data traffic. This approach gives the ground station maximum flexibility for making efficient use of channel capacity and for implementing prioritization in the media access layer. Access for downlink data traffic is granted by the ground station based on reservation requests made by airborne radios. Access for uplink data traffic is managed directly by the ground station. A complete media access control (MAC) cycle consists of two consecutive TDMA frames for a period of 240 ms.

2.3 Operating Scenarios/Examples

2.3.1 Operating Scenarios for Voice Operations

2.3.1.1 The voice communications system must provide all of the functional capabilities of the present voice system if it is to meet its basic operational requirements. In general, these requirements can be divided into two discrete types:
a) communications channel performance requirements; and
b) coverage requirements.

The coverage requirements are related to the various operating scenarios postulated for the voice communications system and can be further sub-divided into the following groups:

a) air-ground coverage provided by a single ground station;
b) air-ground coverage provided by multiple ground stations;
c) air-air coverage when both aircraft are within the coverage of the ground station;
d) air-air coverage when only one aircraft is within the coverage of the ground station; and
e) air-air coverage when neither aircraft is within the coverage of the ground station.

Note.— Note that, for the purpose of describing these scenarios, the airborne segment is taken to include aircraft on the ground, vehicles and personnel on the ground carrying mobile equipment, and mobile equipment used as a low cost ground stations by some users.

2.3.1.2 Air/Ground Voice Coverage from a Single Ground Station

2.3.1.2.1 Air-ground coverage from a single ground station will satisfy the operating requirements of the majority of users. These users will require the ability to maintain communication within a limited geographical area covered from a single ground station. Typical requirements will include:

a) ground movement, tower, approach and ATIS services at aerodromes;
b) en-route channels for use in busy airspace where coverage requirements can be met from a single ground station;
c) aeronautical operational control (AOC) operations; and
d) other users.

2.3.1.2.2 The AOC and other users may be required to share a common channel in order to improve spectrum utilization. These users will place low traffic demands on the channel and may be geographically distributed such that they each need their own ground station.

2.3.1.3 Air-Ground Voice Coverage from Multiple Ground Stations

2.3.1.3.1 This requirement fulfills the needs of single user groups requiring coverage beyond that achievable from a single ground station. In the present system, this facility is provided by operator selection
of the appropriate ground station or by use of the offset carrier system. The latter technique is often preferred by ground users because it requires a simple human-machine interface.

2.3.1.3.2 The need for multiple ground station operation by a single user group will arise for two reasons:

a) the required coverage area is large; and

b) low level coverage of a single radio station is restricted by topographical features.

2.3.1.3.3 Large coverage areas will be required when an ATC sector controls lightly used airspace and the control team can deal with a large area without experiencing an overload and for other specialized ATC applications. Typical applications will include upper air sectors away from main air routes, FIS, Volmet and oceanic Clearance Delivery channels. AOC communications will also employ wide area networks along high traffic routes.

2.3.1.3.4 Where coverage is restricted because of hilly or mountainous terrain, and ATC sectors require good low level coverage, multiple station operation will also be employed to provide fill-in cover in areas not covered by the primary radio station.

2.3.1.4 Air-Air Voice Coverage When Both Aircraft are Within Range of a Ground Station

2.3.1.4.1 A party line capability, which permits all users of a voice circuit (both air and ground) to monitor the voice traffic, is an essential requirement. Its primary purpose is to facilitate channel management by allowing all users in a user group to be aware when the voice circuit is occupied. Only when the voice circuit is perceived to be free, should users attempt to access it. This capability would also allow direct air-to-air communications and air-crew operating within a sector to monitor the content of all communications and build up a picture of the traffic situation in their vicinity.

2.3.1.5 Air-Air Voice Coverage with Only One Aircraft Within Range of a Ground Station

2.3.1.5.1 The ability to maintain air to air coverage when only one aircraft is within range of a ground station is an essential safety feature which will allow an aircraft outside of coverage to maintain indirect contact with ATC through an intermediary. Although ATC communications systems are normally designed to provide direct air-ground communications with a high availability, a number of technical and operational situations can develop which cause coverage to be reduced. Examples of such situations include:

a) a ground station failure in a multiple ground station system;

b) failure of the primary ground station in a single ground station system and reduced coverage from the back-up ground station due to its non-optimum location;

c) propagation path perturbations due to weather effects, particularly on channels providing coverage on over sea sectors, where land-based radio stations are operating close to their maximum practical range; and
d) aircraft faults and adverse weather conditions (e.g., icing) which require aircraft to descend below the altitudes normally served.

2.3.1.6 Air-Air Voice Coverage When Out of Range of a Ground Station

2.3.1.6.1 An air-to-air communication capability when both aircraft are out of range of a functional ground station is required to support safety back-up procedures. A typical application will be to provide a fallback mechanism in the event of a ground station failure by allowing the affected aircraft to be directed to a standby channel by a communication relay via a co-operating aircraft flying in an adjacent sector. It will also be used to allow aircraft to maintain air to air contact in remote areas, including oceanic areas, where no ground infrastructure exists.

2.3.1.6.2 The ability of mobile user systems to maintain communications links without recourse to fixed ground station will be used to allow other ground users, for example, private flyers, flying clubs, gliding clubs and balloonists to employ portable equipment as a flexible ground station.

2.3.2 Operating Scenarios for Data Operations

2.3.2.1 The data communications subnetwork must provide all of the functional capabilities to meet the basic operational requirements of air-to-ground and ground-to-air point-to-point data link and ground-to-air data broadcast within the user group subnetwork. In addition, the data subnetwork must also provide connectivity through the ground station via a terrestrial communications network to aeronautical telecommunication network (ATN) intermediate systems which will offer access to ground ATN end systems. In general, these requirements can be divided into two discrete types:

a) communications channel performance requirements; and

b) coverage requirements.

2.3.2.2 The coverage requirements are related to the various operating scenarios postulated for the data communications subnetwork. Unlike the coverage requirement of Section 2.1.3.1.3, there is no air-air coverage requirement for data link and there is no data operation involving multiple ground stations serving a common user group. The coverage requirements for data can thus be further sub-divided into the following groups:

a) air-ground coverage provided by a single ground station; and

b) ground-air broadcast coverage.

Note.— Note that, for the purpose of describing these scenarios, the airborne segment is taken to include aircraft on the ground, vehicles and personnel on the ground carrying mobile equipment, and mobile equipment used as a low cost ground stations by some users.
2.4  Concept of Operations

2.4.1  Network Operations

2.4.1.1  Airborne Radio Initialization

2.4.1.1.1 Upon entering a new sector, an aircraft user needs to tune its transceiver to the designated channel and acquire the appropriate uplink M channel broadcast message to establish the proper timing reference and to extract the network information to properly configure its radio.

2.4.1.1.2 A radio can begin operation immediately after initialization (except in 3T configuration). However, it will only be able to operate in the basic voice mode and will not be able to operate in data mode or any of the optional enhanced voice modes, which require the aircraft radio to register with the ground controller to receive a discrete address.

2.4.1.2  Net Entry

2.4.1.2.1 Upon completion of net initialization the aircraft radio transmits a Net Entry Request message in an appropriate downlink M channel. The ground station responds to a Net Entry Request message by transmitting a Net Entry Response message containing a discrete address that the entrant will use while it is in the net. Upon receiving the discrete address, the aircraft user can participate in enhanced voice, air/ground point-to-point data and uplink data multicast services.

2.4.1.3  Connection Management

2.4.1.3.1 Connection management can be automated and driven by an external ground-based application (e.g., ATC procedures or automation) to the degree desired by the Civil Aviation Authority (CAA) or service provider. A completely manual approach to connection management (as is required in the voice-only system) is always available as an option. Alternatively, a semi-automated approach could be used whereby the new channel assignment is uplinked to the proper airborne radio under initiation by the ground user which is then “activated” by the pilot to effect the actual channel change. Finally, a fully automated approach could be used whereby the new channel assignment is uplinked to the proper airborne radio under direct control of an external ground-based application without ground user intervention, which is then “activated” by the pilot to effect the change.

2.4.1.3.2  Automated Handoff

2.4.1.3.2.1 Ground stations supporting 3T configuration may also support automated 3T handoff for airborne users capable of retuning frequencies within 2 ms. To support automated 3T handoff, the ground station transmits a 3T handoff check message after the uplink M burst transmission as a separate burst in slot A of the odd TDMA frames. The handoff check messages are broadcast by all participating ground stations permitting an aircraft station to listen to all nearby ground stations (one per MAC cycle) and determine which ground station provides the strongest signal. In the handoff check message, the current ground station broadcasts its Ground Station Code, Ground Subnetwork Address and the frequencies of up to next four proximate nets to be monitored. Additional proximate nets can be accommodated by rotating the frequencies
through the handoff check burst. The aircraft station will scan through these Adjacent Frequencies in handoff check messages, and compare the received signal quality from the ground stations. After scanning the last Adjacent Frequency, the aircraft station will scan the current ground station frequency again, which may contain different Adjacent Frequency information if there are more than four nets to be monitored. The aircraft station will accumulate and maintain a database of all nearby nets to be scanned, including frequency, Ground Station Code, Ground Subnetwork Address and their latest signal quality measurement. When the signal quality from a proximate ground station is determined to provide a better link than the one provided by the current ground station, the aircraft station initiates an automatic handoff to the new ground station. If the aircraft station cannot acquire the new net, it will attempt to acquire the other nets and the previous net, in descending order of signal quality. The Ground Subnetwork Address can be used by the aircraft when signal quality estimates are close to provide preference to those ground stations that minimize impact to the IDRP protocol by attempting to remain connected to the same router port.

2.4.1.4 Polling

2.4.1.4.1 To provide orderly channel access, the slotted ALOHA random access reservation protocol is supplemented by a sequential polling of its registered users by the controlling ground station. Every uplink M channel can support a polling command from the ground station. Polling is also used by the air and ground radios to support link management.

2.4.1.5 Simultaneously Active Transmitter Lockout

2.4.1.5.1 Implementers are recommended to provide a lockout function to prevent multiple VDL Mode 3 transmitters from being tuned to the same frequency and slot on a common airframe. This is to prevent the passive radio from occupying too much of the local identifier address space and prevent other users from accessing discrete addressing services.

2.4.1.5.2 Alternately, implementers could enable a system to be put in a mode where it would tune to the channel and either never attempt net entry, or log out upon command, so that the radio would only operate as a voice monitoring setup.

2.4.2 System Operations for Voice Service

2.4.2.1 Circuit Initialization

2.4.2.1.1 Upon entry of the logical voice channel into the airborne radio, the airborne radio immediately begins monitoring the M channel uplink associated with the selected time slot and frequency to acquire net timing and net configuration information. The net configuration information is used to initialize the airborne radio with the proper configuration for the net. Initialization takes less than 1 second.

2.4.2.2 Basic Voice Operation

2.4.2.2.1 The basic voice operation is based on the same “listen-before-push-to-talk” protocol used in the current 25 kHz double sideband (DSB)-amplitude modulation (AM) system. Upon net initialization, the pilot is able to monitor the transmissions of any user on the circuit. In addition, the airborne radio will receive
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the voice circuit status from the uplink M burst to indicate the voice circuit to be idle, occupied by an airborne user, or occupied by the ground station. When the circuit is clear, the pilot asserts push-to-talk (PTT) to seize the channel and begins transmission. The basic voice operation provides direct air-air “party line” connectivity within a user group.

2.4.2.2 For 3T configuration, the activation of the PTT will result in the transmission — in the downlink M channel — of a reservation request for voice transmission. Upon receiving the request the ground station will make a time slot assignment if capacity is available. A signal will accompany the assignment to cue the airborne requester to speak. The request and assignment are transparent to the user, other than a short delay required between assertion of the PTT and the cue prompting the user to speak. The 3T configuration also provides “party line” connectivity within its user group.

2.4.2.3 **Voice Signalling**

2.4.2.3.1 Since all airborne radios (even those in PTT transmit mode) continue to monitor the uplink M channel voice circuit status, voice signalling features can be supported. The ground user can be given special status on the voice circuit with the ability to assert PTT at any time and cause any airborne radio in PTT mode to cease transmitting. The airborne user could be informed of the preemption by the loss of local side tone (and presence of ground user audio). Lockout of this airborne user would be reset by release of PTT by the ground user and release of PTT by the airborne user.

2.4.2.3.2 An additional similar capability supported is the ability to resolve contentions among airborne users attempting to access the channel. If one airborne user asserts PTT more than one TDMA frame (120 ms) after another competing airborne user, the logic, signalling, and voice channel monitoring would support contention-free access on a “first come-first serve” basis. Voice channel contentions of overlapping transmissions by multiple airborne users can be either resolved by uplink M channel signalling or by the ground user activating the PTT, thus terminating the transmissions of the airborne users.

2.4.2.4 **3T Voice Operations**

2.4.2.4.1 In the 3T system configuration, aircraft radios utilize the voice request field of the downlink reservation message to request voice access from the ground station. Due to the trunked nature of the system, the voice access may have additional delay over other system configurations while any message occupying the voice slot finishes transmission. The voice circuit access still requires the aircraft radio to exercise the listen-before-push-to-talk discipline, monitor the voice circuit status for possible voice and data activity, and activate the PTT after it has been determined that the voice circuit is idle. Because of the need to submit voice reservations, voice capability is inhibited while the aircraft radio is in TS2.

2.4.2.5 **Enhanced Voice Operations**

2.4.2.5.1 For airborne users that are participating in discrete addressing/data link, some enhancements to voice operation can be supported as options if found operationally desirable from the ground user’s perspective. Essentially this would entail a “caller ID” feature that could reinforce/replace the verbal identities used by the pilot on downlink and a “selective call” feature that enables the ground user to selectively signal
the airborne user that is the recipient of a voice call. The local user ID in the header of the V/D bursts used for voice traffic is used to implement these capabilities.

2.4.2.5.2 Additional optional voice features may be implemented through the use of the downlink M burst include “call waiting” and urgent message indication. The call waiting feature comes into play if an airborne user activates PTT while another user is already talking on the net. When this occurs the airborne radio can transmit a special signal in the voice request field of the downlink M burst. This signal can be used to notify the ground controller that an additional airborne user wishes to speak. If an airborne user is experiencing an emergency, a special downlink M burst can be sent to indicate an urgent need to use the occupied voice channel. This will notify the ground controller of the urgent situation and the controller can take appropriate action.

2.4.3 Data Operation

2.4.3.1 Point-to-Point Data Link Access

2.4.3.1.1 Data link operation is based on user making reservation request to the ground station for the exclusive use of the V/D slots for the duration necessary to complete the data transfer. Data link service requires discrete addressing and is available for the registered users only.

2.4.3.1.2 On downlink, airborne radios with data to transmit make reservation requests via a slotted ALOHA protocol with provision for retransmission, in the event of a collision in the request transmission. In addition to this random access reservation request the ground radio will also periodically poll the registered users in sequence. As each user is polled, it is given an opportunity to use the downlink M channel, without contention, to transmit its reservation request. This ensures that each airborne user will have a chance to have aircraft requests heard by the ground receiver.

2.4.3.1.3 The request includes the message length in terms of the number of V/D bursts required and the priority of the downlink message. Upon successful receipt of a reservation request, the ground station issues a reservation response. The scheduling of downlink message transmissions is controlled by the ground station and is dependent upon the priorities of the messages. On uplink, the ground station schedules its traffic for the V/D uplink bursts also based on message priority.

2.4.3.1.4 For reliable data service, some of the point-to-point data transmissions require acknowledgment. Protocol is provided to initiate retransmission automatically if acknowledgment is not received within allowable time.

2.4.3.2 Data Broadcast

2.4.3.2.1 A one-way data broadcast service can be provided by the ground station in the uplink direction to all its users. Data broadcast messages are treated just like point-to-point data messages in terms of scheduling and are scheduled based on message priorities and first-come-first-serve basis among equal priority messages. The major difference between point-to-point data transmission and data broadcast is that data broadcast messages are not acknowledged. Broadcast messages also do not make use of the Toggle
bit sequencing for duplicate suppression. To improve data broadcast integrity, data broadcast is normally retransmitted multiple times.

2.4.3.3 **3T Trunked Access**

2.4.3.3.1 The 3T system configuration can stream data transmissions across all available slots as commanded by the ground station. The ground scheduler in the case of 3T has more flexibility in assigning the available time slots to the requests. The voice request has priority over data for the use of slot D and the voice reservation can start in even frame or odd frame. In the absence of any voice request, the data reservation can be assigned to start in one of the following fashions:

- C in even B-slot
- C in odd B-slot
- C in even B-slot, skip slot D
- C in odd B-slot, skip slot D
- C in even C-slot
- C in odd C-slot
- C in even C-slot, skip slot D
- C in odd C-slot, skip slot D
- C in even D-slot
- C in odd D-slot

2.4.3.3.2 The data reservation options in the case that the voice slot is occupied will be restricted to the options above that use only slots B and C.

*Note.*— *Note that 3T could also be used to support a high capacity data-only service if desired.*
SECTION 3

3. FORMATS

Various types of message bursts are transmitted in the different VDL Mode 3 subslots. All the burst types share a common overall structure and include the following components:

(1) Ramp up and power stabilization sequence. This consists of no more than 5 symbol periods. The ramp up provides for a gradual rise from zero power to full power (for spectral containment) and the power stabilization sequence provides time for Automatic Gain Control (AGC) settling. One way to implement the proper sequence is to affix three 000 symbols ahead of the beginning of the synchronization sequence. Subsequent filtering with a truncated Nyquist filter will then provide an appropriate ramp up shaping. Other techniques can accomplish the same objective.

(2) Synchronization sequence. The synchronization sequence consists of 16 symbols, which have good correlation properties to allow for accurate burst time synchronization. The synchronization sequence is also called the Unique Word. There are two pairs of synchronization sequences which are described below.

(3) Information. The amount of information contained in a burst depends on the burst type. Most of this section is devoted to describing the different information formats.

(4) Ramp down. The ramp down consists of no more than 2 symbol periods. It provides for a gradual decrease from full power to zero power (for spectral containment). As with the ramp up, the ramp down shaping can be accomplished by allowing the same truncated Nyquist filter to control the waveform envelope.

The types of messages include the following:

(1) Voice/Data. V/D messages are used to convey V/D information. They consist of a ramp up, a synchronization sequence, a header (one (24,12) Golay word), 576 bits of voice or data (or 480 bits in the case of truncated voice), and a ramp down.

(2) Channel Management (M) Uplink. These messages are used to control network functions. They consist of a ramp up, a synchronization sequence, information consisting of 4 (24,12) Golay words, and a ramp down.

(3) Channel Management (M) Downlink. These messages are used to control network functions. They consist of a ramp up, a synchronization sequence, information consisting of 2 (24,12) Golay words, and a ramp down.
There are also some special formats that are used in the uplink M channel of the 3T configuration. These will be discussed in the section on 3T. The remainder of this discussion will focus on the information content of the standard message formats.

3.1 Synchronization Sequences

3.1.1 There are 4 synchronization sequences that are used in VDL Mode 3. These are arranged in 2 pairs called $S_1$ and $S_1^*$ and $S_2$ and $S_2^*$.

$S_1 = 000\ 111\ 001\ 001\ 010\ 110\ 000\ 011\ 100\ 110\ 011\ 110\ 010\ 101\ 100\ 101$

$S_1^* = 000\ 001\ 111\ 111\ 100\ 000\ 110\ 101\ 010\ 000\ 101\ 001\ 100\ 011\ 010\ 011$

$S_2 = 000\ 111\ 011\ 010\ 000\ 100\ 001\ 010\ 100\ 101\ 011\ 110\ 001\ 110\ 101\ 111$

$S_2^* = 000\ 001\ 101\ 100\ 110\ 010\ 111\ 100\ 010\ 011\ 101\ 000\ 111\ 000\ 011\ 001$

3.1.2 The sequences $S_n$ and $S_n^*$ are considered a pair because the phase change sequences they imply differ by exactly 180°/symbol. This allows a single synchronization correlation process, if it is using an appropriate algorithm (see reference 3), to search for both sequences simultaneously. The formats and protocols have been arranged so that a receiver never needs to search for more than one pair at a time. The association of different burst types with different sequences will be described below.

3.2 V/D Formats

3.2.1 The V/D messages include the synchronization sequence $S_2$, 24 bits of header and 576 bits of voice or data information. (For the truncated voice mode there are only 480 bits of information.) The content of the header depends on whether it pertains to voice or data.

3.2.2 The voice header consists of one (24,12) Golay word, so that there are actually only 12 bits of information. These bits are organized as follows:

- Message ID: 3 bits
- Local ID: 8 bits
- EOM: 1 bit

3.2.3 The data header consists of one Golay word containing 12 bits of information. These bits are organized as follows:

- Message ID: 3 bits
- Ground Station Code: 3 bits
- Segment Number: 4 bits
- Spare: 1 bit
- EOM: 1 bit
Note.—Note that the V/D (data) header does not contain any information about the address of the data source or the destination. It is assumed that addressing information will be contained in each individual data frame. Because all data communications are between airborne users and individual ground stations, it is sufficient that each frame contain the 24-bit ICAO address of the airborne end of the link.

3.2.4 The meaning of the Message ID (MID) is as follows:

0 Uplink Voice
001 Downlink Voice: TS1
010 Downlink Voice: TS2
011 Downlink Voice: TS3
100 Uplink Data (Acknowledgement Required)
101 Downlink Data (Acknowledgment Required)
110 Uplink Data (Acknowledgment Not Required)
111 Downlink Data (Acknowledgment Not Required)

3.2.5 The meanings of the timing states of TS1, TS2, and TS3 were discussed briefly in Section 1.3.5 and will be discussed in detail in Section 8. Here it is sufficient to note that the normal state of VDL Mode 3 is TS1. The aircraft Local ID consists of a 2-bit prefix (Group ID) plus a 6-bit numerical suffix (Aircraft ID). The 6-bit numbers are used as follows:

0 Reserved for ground station
1–60 Available for airborne users
61 Discrete addressing not supported/Dummy address
62 Discrete addressing not supported (alternate validity window)/Dummy address
63 Broadcast

3.2.6 The EOM indicates the last burst of a voice or data sequence. EOM = 1 indicates that the current burst (or time slot) is the last one. The GSC is a 3-bit number that identifies the ground station. This number helps to differentiate the correct ground station from others sharing the same frequency in distant service volumes. Note that the range of valid GSC is 1 through 7. A value of 0 is a dummy code meaning “no information.” The Segment Number is a 4-bit number (varying between 1 and 15) that counts the number of a burst in a data burst sequence.

3.2.7 The voice or data information follows the header. For voice messages the first bit of the MID is 0. The voice encoding algorithm will be Augmented Multiband Excitation (AMBE), version AMBE-ATC-10, from Digital Voice Systems, Inc. (DVSI). It generates a 96-bit vocoder frame each 20 milliseconds. There are six vocoder frames per TDMA frame, for a total of 576 bits. For truncated voice, the number of bits is 480, as described in Section 8.2.4. It is assumed that the time slots are aligned in a fixed way with respect to the vocoder and that whole vocoder “frames” are contained in each slot.

3.2.8 For data messages, the first bit of MID is 1. The content of a data message will be subject to error correction and detection coding. The exact type of coding will be described below.
3.3  **M Uplink Formats**

3.3.1  The M uplink messages consist of the synchronization sequence $S_2^*$ and 96 bits. Of these, 48 are information bits, which are contained in four (24,12) Golay words. A message is created by assembling 4 separate words. There are six types of standard words listed below, along with their contents.

- **Beacon 1**
  - Message ID 4 bits
  - Voice Signal 2 bits
  - Aircraft ID (Poll) 6 bits

- **Beacon 2**
  - Configuration 4 bits
  - Slot Number 2 bits
  - Ground Station Code 3 bits
  - Squelch Window 3 bits

- **Reservation**
  - Local ID 8 bits
  - Reserved Slot 4 bits

- **ICAO Address (2 words)**
  - ICAO Address 24 bits

- **Next Net 1**
  - Next Group ID 2 bits
  - Next Frequency 10 bits

- **Next Net 2**
  - Next Net Type 1 bit
  - Next Ground Station Code 3 bits
  - Local ID 8 bits

3.3.2  **Beacon 1**

3.3.2.1  Every uplink M channel message begins with Beacon 1. The initial field of Beacon 1, the MID, identifies the type of information to follow. The first bit of all uplink MIDs is a 0. The remaining bits are described below:

<table>
<thead>
<tr>
<th>MID</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0000</td>
<td>Normal Message</td>
</tr>
<tr>
<td>0001</td>
<td>Net Entry Response 1: No previous link</td>
</tr>
<tr>
<td>0010</td>
<td>Net Entry Response 2: Previous link preserved</td>
</tr>
<tr>
<td>0011</td>
<td>Next Net Command</td>
</tr>
<tr>
<td>0100</td>
<td>Recovery</td>
</tr>
<tr>
<td>0101</td>
<td>Handoff Check</td>
</tr>
<tr>
<td>0110-1111</td>
<td>Spare</td>
</tr>
</tbody>
</table>
Note.— Note that there are two separate Net Entry Response messages. If the new ground station is unable to redirect the link from the previous ground station, MID = 0001 is used. If the new ground station can support redirection, MID = 0010 is used. The defined messages will be described more completely below.

3.3.2.2 The Voice Signal bits indicate the activity that is happening within a particular user group.

<table>
<thead>
<tr>
<th>Voice Signal</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>00</td>
<td>Ground Access</td>
</tr>
<tr>
<td>01</td>
<td>Occupied by Airborne User</td>
</tr>
<tr>
<td>10</td>
<td>Voice Channel Idle</td>
</tr>
<tr>
<td>11</td>
<td>Spare</td>
</tr>
</tbody>
</table>

3.3.2.3 The meaning of these messages is fairly obvious. More details will appear in the section on protocols.

3.3.2.4 The final part of Beacon 1 is the Aircraft ID (Poll) field. This field is used to poll each of the members of a net in an orderly way. The Local ID suffix of the airborne user to be polled is the 6-bit Aircraft ID field. For configurations other than 3T, 3S and 2S1V, the Group ID is the same as the Slot Number in Beacon 2. For 3T, the Group ID is implied by the position of the Beacon 1 field in the uplink M channel burst. For 3S the Group ID is irrelevant and is arbitrarily set to A = 00. For the wide area coverage slots of 2S1V, the Group ID is also arbitrarily set to A = 00. Polling is described in more detail in the section on protocols.

3.3.3 Beacon 2

3.3.2.1 Every uplink M channel message contains a Beacon 2 word that follows Beacon 1. Beacon 2 contains static information that is not expected to change from cycle to cycle. This information is required by radios entering a net. The first field, labeled Configuration, defines how the system is configured in the area covered by the ground transmitter. There can be up to 16 different configurations. Those that have been defined are as follows:

<table>
<thead>
<tr>
<th>Configuration</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0000</td>
<td>4V</td>
</tr>
<tr>
<td>0001</td>
<td>3S</td>
</tr>
<tr>
<td>0010</td>
<td>3V1D</td>
</tr>
<tr>
<td>0011</td>
<td>2V2D</td>
</tr>
<tr>
<td>0100</td>
<td>3T</td>
</tr>
<tr>
<td>0101</td>
<td>3V</td>
</tr>
<tr>
<td>1100111</td>
<td>2V1D</td>
</tr>
<tr>
<td>1000–1111</td>
<td>2S1X</td>
</tr>
<tr>
<td>1000–1111</td>
<td>Spare</td>
</tr>
</tbody>
</table>

Note.— Note that there can be different configurations associated with different ground stations at any given time. It is also possible to provide mixed configurations at a single ground site. For example, a single ground site could support a 2V2D net using slots A and C and two separate 4V nets using slots B and D.
The field called Slot Number is just the number of the slot in which the beacon is transmitted (A = 00, B = 01, C = 10, D = 11). The GSC is a 3-bit number described previously. The Squelch Window is a 3-bit number that is related to the physical size of the volume served by the ground station. More details on the Squelch Window will be found below.

### Reservation

3.3.3.1 The Reservation word is used to acknowledge the receipt of a reservation request or to provide the slots necessary for an airborne radio to transmit up to 15 slots’ worth of data. In the 3T configuration, the Reservation word is also used to reserve slots for airborne voice communications. The first part of the Reservation message is the Local ID of the relevant airborne user. The second field (Reserved Slot) indicates whether the message is a reservation or a reservation request acknowledgment (RACK). A RACK message indicates to an airborne reservation requester that the ground has received the request but is currently unable to reserve any slots.

3.3.3.2 In case the Reservation message is an actual reservation, the Reserved Slot field indicates the slot in which the reservation should begin. For a data reservation, the airborne radio should begin transmitting data bursts in the designated slot in the MAC cycle following the cycle containing the Reservation word. The airborne radio continues to transmit data using every available data slot until the message is completed. In the case of the 3T configuration a voice reservation will begin in the D slot of either the even or odd frame of the subsequent cycle. When a data reservation is given while a voice transmission is active, the data transmission must avoid the D slots. This requirement is also indicated in the Reserved Slot field.

3.3.3.3 The exact meaning of the 4-bit Reserved Slot field is as follows:

<table>
<thead>
<tr>
<th>Decimal</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>No reservation information</td>
</tr>
<tr>
<td>1</td>
<td>RACK</td>
</tr>
<tr>
<td>10</td>
<td>Spare</td>
</tr>
<tr>
<td>11</td>
<td>Spare</td>
</tr>
<tr>
<td>100</td>
<td>Data reservation (start in even B slot)</td>
</tr>
<tr>
<td>101</td>
<td>Data reservation (start in odd B slot)</td>
</tr>
<tr>
<td>110</td>
<td>Data reservation (start in even B slot, skip D)</td>
</tr>
<tr>
<td>111</td>
<td>Data reservation (start in odd B slot, skip D)</td>
</tr>
<tr>
<td>1000</td>
<td>Data reservation (start in even C slot)</td>
</tr>
<tr>
<td>1001</td>
<td>Data reservation (start in odd C slot)</td>
</tr>
<tr>
<td>1010</td>
<td>Data reservation (start in even C slot, skip D)</td>
</tr>
<tr>
<td>1011</td>
<td>Data reservation (start in odd C slot, skip D)</td>
</tr>
<tr>
<td>1100</td>
<td>Data reservation (start in even D slot)</td>
</tr>
<tr>
<td>1101</td>
<td>Data reservation (start in odd D slot)</td>
</tr>
<tr>
<td>1110</td>
<td>Voice reservation (start in even D slot)</td>
</tr>
<tr>
<td>1111</td>
<td>Voice reservation (start in odd D slot)</td>
</tr>
</tbody>
</table>

*Note.— Note that only configuration 3T uses the codes 0100, 0101, 0110, 0111, 1010, 1011, 1110, and 1111.*
3.3.4 ICAO Address

3.3.4.1 When a radio enters a net, it identifies itself using its unique ICAO address, which is 24 bits. As part of the net entry procedure, the ground station echoes this address back up to the entrant along with the entrant’s temporary Local ID number.

3.3.5 Next Net

3.3.5.1 A ground controller can send to a particular user the identity of the Group ID, frequency, and GSC of his next connection using the Next Net messages of the uplink M channel. The first part of Next Net 1 indicates the next net’s Group ID. The following 10-bit field indicates the next net’s frequency. The frequency is encoded so that if the frequency in megahertz (MHz) is X, the message is

\[ \text{“Frequency”} = 40(X-112) \]

For example, if X = 121.525 MHz, then

\[ \text{“Frequency”} = 381 = 0101111101 \]

3.3.5.2 The first bit of Next Net 2 indicates whether the next net is a TDMA net or simply an amplitude modulation (AM) net. A 1 indicates TDMA and a 0 indicates AM. If the next net is an AM net, the Next Group ID bits in the Next Net 1 word indicate whether the channelization is 25 kHz or 8.33 kHz according to the following rule:

<table>
<thead>
<tr>
<th>Next Group ID</th>
<th>Frequency</th>
<th>Channelization</th>
</tr>
</thead>
<tbody>
<tr>
<td>00 X</td>
<td>25 kHz</td>
<td></td>
</tr>
<tr>
<td>01 X</td>
<td>8.33 kHz</td>
<td></td>
</tr>
<tr>
<td>10 X + 0.00833</td>
<td>8.33 kHz</td>
<td></td>
</tr>
<tr>
<td>11 X + 0.01667</td>
<td>8.33 kHz</td>
<td></td>
</tr>
</tbody>
</table>

3.3.5.3 The second field of Next Net 2 indicates the next net’s GSC. (GSC is set to 000 if the next net is AM.) The final field of Next Net 2 is the Local ID of the recipient of the Next Net message.

3.3.6 Message Types

3.3.6.1 In this section, we show how the various types of uplink messages are constructed.

Normal Message (MID = 0000)

| Beacon 1 | 12 bits |
| Beacon 2 | 12 bits |
| Reservation #1 | 12 bits |
| Reservation #2 | 12 bits |

Net Entry Response (MID = 0001 or 0010)
3.3.6.2 The usage of the various uplink M channel message types will be explained in the section on protocols.

3.4 M Downlink Formats

3.4.1 There are three types of downlink M channel messages: (1) Net Entry Request messages, (2) Poll Responses and Next Net ACKs, and (3) everything else.

3.4.2 The Net Entry Request messages consist of the synchronization sequence $S_1^*$ and 48 bits. Of these, 24 are information bits, which are assembled into 2 (24, 12) Golay words. The 24 bits of information are the ICAO address of the entering aircraft.

3.4.3 The Poll Responses and Next Net ACKs consist of the synchronization sequence $S_2^*$ and 48 bits. Of these 48 bits, 24 are information bits assembled as 2 (24, 12) Golay words. Included in each message is a 4-bit MID. To distinguish the Poll Responses and Next Net ACKs from the uplink M messages (which also use synchronization sequence $S_2^*$), the first bit of all such messages is a 1. The remaining bits are defined as follows:

<table>
<thead>
<tr>
<th>MID</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1000</td>
<td>4-Slot Configuration Poll Response (ATS)</td>
</tr>
<tr>
<td>1001</td>
<td>Spare</td>
</tr>
<tr>
<td>1010</td>
<td>3-Slot Configuration Poll Response (ATS)</td>
</tr>
<tr>
<td>1011</td>
<td>Spare</td>
</tr>
<tr>
<td>1100</td>
<td>3T Configuration Poll Response</td>
</tr>
</tbody>
</table>
3.4.4 Other types of downlink M channel messages, including random access Reservation Requests, data Acknowledgments, and Leaving Net messages, consist of synchronization sequence $S_i$ and 48 bits. Of these, 24 bits are information bits, which are assembled into 2 (24, 12) Golay words. The MIDs associated with these messages are:

- MID 1000: Reservation Requests (Random Access)
- MID 1001: ACK
- MID 1010: Leaving Net
- MID 1011: Spare
- MID 1100: Spare
- MID 1101: Spare
- MID 1110: Spare
- MID 1111: Next Net Acknowledgment

Note.— Note that Poll Responses are Alternate Timing Signals (ATS) except in the 3T configuration. The meaning of the designation ATS will be revealed in Section 8.

3.4.5 Message Types

3.4.5.1 The various downlink messages are defined below.

<table>
<thead>
<tr>
<th>Poll Response (S₂*: MID = 1000, 1010, 1100)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reservation Request (S₁: MID = 1000)</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Acknowledgment (S₁: MID = 1001)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Message ID</td>
</tr>
<tr>
<td>Local ID</td>
</tr>
<tr>
<td>Ground Station Code</td>
</tr>
<tr>
<td>Voice Request</td>
</tr>
<tr>
<td>Spare</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Next Net ACK (S₂*: MID = 1111)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Message ID</td>
</tr>
<tr>
<td>Local ID</td>
</tr>
<tr>
<td>Ground Station Code</td>
</tr>
<tr>
<td>Voice Request</td>
</tr>
<tr>
<td>Spare</td>
</tr>
</tbody>
</table>

Leaving Net (S₁: MID = 1010)
Message ID 4 bits
Local ID 8 bits
Ground Station Code 3 bits
Spare 9 bits

Net Entry Request (Si*: No MID)

ICAO Address 24 bits

Note.— Note that every downlink message (except the Net Entry Request message) contains a MID, a Local ID, and a GSC.

3.4.5.2 The Voice Request field contains information related to voice access. The specific messages are as follows:

<table>
<thead>
<tr>
<th>Voice Request</th>
<th>00</th>
<th>01</th>
<th>10</th>
<th>11</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No Request</td>
<td>Routine Request</td>
<td>Priority Request</td>
<td>Spare</td>
</tr>
</tbody>
</table>

3.4.5.3 The Routine Request message is used only in 3T to request time slots for a pending voice message as described in Section 6.2.5. The use of the Priority Request is described in Section 4.5.

3.4.5.4 The use of these messages will be described in the section on protocols.

3.5 Media Access Control Message Format Summary

3.5.1 The various message formats described in Section 3 are summarized in Tables 3-1, 3-2, and 3-3. (The numbers following the colons represent the number of information bits contained.)
### Table 3-1. Burst Format Summary (M Channel Uplink)

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal</td>
<td>0000</td>
<td>S₂*</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Net Entry Response 1</td>
<td>0001</td>
<td>S₂*</td>
<td>Beacon 1: 12</td>
<td>Beacon 2: 12</td>
<td></td>
<td></td>
<td>Next Net 1: 12</td>
<td>Next Net 2: 12</td>
</tr>
<tr>
<td>Net Entry Response 2</td>
<td>0010</td>
<td>S₂*</td>
<td>Beacon 1: 12</td>
<td>Beacon 2: 12</td>
<td></td>
<td></td>
<td>Next Net 1: 12</td>
<td>Next Net 2: 12</td>
</tr>
<tr>
<td>Next Net</td>
<td>0011</td>
<td>S₂*</td>
<td>Beacon 1: 12</td>
<td>Beacon 2: 12</td>
<td></td>
<td></td>
<td>Next Net 1: 12</td>
<td>Next Net 2: 12</td>
</tr>
</tbody>
</table>

{ } = Golay Codeword (two words in the case of ICAO address)

{Beacon 1: 12} = {(Message ID: 4)(Voice Signal: 2)(Aircraft ID (Poll): 6)}

{Beacon 2: 12} = {(Configuration: 4)(Slot Number: 2)(Ground Station Code: 3)(Squelch Window: 3)}

{Next Net 1: 12} = {(Next Group ID: 2)(Next Frequency: 10)}

{Next Net 2: 12} = {(Next Net Type: 1)(Next Ground Station Code: 3)(Local ID: 8)}

{Reservation: 12} = {(Local ID: 8)(Reserved Slot: 4)}
<table>
<thead>
<tr>
<th>Type</th>
<th>Message ID</th>
<th>Sync</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Res. Request</td>
<td>1000</td>
<td>S₁</td>
<td>{(Message ID:4)(Local ID: 8)}{(GSC: 3)(Voice Request: 2)}</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(Number of Slots: 4)(Priority: 3)</td>
</tr>
<tr>
<td>Acknowledgment</td>
<td>1001</td>
<td>S₁</td>
<td>{(Message ID:4)(Local ID: 8)}{(GSC: 3)(Voice Request: 2)(Spare: 7)}</td>
</tr>
<tr>
<td>Leaving Net</td>
<td>1010</td>
<td>S₁</td>
<td>{(Message ID:4)(Local ID: 8)}{(GSC: 3)(Spare: 9)}</td>
</tr>
<tr>
<td>Poll Response</td>
<td>1000/1010/1100</td>
<td>S₂*</td>
<td>{(Message ID:4)(Local ID: 8)}{(GSC: 3)(Voice Request: 2)}</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(Number of Slots: 4)(Priority: 3)</td>
</tr>
<tr>
<td>Next Net ACK</td>
<td>1111</td>
<td>S₂*</td>
<td>{(Message ID:4)(Local ID: 8)}{(GSC: 3)(Spare: 9)}</td>
</tr>
<tr>
<td>Net Entry Request</td>
<td>N/A</td>
<td>S₁*</td>
<td>{ICAO Address: 24}</td>
</tr>
</tbody>
</table>
### Table 3-3. Burst Format Summary (V/D Channel)

<table>
<thead>
<tr>
<th>Type</th>
<th>Message ID</th>
<th>Sync</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Uplink Voice</td>
<td>000</td>
<td>S₂</td>
<td>{Voice Header: 12}(Voice: 576)</td>
</tr>
<tr>
<td>Uplink Data</td>
<td>100/110</td>
<td>S₂</td>
<td>{Data Header: 12}(Data: M)</td>
</tr>
<tr>
<td>Downlink Voice</td>
<td>001/010/011</td>
<td>S₂</td>
<td>{Voice Header: 12}(Voice: 576)</td>
</tr>
<tr>
<td>Downlink Data</td>
<td>101/111</td>
<td>S₂</td>
<td>{Data Header: 12}(Data: M)</td>
</tr>
</tbody>
</table>

M: 496 information* bits + 80 error correction bits
496 information* bits include DLS sublayer overhead for flags, error detection, etc.

\{Voice Header: 12\} = \{(Message ID: 3)(Local ID: 8)(EOM: 1)\}

\{Data Header: 12\} = \{(Message ID: 3)(Ground Station Code: 3)(Segment Number: 4)(Spare: 1)(EOM: 1)\}
3.6 Data Link Service Formatting

The Data Link Service sublayer applies a header to all user data flowing through the VDL Mode 3 protocol stack. This header provides information to identify the ground and airborne entities communicating as well as priority and error detection information.

The format of the frame is as follows:

- Aircraft Station Address: 24 bits
- XOR
- CRC-24Q Parity Word
- Address Type: 3 bits
- Toggle: 1 bit
- More Frame: 1 bit
- Frame Type/Priority: 3 bits
- Subnetwork Address: 6 bits
- Data Length: 10 bits
- User Data: up to 7392 bits

The Address Type field indicates the direction of communication as well as indicating whether the address is a point-to-point address or a multicast address. The field is encoded as follows:

- 000: Directed Ground-to-Air
- 001: Directed Air-to-Ground
- 010-110: Reserved
- 111: Broadcast Ground-to-Air

The Frame Type field indicates the use of the frame contents. It is encoded as follows:

- \( p_0p_1 \): Information (INFO), where \( p_0p_1 \) represents the priority encoding
- 001: Control-Command (CTRL_CMD)
- 011: Control-Response (CTRL_RSP)
- 101: spare
- 111: Acknowledge (ACK)

The Acknowledge frame does not include the Ground Subnetwork Address, Data Length, or User Data fields of the DLS frame.
Details of the DLS protocol are described in Section 5.

3.6.1 **Control Frame Formatting**

3.6.1.1 The CTRL_CMD and CTRL_RSP frames contain one or more parameters to configure the link. Parameters only need to be sent if non-default values are desired.

- Format Identifier (82H) 8 bits
- Group Identifier 8 bits
- Group Length 16 bits
- Parameter Set Identifier 8 bits
- Parameter Length 8 bits
- Parameter Set Value 8 bits
- Parameter Identifier 8 bits
- Parameter Length 8 bits
- Parameter Value Variable

Details of the protocol are described in Section 4.13.

3.7 **Subnetwork Formatting**

The Subnetwork sublayer applies a header to all user data it passes to indicate the network interface to use and to support any compression used. The first byte of the user data in the DLS frame is a payload field.

- Network Type 4 bits
- Compression Type 4 bits

3.7.1 **VDL Packet Layer Protocol (ISO8208) Interface**

The VDL PLP interface is identified by a Network Type field of 0. ISO 8208 compression is described in Section 4.15.1.

3.7.2 **Connectionless Network Protocol (CLNP) Interface**

The CLNP interface is identified by a Network Type field of 1. The Compression Type (CT) field indicates the compression status of the subnetwork packet:
Compresssion Type | 0000 CLNP  
|-------------------|-------------------
| 0001 Restart  
| 0010 Uncompressed CLNP with compression information  
| 0011 Compressed CLNP - Long with Options  
| 0100 Compressed CLNP - Long  
| 0101 Compressed CLNP - Short  
| 0110 Multicast  
| 0111-1111 Reserved

The CLNP compression header removes the Protocol, Version, and Packet Length fields and prepends the following header in their place. This ensures the packet size does not increase even when an uncompressed packet is sent to set the compression state information.

The Short Compressed header is formatted as follows following the payload byte:

- **Index Number**: 7 bits
- **Q (QOS Present)**: 1 bit
- **Priority**: 4 bits
- **Quality of Service (QOS)**: 4 bits
- **Security**: 8 bits

The Long Compressed header is a variable length format that includes a Short Header followed by a series of bits indicating whether certain optional fields are included:

- **D**: Discard Reason (ER PDU Only)
- **L**: Total Length
- **O**: Segment Offset
- **H**: Lifetime
- **T**: Sequencing vs. Transit Delay(S/T) bit of QOS field
- **M**: More Segments (MS) bit from CLNP header
- **E**: Error Report (ER) bit from CLNP header
- **S**: Segmentation Permitted (SP) bit from CLNP header

For these optional fields, their order of inclusion in the header is as follows:

- Lifetime
- Data Unit Identifier
- Segment Offset
Total Length
Discard Reason

If the CT field indicates that options are included, then these will follow here before the user data of the network packet. A one-octet length field precedes the options indicating the length in octets of the option fields.

The protocol supporting this subnetwork interface is described in Section 4.15.2.

3.7.3 Raw Interface

The raw interface is identified by a Network Type field of 2. The Compression Type (CT) field is always set to 0. This interface is used to imply no networking protocol is being used. This is primarily intended to support Minimum Operational Performance Standards (MOPS) testing. It could also be used for a dedicated link, if so desired by a given State.
SECTION 4

4. PROTOCOLS

Described in this section are the various protocols to be followed by the radios in performing their functions. Emphasis is placed on the “normal” operations of the system, when all the radios of a group (in the air and on the ground) have full connectivity. In such case, a new radio joining the group can establish an air/ground link through a process of net initialization and possibly net entry. If only net initialization is accomplished, then only a rudimentary voice capability is possible. However, if net entry is completed, the full range of services provided by the local configuration is available.

Cases of “abnormal” operation, when air/ground connectivity is lost, are covered in Section 8. There it is pointed out that there is a sequence of timing states, labeled TS0 through TS3, that describe an airborne radio’s connectivity status. This section focuses on TS0 and TS1. TS0 refers to a radio which has not yet completed net initialization, and TS1 refers to a radio which has completed net initialization and has maintained its connection with the ground. TS2 and TS3 apply to radios which have lost (or never had) air/ground connectivity.

Finally, a general rule, which is obeyed by all the protocols, is as follows:

In every case the information contained in an uplink M channel message is based on information that is available to the ground station at the end of the previous cycle. The “instructions” in the uplink M channel message will pertain to the activities of the airborne radios starting in the next cycle. The only exception to this rule is that if voice signaling information is made available in the first half of a cycle it will affect the uplink M channel in the same cycle. For example, if a voice message is transmitted in a V/D channel in the first half of a cycle, the M channel beacon will so indicate in the next uplink M channel message. This exception does not apply to the 3T configuration.

4.1 Link Establishment

All airborne radios perform link establishment within a particular net prior to performing any other function. A net is determined by a particular frequency, Group ID, and GSC.
4.1.1 **Net Initialization**

4.1.1.1 The first part of the net initialization procedure is the reception (or acquisition) of the appropriate uplink M channel beacon signal. To accomplish this, the airborne radio is set in receive mode. During this period, the receiver attempts to synchronize with incoming signals—looking for an appropriate GSC. Note that upon first entering into the TDMA system a radio and its operator may not know the appropriate GSC or may not have a way to enter the code into the radio’s memory. In that case, the default GSC is 000, which will signify that the radio should accept a valid signal without regard to the GSC. The initializing radio will assume the received GSC is the correct one. If there are two or more successful synchronizations, one is chosen by using some criterion such as signal strength. (There could be more than one if, for instance, the same frequency and slot is used in a nearby service volume. This “incorrect” signal is supposed to have [20] decibels [dB] less power than the “correct” one; but it still might be strong enough for a successful synchronization. It is highly unlikely that this situation will arise since nearby service volumes should have different GSCs.)

4.1.1.2 Note that the net entrant must be able to accommodate overlapping signals. If two signals of unequal strength are present, the receiver must successfully receive the stronger of the two provided the signal strength difference is at least [20] dB. If the weaker signal precedes the stronger one, the receiver may synchronize with the weaker one. Nevertheless, the receiver must recognize the stronger one. This means that the receiver must do one of two things during initialization: (1) continue to search for new signals while demodulating old ones (replacing the old with the new), or (2) make an initial scan, searching for synchronizations and measuring signal strengths, etc., choosing the best candidates for full demodulation later.

4.1.1.3 If the entrant identifies one or more signals with the correct GSC, it will then check the Configuration field. If the configuration is *not* 3T or 3S, it will then check that the Slot Number field agrees with the Group ID of the net it is trying to enter. (If the configuration is 3T, the Group ID and Slot Number may not agree, and the special procedures necessary are described in Section 4. For 3S, the entrant will choose whichever slot (A, B, or C) appears to provide the “best” signal as described in Section 5.) Having identified a candidate beacon signal, the airborne radio will verify it by detecting the same beacon in a later MAC cycle and determining that the information in Beacon 2 has not changed. (In general, a beacon is considered valid only if the information in the Beacon 2 word is the same as the information in the Beacon 2 word in the previous beacon reception. The effect of this is that a minimum of 2 beacon receptions is required for net initialization.) If all the tests are passed, the new net’s configuration and timing are known, and the airborne radio enters Timing State 1 (TS1). It then can proceed to the next stage—net entry.
4.1.2  **Net Entry**

4.1.2.1  A radio can, as an option, begin operation immediately after net initialization, i.e., as soon as it enters TS1. However, it will be able to transmit only voice messages and will not be able to use functions requiring downlink M channels, such as two-way data transmission. Normally, a net sign-in procedure must occur. (Note that a ground station beacon with Local ID = 61 indicates that the ground station does not support discrete addressing, and net entry should not be attempted.) This process is begun when the airborne radio transmits a Net Entry Request message in a downlink M channel RA opportunity. Prior to signing in, the entrant must determine the location of the possible RA opportunities. This is done by listening to the net for one entire cycle. During this listening period, the entrant notes which slots are scheduled for acknowledgments (ACKs) and poll responses. This process can take place in the same MAC cycle during which the beacon was “verified.”

4.1.2.2  The entrant will use an appropriate RA opportunity for net entry. In order to indicate to the ground station the identity of the user group it wishes to enter, the entrant must transmit its Net Entry Request message in a RA opportunity associated with that user group. For the 4V (and 3V) configuration, this opportunity is just the poll response slot (if it is unused for polling). For the 2V2D configuration, any downlink M channel opportunity labeled A or C will indicate user group A. For 3T, an entrant may use any available RA slot. If no appropriate RA slots are available in one cycle, the entrant must wait until the next one. The rules for choosing RA slots based on a random number generator are discussed in Section 4.10.

4.1.2.3  The Net Entry Request message consists of a special net entry synchronization sequence \(S_1^k\) plus the entrant’s ICAO address (and nothing else). Note that the net entry synchronization sequence is similar to one of the downlink M channel synchronization sequences \(S_1\) except that all the phase changes are incremented by 180 degrees. Because of this relationship, one synchronization procedure can search for both synchronization patterns simultaneously.

4.1.2.4  Upon receiving a Net Entry Request, the ground station responds by transmitting a Net Entry Response message (MID = 0001 or 0010) containing the entrant’s ICAO address plus the Local ID number that the entrant should use while it is in the net. The ground station will send MID = 0010 if it already has enough information to connect the entrant to the ground network for two-way data link operation. It will send MID = 0001 to initiate additional procedures required for ground network management.

4.1.2.5  The pool of Local ID numbers that are available to be distributed depends on the configuration of the net. For instance, for all configurations except 3T and 3S the Local ID prefix always agrees with the User Group ID. However, for the 3T configuration the Local ID prefix is chosen by the ground station based on other considerations, as described in Section 6. For 3S the Group ID is not relevant, and a single, arbitrary ID (i.e., A) is used for all users.

4.1.2.6  There can be up to 60 Aircraft IDs provided for each Local ID prefix. The ground station will choose an ID number between 1 and 60. Number 0 is reserved for the ground station. Numbers will be assigned to the airborne users in sequence. Thus, if the previous entrant had been given number M, then the new entrant will be assigned number M+1. If the number M+1 has already been assigned then the next higher available number will be chosen. For the purposes of this algorithm, the numbers are “rolled over” so that the next number after 60 is 1. If all the numbers are used up, the number 0 will be given to indicate a full net. If
Aircraft ID = 0 is indicated, the airborne radio can still participate in the net in a limited way (using the dummy ID = 61). In this case, the airborne radio becomes the equivalent of a radio that has not “signed in,” which cannot provide features that require discrete addressing. The airborne user should be given some indication (to be determined) to tell him he is entering the net with reduced capability. If this is not acceptable the operator can take appropriate action.

4.1.2.7 The Net Entry Response message also acts as a polling command (see Section 3.3). Thus, the airborne user will respond with a Poll Response message (see Section 2.4) in the following polling slot. This message may or may not contain a reservation request depending on other considerations.

4.1.2.8 If the Poll Response has the correct information (i.e., the entrant echoes back the correct Local ID) then the ground radio will confirm that the net entry procedure has been successfully completed by sending some sort of Reservation message to the entrant. If the entrant requested slots in its Poll Response and slots are available in the next cycle, an actual reservation will be delivered. For all other cases, a RACK must be delivered. Note that this is the only case where a RACK is delivered after a poll response. Otherwise, RACKs are provided only for RA Request Messages.

4.1.3 Net Entry Retransmission

4.1.3.1 Normally, an airborne radio will receive a response within one cycle of transmitting a Net Entry Request message. However, if more than one radio attempts to enter in one cycle, the ground radio will not be able to respond to them all at once. The ground radio will generally respond to entry requests in the order it receives them.

4.1.3.2 To account for a possible delayed response the net entrant will wait for a number of MAC cycles equal to WE before it initiates another Net Entry Request using a new random number as discussed in Section 4.10. This process may result in a duplicate Net Entry Request (i.e., with the same ICAO address) being received by the ground radio before it can respond. If this occurs, the second request will be rejected.

4.1.3.3 Each time a Net Entry Request fails to elicit a response, a counter is incremented. If this counter reaches 3, the net initialization process is started again and the counter is reset to 0. Also, each time a Net Entry Request fails to elicit a response, a second counter is incremented. When the second counter reaches the threshold, NL1, an upper level protocol (SN-SME) is notified and the data link connection (if any) may be declared broken.

4.2 Acquisition Window/Squelch Window/Validity Window

Three types of “windows” are typically used to control the signals that are received and processed by the airborne and ground radios. The sizes of the windows are measured in symbol periods.

The first type of window is the acquisition window, which applies to the synchronization sequence for which the receiver should search. Airborne radios will always receive signals whose synchronization sequences are $S_1$ or $S_2^*$, which can be simultaneously searched by a single correlator. Thus, the concept of an acquisition window doesn’t apply to airborne radios. However, ground radios have to search
for $S_1$ and $S_1^*$, or $S_2$ and $S_2^*$, depending on the situation. The ground radio will set its acquisition window for $S_2$ and $S_2^*$ during V/D subslots and in M subslots scheduled for Poll Responses. During M subslots which are scheduled for downlink ACK messages or are available for downlink random access messages, the acquisition window is set for $S_1$ and $S_1^*$. Note that there is never a requirement for a ground radio to search for both $S_1$ and $S_2$ simultaneously.

The second type of window is the squelch window. The squelch window is used to determine which of the received V/D messages are actually processed. When the airborne radio is searching for a new voice signal, the squelch window is set to the value specified in the uplink M channel beacon. After it has begun to receive a voice message, the squelch window should be reduced to ±1 symbol periods with respect to the perceived timing of the voice message. After EOM, the window should return to its larger value. For data reception by aircraft radios, the window is the same as that for uplink voice messages.

The third type of window is the validity window. The validity window is used to control the processing of M channel messages. When an airborne radio is in net initialization mode (TS0) its validity window is wide open; it is looking for any M channel signal. After net initialization, when it is searching for uplink M channel signals, its validity window should be reduced to the range from -1 to +1 symbol periods with respect to the timing of its most recent successful beacon reception. (The finite size of the range is to account for clock drift between M channel receptions; it is assumed that the airborne radio will update its clock often enough to keep its error significantly less than one symbol period under normal circumstances.) A beacon is considered valid if the information in the Beacon 2 word (including GSC) is unchanged from the previous Beacon 2 information and if it falls within the current validity window. If either of these conditions is not met, the new Beacon 2 information and timing information will be held in escrow until it is confirmed by the next beacon reception. Note that this beacon processing rule also applies to cases where the ground timing shifts abruptly (perhaps due to a switch from main to backup transmitters) as described in Section 9.6.

In cases where the ground station is supporting a select-key operation, as indicated by aircraft ID 62 in the ground beacon, the validity window should be increased to the range from –K(n+1)+1 to +1, where, K=4 for 4-slot configurations and K=8 for 3-slot configurations, and n is the squelch window parameter. (Beacons outside this window should be completely ignored and not held in escrow, as above.) This allows the aircraft radio to track the closest ground station. Due to a failure or other circumstance, a particular ground station may be removed and/or replaced. In this case, the distance between an aircraft radio and its nearest ground station might increase abruptly. To accommodate this possibility, the aircraft needs to react in a timely fashion. To allow it to do so, it should extend its validity window to include all relative time differences whenever its counter CTC1 exceeds 24. This change will enable it to find a valid beacon before it enters timing state TS2.

For ground stations, the squelch window for V/D channels and the validity window for M channels should be equivalent to the size transmitted to the airborne users as the Squelch Window parameter. This is described in more detail in Section 8.2.6. Again, for V/D messages the window can be temporarily reduced after the initial synchronization.

As described in Section 3.3.2, Squelch Window is a 3-bit parameter indicating to an airborne radio the range over which to search for a voice signal. This range depends on the size of the volume being served. The size is measured as the largest distance from the ground station to any part of the service volume.
The relationship between the squelch window parameter, the timing of the window (in symbol periods), and the size of the service volume (in nmi) is shown in Table 4-1.

Normally, an airborne receiver will accept a voice message from an airborne transmitter only if the message falls within the relevant squelch window. Ground voice and data messages should be accepted if they are within a window of ±1 symbol periods. As described in Section 8, a radio may enter the “truncated voice” mode if it loses contact with the ground station. To receive such messages, receivers need to accept messages within the extended window boundaries as described in Table 4-1. Except for the last column, the entries are in units of symbol periods. Section 8 also describes the so-called “free-running” voice mode (TS3). The window for receiving such messages is wide open.

Note that Table 4-1 applies to airborne radios receiving voice messages. The radios are assumed to be in TS1 and in a 4-slot configuration. Other timing states and configurations are dealt with in Section 8.

### Table 4-1. Squelch Window Values

<table>
<thead>
<tr>
<th>Squelch Window</th>
<th>Beginning of Window</th>
<th>End of Window</th>
<th>End of Extended Window</th>
<th>Size (nmi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>-2</td>
<td>4</td>
<td>36</td>
<td>15</td>
</tr>
<tr>
<td>1</td>
<td>-2</td>
<td>8</td>
<td>40</td>
<td>46</td>
</tr>
<tr>
<td>2</td>
<td>-2</td>
<td>12</td>
<td>44</td>
<td>77</td>
</tr>
<tr>
<td>3</td>
<td>-2</td>
<td>16</td>
<td>48</td>
<td>107</td>
</tr>
<tr>
<td>4</td>
<td>-2</td>
<td>20</td>
<td>52</td>
<td>138</td>
</tr>
<tr>
<td>5</td>
<td>-2</td>
<td>24</td>
<td>56</td>
<td>169</td>
</tr>
<tr>
<td>6</td>
<td>-2</td>
<td>28</td>
<td>60</td>
<td>200</td>
</tr>
<tr>
<td>7</td>
<td>No Information</td>
<td>No Information</td>
<td>No Information</td>
<td>No Information</td>
</tr>
</tbody>
</table>

4.3 Polling

In order to provide guaranteed access for reservation requests and link management functions, the slotted ALOHA reservation protocol provided by the RA downlink M channel slots is supplemented by an orderly polling procedure. Every uplink M channel message (except the Handoff Check message, where it’s irrelevant) can support a polling command from the ground station using the Beacon 1 word. In the absence of a net entrant, the ground station will sequentially poll all of its “registered” airborne radios in ascending numerical order. (The numbers are “rolled over” so that 1 follows 60.)

One exception to this algorithm occurs during net entry. In that case, the net entrant will be issued a poll command in the form of a Net Entry Response message (MID = 0001 or 0010) in the cycle following the Net Entry Request. Note that it is possible that more than one Net Entry Request can be received in one cycle. In such cases, Net Entry Requests will be serviced in the order they are received, and the normal polling sequence will be resumed after all net entrants are served.
As stated in the first paragraph of this section the normal polling sequence will be in ascending numerical order. The schedule depends on the configuration and on the number of users as follows. For configurations 2V2D and 3T, if the current number of users with a particular Group ID is $N$, then

1. If $N \# 4$, there will be one poll command every fourth cycle.
2. If $4 < N \# 8$, there will be a poll command every other cycle.
3. If $8 < N \# 12$, there will be one “no poll” every fourth cycle.
4. If $12 < N$, there will be a poll command every cycle.

These rules guarantee that (in the absence of net entrants) every user is polled at least as often as once per 3.84 seconds, wherever there are 16 or less users. The “no poll” message will be denoted by the value 0 in the Aircraft ID (Poll) field. This feature will provide opportunities for net entrants to use the poll response slot periodically for net entry requests.

For configuration other than 2V2D and 3T the above sequence ends at the second step. Thus, the maximum polling frequency is every other cycle.

Note that if a ground station does not support polling or any other type of downlink M channel activity, it will transmit the value 61 in the Aircraft ID (Poll) field of its uplink M channel message.

Below is a summary of meanings of the various possible entries in the Aircraft ID (Poll) field of Beacon 1.

0 In the case of a Net Entry message, this means that the net supports addressing, but there are no available addresses at this time. For all other message types, this means that no poll response is scheduled in the next cycle. In either case, the poll response slot in the next cycle is available for RA.

1–60 In the case of a Net Entry message, this is the new ID number of the entrant identified by the attached ICAO number. In any case, this is the ID of the airborne user who must respond in the poll response slot of the next cycle.

61 This means that the ground station does not support addressing. Only voice communication is possible (and possibly uplink data broadcasts).

4.4 **Net Exit**

The process of leaving a net will be enabled manually by the airborne user of a radio that is currently signed into a particular net. (This process can also be automatic in the 3T mode.) The identity of the new net can be entered manually or automatically.
4.4.1 **Next Net Message**

The process of net transfer can be initiated by the ground controller by transmitting to a particular user the frequency, Group ID, and GSC of its next net. This manual operation will cause a Next Net message to be sent. The Next Net message will also contain the current Local ID of the intended recipient. In addition, the message indicates if the next net is a TDMA net or an AM net. In either case, the relevant information is held in the memory of the airborne radio until the airborne user allows the transfer to occur.

To ensure that the Next Net message is received correctly, the Next Net message will be sent twice in two consecutive cycles. In order for the message to be accepted by the recipient, both Next Net messages must be identical.

4.4.2 **Next Net Acknowledgment**

If an airborne radio receives two identical Next Net messages in consecutive time slots, it will indicate success to the ground station by transmitting a Next Net Acknowledgment (Next Net ACK) message in response to its next polling command. If the ground station does not receive a Next Net ACK as a response, it will retransmit a Next Net message pair. Note that if the ground receives a Leaving Net message (see below) prior to the time it polls the Next Net message recipient, the ground station will treat it as an alternative form of acknowledgment and will *not* repeat the Next Net transmission.

4.4.3 **Leaving Net Message**

Upon activation, the radio will transmit a Leaving Net message (MID = 1010) in its current net and enter the new net. This Leaving Net message should be sent in a RA slot as described in Section 3.10. After transmitting this message the exiting radio is free to participate in its new net; and, upon reception, the ground radio will remove the radio from its list of active users and make the Local ID number available for new entrants.

If the ground radio should miss the Leaving Net message for any reason, it will eventually note the absence of the exiting radio via the polling procedure. If the ground radio fails to receive NL2 (default =3) consecutive responses (Poll Responses or Next Net ACKs), the airborne radio will be considered a candidate for purging. For data operation, the ground Link Management Entity (LME) will change the link status to “idle” and other appropriate action as outlined elsewhere will be taken. For voice operation, notification to the controller or air traffic control (ATC) automation can be supported.
4.5 **Airborne Voice Transmission (Not 3T)**

Under normal circumstances, an airborne user waits for a quiet period and begins voice communication by activating push to talk (PTT). This will cause the radio to begin transmitting in the first available voice time slot. The header will contain MID = 001, the Local ID, and EOM = 0. A radio that has no local ID will substitute the dummy ID = 61. It may happen that the radio will begin transmitting before a full complement of vocoder frames is available (there may even be no vocoder frames to transmit). If this occurs, the unfilled frames should be filled with a “silence” pattern. When PTT has been deactivated, the header will contain EOM = 1 in the last time slot of the V/D (voice) burst sequence. Note that the maximum duration of downlink voice message is 35 seconds. If PTT is activated for a longer time, transmission will cease and the user will be notified.

A net entrant can transmit a voice message prior to completing the net entry procedure. However, such a radio must use the dummy Local ID value (= 61) until its new Local ID is confirmed by an appropriate Reservation message.

Upon receipt of a voice message, the ground radio will change the beacon message Voice Access field from 10 (idle) to 01 (occupied by airborne user).

An airborne radio transmitting voice will monitor the M channel uplink. It expects to see Voice Signal = 01. If an uplink M channel beacon without Voice Signal = 01 is received after 2 or more MAC cycles, the radio will assume nonreceipt by the ground and cease transmitting. An audible signal will be delivered to the airborne operator, who can try again. (The assumption here is that the failure was caused by two or more radios being activated nearly simultaneously or by the fact that the airborne voice message fell outside the ground radio’s squelch window.)

If PTT is activated while a voice signal is already on the air, the radio will not transmit, and an audible signal (e.g., the preexisting voice message) will be delivered to the operator. The airborne radio has two ways of knowing that a voice signal is already on the air: (1) a voice message is being received, or (2) the M channel uplink beacon has its voice signal bits set to 00 or 01. If either (or both) is true the radio will not begin transmitting.

If the airborne user has an urgent message, a “priority”M channel signal can be sent. The Voice Request field will read 10. When the ground radio receives this message, it can activate a special feature on the ground display that will indicate an urgent/priority message. The controller can then take appropriate measures. This feature could be supported as a future option.

The slots used for sending and retransmitting the urgent/priority message are chosen using the same rules that are used for making a data reservation request. The airborne user will continue sending the message until it receives a RACK.

*Note.— Note that an EOM normally appears in the header of the last burst of a voice message. For a number of reasons, it may happen that this EOM is not received. In this case, the receiving radio will continue to “look for” the absent voice signal. In order to account for this possibility, the radio should declare the message ended if 2 successive bursts are missed. During this*
time, the receiving vocoder should be supplied an appropriate message. This procedure allows the receiver to ride through a short fade while still purging vanished signals in a timely way. For the purposes of this procedure, missing a synchronization or receiving a header that fails validation constitutes a missed burst.

4.6 **Ground Voice Transmission (Not 3T)**

Under normal circumstances, a ground user also waits for a quiet period before activating PTT. When this occurs, voice will be transmitted in a fashion similar to airborne transmissions. The header will contain MID = 000 and the Local ID will consist of the Group ID and 6-bit number 000000 that is reserved for the ground.

While the ground transmitter is transmitting voice messages, the Voice Signal bits of the M channel uplink beacon will be set to 00 (ground access).

If the voice channel is already occupied by an airborne user when ground PTT is activated, the ground radio will begin transmitting beacon messages with Voice Signal set to 00. Voice transmission will not begin until the next available voice time slot following the change in the beacon signal. This procedure may entail a very small amount of clipping of the uplink voice signal. However, the clipped portion would (most likely) have been lost anyway due to interference caused by the airborne user before it ceases transmission in the next MAC cycle. As an alternative to such clipping, the ground radio can store the digitized voice until the designated time. This may add up to 240 ms to the throughput delay for such a message.

It is clear from the previous paragraph that uplink voice messages will preempt downlink voice messages. Even if an airborne user has activated PTT, his radio will cease transmitting. He will be aware of this change because he will hear the uplink voice message. This preemption feature will allow the controller to correct the “stuck microphone” problem verbally.

4.7 **Airborne Data Transmission**

In order to transmit data messages, an airborne radio first needs to reserve data slots. To request a reservation, an airborne radio chooses a RA slot (using a random number as described in Section 4.10) and uses it to transmit a Reservation Request (MID = 1000). The request contains the airborne user’s Local ID and the number of data slots desired (up to 15). Note that if the number of slots desired is set to 0, then the request message indicates that no data slots are needed (although the message may contain a request for voice slots in the 3T configuration). If it is a request for data slots, the request can be assigned up to 8 levels of priority using the 3-bit Priority field.

Using an algorithm described in Section 4.9, the ground station will determine the time when the data reservation request can be honored. This information is conveyed to the requester using one of the Reservation words of the normal message (MID = 0000). This word contains the requester’s Local ID and the identity of the slot where the data transmission should begin. The manner in which this information is coded is described in Section 3.3.3. The airborne transmitters will then use all available data slots consecutively until the reservation is completed. In all cases, the requester should assume that the number of slots that was requested has been granted.
It is possible that the ground station received a Reservation Request message but is unable to supply a reservation due to the unavailability of time slots. If this is the case then the ground station can send a Reservation Request Acknowledgment (RACK) (as described in Section 3.3.3). The RACK message should be transmitted whenever there is a RACK message to be sent and there are Reservation words available in the uplink M channel which would otherwise be unused. The RACK should be transmitted on a first-in-first-out (FIFO) basis.

It may happen that a reservation request is not received by the ground station. This can happen due to a conflict or a noisy channel. Also, it is possible that a Reservation or a RACK cannot be transmitted in a timely fashion. In either case, the airborne radio can retransmit its request after waiting WR MAC cycles. The exact retransmission algorithm is described in Section 4.10. To reduce the possibility of reservation conflicts, the retransmitted request must be for a number of slots equal to or less than the number requested previously. This is necessary because the eventual Reservation message cannot indicate which request elicited it. To increase the number of slots requested, an airborne user must wait until its next poll response. The RA process may continue until the airborne radio receives a poll command, after which it can continue repeating the request only in each subsequent Poll Response. The airborne radio can transmit up to NM1 (default =20) Reservation Requests for a particular data message. If NM1 is exceeded, a higher level protocol (SN-SME) is notified.

When a polling command is received, an airborne radio must renew any requests that have not been granted. (A request that is granted in the same uplink M channel burst as the poll command should not be renewed.) This mandate to renew reservations applies even to airborne radios which have received a RACK message. A request that is not renewed will be dropped by the ground station. Note that the poll responses can be used by airborne radios to change the reservation request, which might be necessary (for example) if a higher-priority message entered the airborne radio’s transmit queue in the interval between the initial request and the poll command. Another motivation to change a request would be if more frames of data became available for transmission.

After a reservation has been granted, the airborne user will send its message in the slots that are assigned. It should indicate the identity of each burst (segment) of its message by incrementing the number in the Segment Number field in the header and it should indicate the last segment by setting EOM = 1. The Message ID portion of the header will also indicate whether or not an acknowledgment from the ground is required (see Section 3.2).

If an ACK is required, the ground will indicate it has successfully received the message by sending an acknowledgment in an uplink V/D slot using a technique that is described in Section 4.7.2. Note that the ground terminal must send its acknowledgment of the downlink data message within T_ack cycles (default =9) of the cycle in which it received the downlink data EOM.

If the initial message required an ACK, then a Reservation Request for a new message cannot be issued until an ACK has been received. If no such ACK is forthcoming, the airborne radio must wait T1 cycles (default = 10) before deciding to send a Reservation Request to retransmit the pending message. (For a multiframe group, only those frames requiring acknowledgment need to be repeated.) If a
message is transmitted \( N2 \) times (default = 3) without eliciting an Acknowledgment, a higher level protocol (LME) will be notified.

If the initial message did not require an ACK, then the airborne radio can transmit a Reservation Request for a subsequent message immediately after receiving the Reservation for the first one.

4.7.1 **Assembling a Downlink Data Message**

In general a downlink data message may consist of more than one data frame. There are, however, certain rules which pertain to the creation of a “frame group.” The rules are as follows:

1. The total message length of all frames in the group should be no longer than 15 V/D (data) bursts (7440 bits).

2. Only frames of the same priority can be grouped together. A frame of lower priority can be included in the group only if it does not increase the number of bursts required.

_Note._— _Note that if an application has more than 15 slots’ worth of data to transmit, the data must be broken into separate frames (whose size is at most 15 slots) prior to reaching the MAC layer._

If a frame group has a total length which is not an integer multiple of 496 bits (= 62 bytes), then the MAC layer will add enough zeros to the end of the message (zero padding) to make it so. Thus, every V/D (data) burst contains a complete RS(72, 62) word.

4.7.2 **Downlink Data Verification and Acknowledgment**

When a ground station receives a downlink data message, it will subject the message to certain validity checks before it will deliver it to higher layers of the protocol stack and (possibly) transmit an acknowledgment to the sender. Note that an airborne user will signify that it expects the message to be acknowledged by using Message ID = 101.

A sequence of V/D (data) bursts from an airborne user will be acknowledged if it passes _all_ of the following criteria:

1. There is an uninterrupted sequence of bursts whose Segment Numbers run from 1 to \( N \), where the segment \( N \) also contains EOM = 1.

2. The headers of all the bursts are successfully decoded by the Golay decoder.

3. Every RS (72, 62) word is able to be successfully decoded.

4. The upper-level protocol that performs the 24-bit CRC error detection procedure indicates that _no_ errors were detected in any of the frames in the burst sequence, and
If all the criteria are satisfied, an ACK message in the form of a data frame will be addressed to the message originator. This ACK, together with any other pending uplink ACKs will be put in the expedited queue and delivered via a sequence of uplink V/D (data) bursts as soon as possible (i.e., without interrupting a burst sequence that has already been scheduled).

4.8 **Ground Data Transmission**

Ground data slots are scheduled according to the algorithm described below. Each data frame can have a length of up to 15 bursts. The header of an uplink data message will have MID = 100 or 110, depending on whether or not an acknowledgment is required. The header also contains the Segment Number, which is incremented with each burst. The last time burst (segment) of a message will have EOM = 1.

4.8.1 **Assembling an Uplink Data Message**

Uplink data frames can be group together to form frame groups similar to the downlink data frame groups. Rules (1) and (2) which apply to downlink data (see Section 4.7.1) also apply to uplink data. For uplink data there is a third rule:

(3) Frames requiring acknowledgment (MID = 100) can be grouped together only if they are addressed to a single airborne user.

Because uplink V/D (data) bursts are also used to carry uplink ACK frames (which are subject to certain timelines requirements), such frames are always given the highest (expedited) priority (see Section 4.9). The restriction to 15 bursts per frame and the requirement to pad zeroes to make an integral number of RS(72,62) words also apply to uplink data messages.

4.8.2 **Uplink Data Verification and Acknowledgment**

Each successful uplink data message (with Message ID = 100) will be acknowledged by the recipient using an Acknowledgment (MID = 1001) in the downlink M channel. This Acknowledgment message must occur in the downlink M channel slot that is delayed exactly one cycle period from the slot containing the EOM indication. The criteria for success are the same as those listed in Section 4.7.2. Note that it is the responsibility of each airborne user to examine the addresses embedded in all data frames to identify those messages that are addressed to it and to identify which messages need to be acknowledged.

It should be reemphasized that acknowledgments of ground data transmissions are strictly scheduled. The airborne radio must process the data fast enough so that the Acknowledgment message can be sent one cycle after EOM. Also note that all airborne users need to monitor the header of all messages, even those that are not addressed to them, in order to recognize that an acknowledgment has been scheduled and the relevant slot in the next cycle is not part of the available RA pool. This allows the Acknowledgment message to be sent without contention.
4.9 Data Scheduling

All use of data slots is strictly controlled by the ground station. As requests are received by the ground station — from airborne radios via downlink M channel Reservation Request or from the ground’s own DLS sublayer — they are put into queues in the order in which they are received. There is a separate queue for each level of priority (up to four levels). If the ground station determines that slots will be available in the next cycle, it will allocate slots to the user whose request is at the head of the queue with the highest priority. If the number of slots provided does not exhaust the number of slots available in the next cycle, the next user in the highest occupied priority queue will be serviced.

The ground station informs a user that its Reservation Request has been honored by transmitting a Reservation addressed to the specified user indicating to it when in the next cycle it should begin transmitting. The airborne user will begin its data transmission on that slot, and it will use all consecutive available data slots until it has no more data to send or until it has used as many slots as it requested in its last Reservation Request, whichever is less. (Note that under most circumstances the number of slots an airborne radio will use is the same as the number it asked for, not less. However, an airborne radio would, in principle, be allowed to substitute a higher priority message if it were no longer than the lower priority message that elicited the original request.) The scheduling algorithm provides for sequential access to the available slots. One user’s data reservation is completed before another has access.

It may happen that a request from an airborne user is received by the ground station but there are no slots available immediately. In that case the ground station can send to that user a Reservation Request Acknowledgment (RACK), which will tell it to stop retransmitting its request (until it is polled). RACK messages will be transmitted in the order they are generated whenever there are Reservation messages which are not being used for another purpose (i.e., to provide a reservation or a net entry confirmation). Clearly, when a reservation is granted, a pending RACK associated with the same reservation should be deleted.

A particular airborne user can have only one request pending at a time. To help ensure that a particular request is received by the ground, the airborne user can retransmit its random access request using a retransmission algorithm described in Section 4.10. Such retransmissions should cease upon receipt of a RACK. Whether or not a RACK has been received, an airborne user can change its reservation via a random access request provided that the new request is for a number of slots equal to or less than the number requested previously.

Whenever an airborne user with a pending request is polled it must respond with the same or another request or its place in the reservation queue will be lost, i.e., the airborne user must renew its request to keep it. A poll response is also the only opportunity to request a larger number of slots than was previously requested. Note that if a pending reservation is changed in any way (other than to reduce the number of slots requested without changing priority) it will be placed at the end of the appropriate queue.

Note that uplink ACKs have a special status among all uplink data messages. Because they must be sent within T_ack cycles of a downlink data EOM, such ACKs are placed in a special “expedited” queue which has priority over all other queues. Thus, uplink ACKs are always sent at the earliest possible
time. In order to prevent such uplink ACK messages from overtaxing network capacity, one or more ACKs can be grouped together.

The scheduling algorithm has the following properties. There is never an unallocated slot if there is a nonempty uplink queue. Uplink ACKs have the highest priority. (Downlink ACKs are sent in M channels without contention.) All data are transmitted in strict priority order on a “first come, first served” basis with no distinction between uplink and downlink data. However, if all the offered load is in one direction (up or down), that direction will utilize all of the system data capacity.

4.9.1 Resolving Reservation Scheduling Conflicts

The uplink M channel is used to deliver many types of messages including Net Entry Responses, Next Net messages, Reservations and RACKs. It can happen that in a particular MAC cycle there are more demands on the uplink M channel than it can satisfy. To deal with such situations, the use of the channel is governed by the following priority ordering (from highest to lowest):

1. Net Entry Response
2. Reservation or RACK to confirm successful net entry
3. Next Net message
4. Reservation
5. RACK

Note that if a Reservation cannot be sent to an airborne user because it is “bumped” by a higher priority message, the ground station can violate the strict first-come, first-served rule to substitute an uplink data message of the same priority.

4.10 Random Access Algorithm

For a variety of message types, airborne radios are required to choose a RA slot in which to transmit. These downlink M channel message types include the Net Entry Request, Reservation Request, and Leaving Net messages. The algorithm which is used is described below.

To support the algorithm the airborne radio must maintain a current listing of all downlink M channel subslots which have not been reserved. This list can be constructed by starting with all allowed downlink M channel subslots and deleting those which are reserved for Poll Response messages or for downlink ACK messages. The content of the initial list depends on whether the airborne radio is choosing a slot for a Net Entry message or it has already entered a net and is choosing a slot for a Reservation Request or a Leaving Net message.

For the Reservation Request and the Leaving Net message, the allowed list includes any of the downward-pointing arrows in Figures 1-1 and 1-2. The allowed slots for Net Entry Requests depend on
the local system configuration and the User Group to be entered. For most configurations the allowed slots are the same as those allowed for Reservation Requests and Leaving Net messages. However, for configurations 3V1D and 2V1D the downlink M channel associated with the data time slot is not allowed for net entry. If this slot were used, the ground station would have no way of knowing to which user group the entrant should be assigned.

As stated previously, slots scheduled for polling or downlink ACK should be removed from the lists. The information needed for this removal process should be available about 1 frame ahead of time in the case of polling and 1 cycle ahead of time in the case of ACKs.

When an airborne radio determines that it needs to transmit a RA message, it will chose a random number, $r$, such that

$$0 \leq r \leq R_n$$

where $n = E, R, L$ depending on whether the slot is being chosen for a Net Entry Request, a Reservation Request, or a Leaving Net message, respectively. The number $r$ is chosen according to the pseudorandom process described in Section 9.1. The airborne radio will skip the next $F$ available slots from the reduced list of allowed slots and transmit in the next one. For the Leaving Net message, this will be the only transmission; however, the Net Entry Request and the Reservation Request may be retransmitted if a satisfactory response is not received in a timely fashion. An airborne radio will wait $W_E$ and $W_R$ MAC cycles before reinitiating the random transmission process for Net Entry Requests and Reservation Requests, respectively. These processes will repeat indefinitely until they are terminated by a valid response or a poll (in the case of a Reservation Request), or the processes exceed time limits, i.e., thresholds $NL1$ (see Section 4.1.3) or $NM1$ (see Section 4.7) are reached. $R_n$ and $W_n$ can depend on the system configuration. Default values are listed in Table 4-2.

This RA process is similar to a standard p-persistence/back-off procedure, but it appears to be easier to implement and does a better job of “balancing” the usage of the various slots in a MAC cycle.

**Table 4-2 Random Access Parameters**

<table>
<thead>
<tr>
<th>Configuration</th>
<th>4V</th>
<th>3V1D</th>
<th>2V2D</th>
<th>3T</th>
<th>3V</th>
<th>2V1D</th>
<th>3S</th>
<th>2S1X</th>
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<td>8</td>
<td>8</td>
<td>3</td>
<td>8</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
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<td>8</td>
<td>8</td>
<td>8</td>
<td>3</td>
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<td>1</td>
<td>2</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>
4.11 **Data Error Detection and Correction**

All data messages are protected by error correction algorithms on a slot-by-slot basis. The error correction is provided by a Reed-Solomon (RS) (72, 62) code that operates on 8-bit (2^8-ary) symbols and corrects up to 5 symbol errors. Error detection is provided by a 24-bit CRC, which is part of the DLS sublayer (Section 5) protocol. Any message segment that passes the error detection process is considered to be correct. Information on the performance of these codes can be found in [4].

4.12 **Priority Queuing**

All DLS frames transmitted over V/D (data) slots are assigned with a message priority. A total of four priority levels are provided to include level 1 through level 4. Level 1 is the lowest and level 4 is the highest priority level. Within Level 4, uplink acknowledgment messages are processed ahead of other messages.

Priority queuing in VDL Mode 3 includes the following:

- Uplink acknowledgment frames are always placed at the head of the transmission;
- Within the protocol constraints of Section 5, higher priority messages are transmitted ahead of lower priority messages;
- Messages of the same priority are served on a first-come-first-serve basis;
- Priority levels are treated equally for the uplink and downlink messages;
- Before the aircraft receives a Reservation Response for the outstanding request, a new higher priority message is, subject to certain limitations (see Section 5 for details), allowed to replace the outstanding message; and
- When the aircraft T1 timer expires indicating that an uplink acknowledgment message fails to arrive in time, a new higher priority message, if available, will be processed instead of retransmitting the outstanding message.

The VDL Mode 3 priority queuing is accomplished with a stop-and-wait protocol at the DLS sublayer and a tightly coupled DLS and MAC sublayers. Detailed description of the DLS sublayer protocol and its interaction with the MAC sublayer are provided in Section 5.

4.13 **Link Negotiation**

The CTRL_CMD and CTRL_RSP frames are used to negotiate the configuration of the link. During link establishment, the aircraft sends a CTRL_CMD frame with the Network Initialization XID to indicate which subnetwork interface is desired to be supported. This CTRL_CMD_LE frame may also include some parameters to inform the ground of the capabilities of the aircraft. The ground station will respond with a CTRL_RSP frame acknowledging the information, called the CTRL_RSP_LE. If the
information cannot be accepted by the airborne protocol stack, the aircraft will send a CTRL_RSP_LCR frame which is a CTRL_RSP frame containing the LCR Cause XID indicating why the link is being rejected. Unlike the CTRL_CMD frame, the CTRL_RSP frame is acknowledged. The standard retransmission procedures apply.

If either the ground or aircraft need to adjust a parameter after it has been established, the CTRL_CMD and CTRL_RSP frames are used for Link Parameter Negotiation. For this purpose, they are referred to as CTRL_CMD_LPM and CTRL_RSP_LPM, respectively.

The ground station may also broadcast a CTRL_CMD frame to indicate the adjustment of a parameter to all aircraft in a user group. If any aircraft cannot accept the change, it should disconnect the link by sending a CTRL_RSP frame containing the LCR Cause XID. There is no other acknowledgement of this CTRL_CMD_LPM frame.

The format for the user data of the CTRL_CMD and CTRL_RSP frames are described in Section 3.6.1. The Format Identifier of 82H is used for all VDL XID messages. The Group Identifier is 80H for public parameters and F0H for private parameters. Both groups may be included in the control frame, but all of the parameters associated with the group must follow its Identifier. The Group Length field encodes the size of the parameter fields within the group in bytes. The Group header is not included in the Group Length size. Within each group, each parameter will have an identifier, length and value fields. The parameters are included in any order within the group. For private parameters, the Parameter Set Identifier is used to distinguish different parameter sets, so all parameters within a set must follow the set identifier before the next set identifier. See Figure 4-1 for an illustration of how the 'V' is completed before the 'W' set is begun within the CTRL frame.

The following hexadecimal example defines the User Data field of a CTRL_RSP_LE frame that indicates a T1 (Delay Before Transmission) value of 11 MAC cycles, an SQP (Signal Quality Parameter) value of 15, and support for a CLNP interface with the CT1 (Multicast Packet Period) parameter set to 10 packets:

<table>
<thead>
<tr>
<th>82</th>
<th>80</th>
<th>00</th>
<th>14</th>
<th>01</th>
<th>0F</th>
<th>38</th>
<th>38</th>
<th>38</th>
<th>35</th>
<th>3A</th>
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<td>GL</td>
<td>PID</td>
<td>PL</td>
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<td></td>
</tr>
</tbody>
</table>

Public Group Parameter Set ID

<table>
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<tr>
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<th>6F</th>
<th>64</th>
<th>65</th>
<th>33</th>
<th>09</th>
<th>01</th>
<th>0B</th>
<th>F0</th>
<th>00</th>
<th>11</th>
<th>00</th>
<th>01</th>
<th>56</th>
<th>02</th>
<th>01</th>
</tr>
</thead>
<tbody>
<tr>
<td>PV (cont')</td>
<td>PID</td>
<td>PL</td>
<td>PV</td>
<td>GI</td>
<td>GL</td>
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<td>PL</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Parameter set ID (cont'd) T1 Timer Private group Parameter set 'V' SQP
### Flexible Subnetwork Interface

The VDL Mode 3 subnetwork interface has been designed to support multiple protocols (for flexibility) and diverse requirements. The first byte of the DLS user data will contain an octet that indicates the network interface being used for the packet, as well as any subnetwork compression being performed.

The system currently has defined interfaces for communicating ISO8208 packets, for communicating CLNP packets, and for raw data. The ISO8208 interface supports segmentation of packets as needed, while the CLNP interface currently does not. The raw interface is primarily intended for MOPS and certification testing of hardware, but could also be used if a State desired a non-networked subnetwork.

*Note.*— If segmentation is needed in the CLNP interface to support ATN communications, either the Compression Type field can be expanded to indicate the inclusion of a Version field, which in turn would allow for a version to include Segmentation, or a new Network Type for a modified CLNP interface that includes segmentation could be added.

### Subnetwork Compression

The VDL Mode 3 system currently supports compression for the ISO8208 subnetwork interface and CLNP subnetwork interface. Compression type—ISO 8208 compression or CLNP compression—is signaled by the Payload Identification octet, the 1st octet of user data in the Information frame of the data link layer.
4.15.1 ISO8208 PLP Subnetwork Compression

The ISO 8208 compressor provides a connection oriented packet data service allowing reliable sequenced delivery of packets in support of ATN mobile SNDCF. It increases subnetwork efficiency by packet multiplexing and provides error detection and recovery from dropped, missequenced or duplicate packets. The ISO 8208 compressor architecture consists of three elements for both ground and airborne systems: 1) ISO 8208 DCE, 2) Internetworking (IW) functions, and 3) VDL Mode 3 Packet Layer Protocol. The ISO 8208 compressor architecture is illustrated in Figure 14-2. As shown, the Airborne Network Interface (ANI) and Ground Network Interface (GNI) refer to the complete functionality required to interface to an ATN router, which implements the ATN ISO 8208 mobile SNDCF and DTE, to the VDL Mode 3 subnetwork. ANI and GNI refer to this functionality when ISO 8208 compression is signaled. Detailed architecture, procedures, and packet formats for packets received from or sent to the local DTE are defined in Appendix E of the Manual on VDL Specifications.

The ISO 8208 compressor supports the priority option. The ATN priority levels 10-14 are mapped to the HIGH priority and ATN priority levels 0-9 are mapped to the LOW priority. (It should be noted that AM(R)S regulations currently prohibit priorities 0-6 from being passed over this subnetwork.) At the link layer, the A-CLDL translates the HIGH priority into priority 2 and the LOW priority into priority 0. The link layer will continue to use priority 3 for its own management messaging and priority 1 is unused for the ISO8208 subnetwork interface.

4.15.2 CLNP Subnetwork Compression

The VDL Compressor is capable of compressing CLNP headers to improve link efficiency. The VDL Compressor receives uncompressed CLNP packets from the router. To initialize the compression, the first packet is sent uncompressed with the compression information included, so that the peer Compressor can associate the Index with the CLNP address pair. The Index is assigned from a pool of idle indexes. The first index will start at 0. The subsequent indexes are incremented from the last assigned up to 127 before looping back to 0. If the index is still in use, it will be skipped until an index not being used is found. If no indexes are idle, the packet is sent uncompressed as Compression Type CLNP. Following the successful sending of the initialization header, the Compressor will send compressed packets until it receives a RESTART packet from its peer, or the connection is terminated by the generation of a Leave_Event by the SN-SME. This will trigger the next packet to contain an uncompressed header along with the Index. A compressor will send a RESTART packet back to the originator of any packet that includes an index for which the Compressor has insufficient information to restore. If no packets are received from an index for CT3 (Index Idle) minutes (default 20), then the Compressor will declare the index is idle and return it to the free pool. Declaring an index idle does not clear the state information for the compression. Only the SN-SME’s generation of a Leave_Event, or the reassigning of the Index will clear the entry. If a packet arrives from the local router with a CLNP address pair for an idle index, that index will still be used with a compressed packet and the index will be removed from the idle pool, and the CT3 timer will be restarted. Detailed compression techniques including compression rules and decompression rules are given in Appendix F of the Manual on VDL Specifications.
Any non-ISO8473 packets, like the Intermediate System Hello (ISH) packets, are sent through the Compressor as Compression Type CLNP packets without any compression.

4.15.3 Raw Subnetwork Compression

The raw subnetwork interface does not currently support compression.

4.16 Broadcast

The VDL Mode 3 link layer supports the transfer of DLS frames being broadcast to all users in the user group. This is accomplished by addressing the frame to the broadcast address of all 1’s and use the broadcast address type. At the subnetwork, the CLNP interface can support broadcast and multicast communications. CLNP header compression can be accomplished by a simplex compression scheme that periodically sends the full header with the uplink data. With this scheme, a user will have to wait for the full header being sent before it can begin decoding the information. If at any time the compression state information is lost, the airborne decompressor just needs to wait for full header to be sent to reload the state information. Alternately, for a simplified broadcast receiver implementation, it might be possible to reserve a compression index to be applied, so that the receiver would be hardcoded with the appropriate state information to decompress the network header.
4.17 **Recovery**

If, for any reason, the ground station loses its state information, the recovery procedure provides a rapid means of reestablishing links with all responding airborne users. The recovery process begins when the ground station transmits a special uplink M channel message with the Message ID in Beacon 1 set to 0100 (Recovery). The meaning of this message depends on the system configuration.

For data-capable configurations (e.g., 2V2D, 3V1D, 2V1D and 3T), the ground station will send reservation messages to every Local ID in ascending order of Aircraft ID. Airborne users will respond to reservations addressed to them with CTRL_CMD_LE frames containing the Expedited Recovery XID and the Network Initialization XID.

While the CTRL frame process is on-going, the ground station will poll every Local ID in descending order of Aircraft ID. Airborne users will respond to polls addressed to them by sending a Net Entry Request message in the next MAC cycle. To speed up the recovery process, the list of Local IDs to whom reservations are sent is pruned by using information gleaned from the poll response procedure. The polling process can cease whenever the Local ID being polled is numerically less than the Local ID currently receiving a reservation. Note that random access (RA) downlink M channel messages such as Reservation Requests are not allowed during the recovery process. Upon completion of the CTRL frame process, the ground station will broadcast a CTRL frame with the Connection Check XID indicating all of the aircraft it has recovered. If an aircraft determines that the information listed is incorrect, it will send a Leaving Net message and then attempt to re-enter the net. If an aircraft does not find itself on the list, when it believes it should be it will attempt the normal Net Entry procedure when the ground station returns to the Normal uplink message.

For voice-only configurations (4V, 3V, 3S), the CTRL frame process is not applicable and the recovery process consists of just the polling process.

If an airborne radio does not receive a poll or a reservation during the recovery process, it will assume that its connection is no longer valid, and it will attempt net entry when normal operation of the ground radio resumes.

4.17.1 **Aircraft Station Failure**

To recover from the failure of an airborne radio whose state information still exists (in the ground station), the radio attempting to reestablish communication will conduct the standard link establishment procedure. The ground station will recognize that it already has a link with the aircraft station address requesting net entry and will flag the existing connection as being suspected of failure. It will respond with a Net Entry Response burst for a new link. The subnetwork layer will also be notified that an aircraft is attempting to establish a new link. The old link will be terminated when the lack of reception of poll responses indicates to terminate the connection to the LME. It may be desirable for the ground subnetwork to reroute communications for the suspect link with the new link to prevent lost packets within the subnetwork. Regardless, the transport layer should recover any lost packets, but it may be desirable to expedite the restoral of the data flow.
If the ground station fails, all of the discrete addressing information and data scheduling state information could be lost. Upon restoral of the ground station, voice service should be restored to Timing State 1 as soon as the beacon information transmits twice. To restore data transmission quickly, the system will undergo an expedited recovery procedure. The ground station will uplink the Recovery M burst granting data access to two potential aircraft per MAC cycle, with one V/D (data) slot assigned to each aircraft. The reservation grants will be conducted sequentially from local ID 1 to 60, as the ground does not yet know which local identifiers are active. This will take 30 MAC cycles to complete, and will allow the ground station to know which aircraft are in the net. The aircraft will send a CTRL_RSP frame including the Expedited Recovery XID and Network Initialization XID. If the ground station does not receive any response on an assigned slot, it will assume no active aircraft has been assigned that local ID. After all 60 local IDs have been stepped through, the ground station will send a CTRL_RSP_LPM frame containing the Connection Check XID that lists the local IDs of all the aircraft from which it received a response. It will then return to sending normal uplink beacons and begin granting data slots as requested to reestablish the network connections. If an aircraft does not find itself in the Connection Check XID, it should attempt the normal link establishment procedure to restore the connection.
SECTION 5

5. MAC-DLS OPERATIONS

5.1 Introduction

To facilitate the implementation of priority message processing within the VDL Mode 3 subnetwork, an Acknowledged-Connectionless Data Link (A-CLDL) has been adopted for the link layer in the VDL Mode 3 draft standards. To provide maximum flexibility in priority queuing, the system requires tight coupling between the functions performed by the MAC and DLS sublayers delineated in the VDL Mode 3 draft standards. In fact, these changes may diminish the value of conceptualizing the MAC and DLS as separated sublayers. However, the standards maintain the conceptual MAC and DLS sublayers separation for legacy reason.

The following subsections provide detailed description of the definition of the link layer design. A detailed example is used to illustrate a possible implementation of the VDL Mode 3 link layer in the context of the conceptual MAC and DLS sublayer separation established in the draft standards.

5.2 VDL Mode 3 Subnetwork Overview

VDL Mode 3 subnetwork provides reliable data link services through its MAC and DLS protocol suites. The MAC sublayer adopts half duplex time slots for channel management and V/D transmission. While V/D (data) slots are used strictly for data transmission, V/D (voice) slots are used for voice transmission only. A transmission from an aircraft to the ground station is referred to as a downlink transmission; while a transmission from the ground station to an aircraft is referred to as an uplink transmission. The MAC sublayer in conjunction with the DLS sublayer also provides procedures for priority queuing, frame acknowledgment, and retransmission. For air-to-ground (downlink) data transmission, requests from different aircraft are handled by the slotted ALOHA multiple access control protocol which is augmented by polling to guarantee access to all users.

Reliable and efficient data link service is accomplished by implementing a stop-and-wait protocol at the DLS sublayer and a centralized reservation based channel access with priority queuing at the MAC sublayer. The stop-and-wait protocol incorporates error detection, frame acknowledgment, frame grouping, and priority queuing and is referred to as the acknowledged connectionless data link (A-CLDL) protocol. Priority queuing at MAC and DLS and frame acknowledgment at DLS require tightly coupled MAC-DLS sublayers. Consequently, interlayer primitives are required to facilitate the operations between the MAC and the DLS sublayers. VDL Mode 3 data link communications between an aircraft and the ground station are facilitated through the exchanges of Protocol Data Unit (PDUs) between peer-to-peer Data Link Entity (DLEs) within the DLS sublayer (Figure 5-1). Only one DLE is required at the aircraft, while as many DLEs as the number of active aircraft within the signaling range of a ground station will be needed for the ground station. For DLS-MAC intralayer interface, the DLS will rely on the Data Link Manager (DLM) which deals with frame grouping, priority queuing, and protocol primitives exchange. This section documents the basic VDL Mode 3 MAC and DLS operations and interface requirements.
A DLS Frame is a stream of contiguous data bits exchanged between two peer DLEs. A VDL Mode 3 DLS frame consists of a DLS frame header and user data. One or more user information frame(s) of the same priority may be grouped together at the DLE to form a frame subgroup. Frames and frame subgroups may be grouped again by the DLS into a frame group to be transmitted by the MAC sublayer in a single media access event. A media access event refers to the transmission of a single frame group in a consecutive V/D (data) MAC burst sequence.

A MAC burst sequence is a sequence of consecutive V/D (data) burst segments. Each V/D (data) burst segment consists of a MAC burst header of 12 bits followed by a 62-octet DLS frame group segment, which conveys all or part of a frame group payload.

Frame Group to Burst Sequence Rules:
a) A frame group, which contains either a single frame or multiple frames, must be equal to or less than the DLS system parameter N1. The default value of N1 is 930 octets, which is equivalent to maximum burst length of 15.

b) An uplink frame group containing acknowledgment frames may include additional DLS frames provided that the number of MAC burst segments required for the frame group does not exceed what is needed to transmit the acknowledgment frames alone.

c) At the DLE, only data frames of the same priority are grouped as a frame subgroup, whereas several frame subgroups of different priorities from different sources may be grouped further at the DLM to form a frame group. DLS frame group sent from the DLM to the MAC sublayer is converted directly into a MAC burst sequence to be transmitted as a single media access event. No further grouping of the DLS frames will be performed by the MAC sublayer.

d) Furthermore, each frame group shall consist of at most one discretely addressed frame subgroup that requires acknowledgment. Figure 5-2 illustrates the mapping between a DLS frame group and its associated MAC burst sequence.

5.3 MAC Operations

VDL Mode 3 requires slightly different MAC operations for the ground station from that of aircraft. Each MAC cycle of 240 ms is divided into a number of management slots and data slots. The management slots are used by the ground station and aircraft to exchange channel control information; The V/D slots are used for uplink and downlink V/D (voice or data) transmission. V/D (data) slots are allocated by the ground station for uplink and downlink MAC media access events in a prioritized first-come-first-served fashion. Each V/D (data) slot corresponds to a single burst segment in a MAC media access event. A downlink MAC media access event consists of a consecutive sequence of burst segments for a single DLS frame group and their associated MAC burst headers. An uplink MAC media access event consists of a consecutive sequence of burst segments for a single DLS frame group with at most one discretely addressed frame subgroup, up to 6 DLS acknowledgment frames, multiple DLS CTRL frames, and their associated
MAC burst headers. In any MAC media access event, the number of burst segments is determined by length of the frame group involved.

**Figure 5-2. VDL Mode 3 DLS Frame Group to MAC Burst Sequence Mapping**

Events between the MAC sublayer and the DLS sublayer are coupled tightly by a set of interlayer protocol primitives to ensure the orderly delivery of DLS frames in frame groups.

### 5.4 DLS Operations

The DLS sublayer used by the ground station or aircraft shares a common set of protocol procedures. The DLS accepts either user data frames from upper layers or data link command/control frames from LME. It also performs frame grouping for outgoing DLS frames and frame ungrouping for incoming DLS frames. DLS frame grouping consists of two distinct stages: initial frame grouping by the DLE to form a frame subgroup and the final grouping by DLM to form a frame group prior to its delivery to the MAC sublayer. At DLE, only INFO frames with the same priority that require acknowledgment are grouped together. At DLM, CTRL frames, acknowledgment frames, non-discretely addressed broadcast frames, and at most one discretely addressed frame subgroup requiring acknowledgment can be grouped in order of priorities within the maximum size constraint of a single media access event. The MF bit of each DLS frame header will be set to 1 initially by DLE and only the last frame of the frame group will be reset to 0 at DLM during frame grouping. The FCS in each DLS frame header will be generated at the DLM prior to the delivery of frame group to the MAC sublayer. Once a frame group is delivered to the MAC sublayer, the MAC sublayer will not attempt to alter its group structure and must always transmit the entire frame group in a single burst sequence as a single media access event. Using protocol primitives, the DLS sublayer will inform the MAC whether or not an outgoing frame group will require peer DLE acknowledgment. DLS frame group that requires acknowledgment will be transmitted by the MAC sublayer with a T1 timer enabled; a DLS acknowledgment frame will be generated by the destination DLE and sent to its MAC sublayer for transmission to the source DLE.

![DLS Frame Group to MAC Burst Sequence Mapping](image_url)

Legend:  
H  DLS Frame Header,  S1, S2, ..., Sn  DLS Frame Group Segments  
BH  MAC Burst Header,  0 < n < 16  

For each incoming DLS frame, the DLM performs FCS check. For a discretely addressed frame subgroup with one or more corrupted FCS, the entire frame subgroup will be rejected by the DLS. Only
when all DLS frames in a discretely addressed frame group pass the FCS check, will the DLE generate an acknowledgment frame for transmission to the source DLE. Upon receiving the acknowledgment frame, the source DLS will immediately inform the MAC sublayer to cancel its T1 timer and cancel any action or preparation for retransmission. A new frame or frame subgroup from a specific DLE may be sent to the MAC sublayer through the DLM whenever the MAC sublayer is ready for next media access event, and that there is no T1 timer active associated with the DLE. Upon expiration of the T1 timer, the MAC sublayer declares time-out for the transmitted frame group and informs the DLM to provide a new frame group. This new frame group will include either the outstanding frame subgroup or a new frame subgroup with priority higher than that of the outstanding frame subgroup to initiate the next transmission. Interlayer protocol primitives may be used by the DLS and MAC to correlate events and to convey the priority level and size of each DLS frame (or frame group) sent between the two sublayers.

In summary, the A-CLDL protocol for the DLS sublayer may be highlighted as follows:

C Peer-to-peer DLE link establishment/disconnect/recovery procedures
C DLE provides stop-and-wait with acknowledgment for transmitting discretely addressed user data from the upper layers
C Prioritized frame subgrouping at DLE
C Frame grouping at DLM
C One frame group per media access event
C At most one discretely addressed frame subgroup requiring acknowledgment per frame group
C DLM generates a DLS frame group by grouping individual DLS frames and frame subgroups from all DLEs in accordance with frame priorities and the maximum size constraints and sends the frame group to the MAC sublayer when the MAC is ready for a new media access event such as:

a) completion of a frame group transmission that does not require acknowledgment.

b) Expiration of the T1 timer for the source DLE.

c) no active MAC T1 timer for the source DLE and there is new frame or frame subgroup available at the DLE; e.g., (1) after the cancellation of its T1 timer upon the arrival of an acknowledgment frame at the DLE with new frame or frame subgroup available at the DLE or (2) any new frame arrives at the DLE without any outstanding frame or frame subgroup awaiting acknowledgment at the DLE (voluntary).
5.5 VDL Mode 3 Prioritized Service

VDL Mode 3 provides priority queuing at both the DLS and MAC sublayers to ensure timely delivery of link management and time critical user messages under all channel loading conditions. There are 4 distinct priority levels for DLS frames. User data (INFO frames) from the upper layers (Figure 5-1) may use all four levels. Management frames (DLS CTRL and ACK) frames only use the top priority, with expedited service for acknowledgment frames within that top priority. This expedited service could be viewed as a fifth priority level. Table 5-1 tabulates these 5 distinct priority levels assigned to individual DLS frame.

The ground station must follow a set of basic rules in dealing with both downlink reservation requests and uplink data slots requests. A total of four distinct rules are established for the DLS and MAC sublayers to control priority processing. These rules are:

a) Highest priority with expedited service for all acknowledgment frames:
Because of critical timing constraints for the DLS acknowledgment frames, a special priority is granted to all DLS acknowledgment frames over other DLS frames or frame subgroups. The aircraft MAC sublayer must have its DLS acknowledgment frame available for transmission at the beginning of its reserved M_down slot. The ground MAC sublayer will allocate the next available (uncommitted) V/D (data) slot for all outstanding uplink DLS acknowledgment frames from all its DLEs. VDL Mode 3 DLS acknowledgment frames are assigned a priority of level 4 with an expedited service indicator.
b) Highest priority for DLS CTRL frames:
DLE and LME control frames are time critical link management protocol data units that do not follow the stop-and-wait discipline. VDL Mode 3 DLS CTRL frames are assigned a priority of level 4. (Note that acknowledgment frame for a CTRL_CMD frame tends to be redundant since handshaking is a prime function of CTRL_CMD frames. Consequently, there is no need for direct acknowledgment of CTRL_CMD frames. The T3 timer handles the retransmission of these unacknowledged frames. CTRL_RSP frames are acknowledged like other INFO frames)

Table 5-1. VDL Mode 3 DLS Sublayer Frame Priority

<table>
<thead>
<tr>
<th>Priority Level(*)</th>
<th>DLS Frame Type</th>
<th>Acknowledgment**</th>
<th>T1 Timer</th>
</tr>
</thead>
<tbody>
<tr>
<td>4 (expedited)</td>
<td>ACK</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>4</td>
<td>CTRL</td>
<td>Yes (RSP)/No (CMD)</td>
<td>Yes (RSP)/No (CMD)</td>
</tr>
<tr>
<td>4</td>
<td>INFO</td>
<td>Yes/No</td>
<td>Yes/No</td>
</tr>
<tr>
<td>3</td>
<td>INFO</td>
<td>Yes/No</td>
<td>Yes/No</td>
</tr>
<tr>
<td>2</td>
<td>INFO</td>
<td>Yes/No</td>
<td>Yes/No</td>
</tr>
<tr>
<td>1</td>
<td>INFO</td>
<td>Yes/No</td>
<td>Yes/No</td>
</tr>
</tbody>
</table>

Note.— * Smaller the value the lower the priority
** Broadcast frames are the only INFO frames that do not require acknowledgment

c) Four distinct priority levels for DLS information frames or frame group:
User data from the upper layers above the data link layer are considered as information (data) frames by the DLS sublayer. All information frames follow the stop-and-wait discipline with frame acknowledgment, time-out, and retransmission. A T1 timer is required for a frame group that contains DLS information frames with the exception of uplink broadcast data. DLS information frames are assigned priority levels from 1 to 4. Information frames are grouped by priority at each DLE output queue for both aircraft and the ground station.
For maximum link efficiency, only information frames of the same priority are grouped together within the DLE.

d) First-come-first-served queuing discipline within each priority level and among all DLE data burst request queues at the ground station:
The ground station must allocate all available data bursts in the following order:

1) DLS ACK frames
2) DLS CTRL and user information (INFO) frame or frame groups with the highest priority and the earliest request arrival time at the ground station MAC sublayer.

All uplink and downlink requests for MAC channel access should be treated equally according to these rules; no preference should be given to either uplink or downlink information frames by the ground station when burst sequences are scheduled. Since burst sequence transmission is scheduled by the ground station MAC, the priority queuing process at the ground station is considerably more complicated than at the aircraft. Figures 5-3 and 5-4 illustrate the priority queuing process for outgoing MAC burst sequences to the physical layer. There is no queuing delay for incoming MAC burst sequences; they are converted to a DLS frame group and forwarded directly to its DLS sublayer which in turn delivers user data to the upper layers and management data to the LME.

Figure 5-3. VDL Mode 3 Aircraft DLS/MAC Priority Queues
5.6 Duplicate MAC/DLS Frame Delivery

With the stop-and-wait DLS protocol without a sequence number to relate an acknowledgment frame to the associated data frame, it is possible that a duplicate frame may be transmitted at the MAC sublayer and be forwarded to the DLS sublayer and above. Transmission of duplicate frames occurs when a DLS acknowledgment frame is not received due to random burst corruption. It can also occur when the timing constraints between the DLS-MAC interlayer primitives are violated. Duplicate frames are expected to be very rare event, however, it can not be completely ruled out. As such, the Toggle bit is used by the A-CLDL as a one-bit sequence number to eliminate duplicate frames for acknowledged frames. The Toggle bit only increments on the reception of the ACK for an acknowledged frame group. Unacknowledged frames have no impact to the Toggle bit and are not retransmitted. It is assumed that applications using the unacknowledged service can accommodate this.

5.7 Implementation of A-CLDL for VDL Mode 3 Subnet

5.7.1 MAC-DLS Interface

Because of timing constraints imposed on VDL Mode 3 MAC protocol, it is important that the DLS and MAC sublayers are tightly coupled. In case that DLS and MAC are implemented on separate hardware entities, interlayer protocol primitives must be used to correlate events in DLS and MAC. Since there is one DLE per aircraft at the ground station, a DLE_identifier attribute is needed for every MAC-DLS interlayer protocol primitive to uniquely identify the source or destination DLE. Table 5-2 identifies potential key MAC-DLS protocol primitives.

The MAC_data.REQ protocol primitive is initiated by the DLE and forwarded to the MAC sublayer by the DLM to transmit its frame subgroup at the top of its DLE output queue to DLM to be grouped with other DLS frames to generate a frame group to be sent to the MAC sublayer under the following five conditions:

a) there is no peer-to-peer DLE frame subgroup awaiting acknowledgment.

b) the new frame group has priority higher than that of the outstanding frame group (waiting for MAC burst sequence assignment) and can replace the outstanding frame group at the MAC sublayer.

c) immediately after an aircraft is polled without an active T1 timer for the associated DLE.

d) immediately after the T1 timer associated with a frame group expired and the arrival of a MAC_time_out.IND protocol primitive from the MAC sublayer.

e) immediately after the delivery of the MAC_cancel_t1.REQ protocol primitive to the MAC sublayer when the DLE has accepted its acknowledgment frame.
### Table 5-2. Potential VDL Mode 3 MAC-DLS Interlayer Protocol Primitives

<table>
<thead>
<tr>
<th>ID</th>
<th>From</th>
<th>To</th>
<th>Attributes &amp; Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>MAC_data.REQ</td>
<td>DLS</td>
<td>MAC</td>
<td>Priority, size, ACK (Y/N), DLE_identifier, Service Data Unit (DLS frame group), Frame Group identifier (local)</td>
</tr>
<tr>
<td>MAC_ack.REQ</td>
<td>DLS</td>
<td>MAC</td>
<td>Priority, DLE_identifier, ACK frame</td>
</tr>
<tr>
<td>MAC_cancel_t1.REQ</td>
<td>DLS</td>
<td>MAC</td>
<td>DLE_identifier</td>
</tr>
<tr>
<td>MAC_data.IND</td>
<td>MAC</td>
<td>DLS</td>
<td>DLE_identifier, Service Data Unit (DLS frame group), Frame type</td>
</tr>
<tr>
<td>MAC_xmit.IND</td>
<td>MAC</td>
<td>DLS</td>
<td>Priority, size, ACK (Y/N), DLE_identifier, Frame Group identifier (local)</td>
</tr>
<tr>
<td>MAC_poll.IND</td>
<td>MAC</td>
<td>DLE</td>
<td>DLE_identifier</td>
</tr>
<tr>
<td>MAC_time_out.IND</td>
<td>MAC</td>
<td>DLS</td>
<td>DLE_identifier, priority, size</td>
</tr>
</tbody>
</table>

The **MAC_data.REQ** primitive must be sent with the parameter ACK=Y(es) or ACK=N(o). A MAC_data.REQ primitive with ACK=Y(es) is used to inform the MAC sublayer that the frame group requires acknowledgment; a T1 timer needs to be started at the MAC when the MAC burst sequence transmission is completed. A MAC_data.REQ primitive with ACK=N(o) implies that the frame group does not require acknowledgment; the MAC will transmit it without starting a T1 timer.

The **MAC_ack.REQ** primitive is used by the DLS sublayer to send its peer to peer DLE acknowledgment frame to the MAC sublayer upon receiving an incoming frame group from the MAC sublayer. Upon receiving an MAC_ack.REQ, the MAC sublayer will send the DLS acknowledgment frame to the physical layer either through the reserved M_RA slot in downlink transmission or within a MAC burst sequence in the uplink transmission.

The **MAC_cancel_t1.REQ** primitive is used by the DLS to inform the MAC sublayer that the expected acknowledgment frame for the DLE has been received. Upon receiving the MAC_cancel_t1.REQ primitive from the DLS sublayer, the MAC sublayer should cancel its T1 timer associated with the source DLE. Time between the arrival of the DLS acknowledgment frame at the DLS sublayer and the delivery of the MAC_cancel_t1.REQ primitive to the MAC sublayer should be minimized. Upon the delivery of the MAC_cancel_t1.REQ protocol primitive, the DLE may forward any frame or frame subgroup from the top of its output queue to the MAC sublayer using the MAC_data.REQ protocol primitive through the DLM.

The **MAC_data.IND** primitive is used by the MAC sublayer to forward an incoming frame group to the DLS sublayer at an aircraft and to all the DLEs of the DLS sublayer at the ground station. If the DLS sublayer and the MAC sublayer at the ground station are separate entities, special mechanism must be available to deliver the MAC_data.IND primitive to all the DLEs at the ground station without repeatedly sending the incoming DLS frame group to individual DLE within the DLS sublayer.
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The **MAC_xmit.IND** primitive is used by the MAC sublayer to inform the DLS sublayer upon the successful burst sequence assignment of either an uplink or downlink media access event to the physical layer. Once data slots are allocated by the ground station for an uplink or downlink burst sequence, the ground station MAC can send the MAC-xmit.IND to the associated DLE within the DLS sublayer. From the priority, DLE identifier, frame group identifier, and size information of the MAC_xmit.IND primitive, the DLS sublayer will determine whether or not it will wait for the acknowledgment of the transmitted DLS frame group and restrain itself from sending an additional DLS frame group to the MAC. For a frame group that requires acknowledgment, this primitive is needed to enforce the stop-and-wait protocol at the DLS sublayer.

The **MAC_poll.IND** primitive is used by the MAC sublayer of an aircraft to inform the DLS sublayer that the aircraft is being polled by the ground station and that the MAC sublayer has exclusive access to the next M_down slot and that a poll response is expected. Upon receiving the MAC_poll.IND primitive, the DLE should immediately forward its frame or frame subgroup at the top of its output queue to the DLM for generation of a frame group to be sent to the MAC sublayer. The MAC sublayer will prepare a poll response as a dedicated reservation request for the frame group. If the DLE has nothing to send, the MAC sublayer can repeat the last unacknowledged reservation request or a null request as its poll response. The MAC_poll.IND will also be used to inform the LME for transmitting an Next Net Acknowledgment message. In case of a conflict between a reservation request and a next net acknowledgment, the next net acknowledgment message will be transmitted.

The **MAC_time_out.IND** primitive is used by the MAC sublayer to inform the DLS sublayer that the T1 timer associated with a frame group transmitted earlier has expired indicating that an ACK message has not been received within the allowable time. Upon receiving the MAC_time_out.IND, the DLE will terminate its WAIT state for the acknowledgment frame and initiate a MAC-data.REQ protocol primitive which carries the highest priority frame subgroup (a new frame subgroup or the outstanding frame subgroup) to the DLM immediately. The DLM will generate a new frame group and send the new frame group to the MAC sublayer.

Figure 5-5 illustrates the suggested VDL Mode 3 MAC-DLS interlayer protocol primitive flow between the DLS and MAC sublayers.

5.7.2 **Operations of a Downlink MAC Sublayer Media Access Event**

The following sequence of operations describes a normal downlink MAC media access event:

**D1: DLS Frame Grouping**

When a DLE is awaiting an acknowledgment for a previously transmitted frame group, new DLS frames, which require acknowledgment, of a given priority are grouped at the DLE to form a frame subgroup on a first-come-first-served basis. This is performed under the restriction that the combined length of the subgroup satisfies the maximum length constraint associated with a single media access event.
DLS frames that do not require acknowledgment are passed without frame grouping from the DLE to the DLM when they become available.

The frame subgroup and the DLS frames that require no acknowledgment can be further grouped at DLM to form a frame group, provided that the resulting frame group length does not violate the maximum length constraint associated with a single media access. To improve transmission efficiency, grouping of different priority frames at DLM is allowed such that the unused portion of a burst sequence may be filled up; however, each frame group must not contain more than one frame subgroup destination that requires acknowledgment. In other words, the frame group may have only one destination from which it needs to receive an acknowledgement.

D2: **Forward DLS Frame Group to MAC**
DLM will forward a MAC_data.REQ primitive containing a frame group to the MAC sublayer. The MAC sublayer will insert the proper MAC burst headers and perform the frame group to burst sequence mapping to generate the MAC burst sequence for transmission through the physical layer under the following four conditions:

a) There is no downlink frame group awaiting acknowledgment, i.e., the MAC sublayer does not have an active T1 timer, and the MAC sublayer does not have any outstanding out-going frame group for transmission.

b) There is no downlink frame group awaiting acknowledgment, i.e., the MAC sublayer does not have an active T1 timer and the MAC sublayer does have an outstanding frame group for transmission; however, the DLM has a smaller frame group with higher priority than that of the outstanding frame group.

c) A new frame subgroup arrives at the DLM from the DLE in response to a MAC_poll.IND protocol primitive from the MAC sublayer; i.e., the MAC sublayer has been polled without an active T1 timer.

d) A new frame subgroup arrives at the DLM from the DLE in response to a MAC_time_out.IND protocol primitive from the MAC sublayer, i.e., the T1 timer at the MAC sublayer has just expired.

For a frame group that requires acknowledgment, a MAC_data.REQ will be sent with an ACK parameter set to Y(es) to inform the MAC sublayer that a T1 timer should be started upon the transmission of the associated MAC burst sequence. For a frame group that does not require acknowledgment, the ACK parameter will be set to N(o) and the DLE will remove the DLS frames from its output queue upon its transmission to the DLM. Any frame grouping for the downlink data with ACK = Y(es) will be done by the DLE. Any further frame grouping for downlink data with ACK = N(o) will be done by the DLM.

D3: Reservation Request for Frame Group

Upon receiving a DLS frame group, the MAC sublayer will send a reservation request through a poll response or through a M_RA slot as part of the slotted ALOHA procedure to request V/D (data) slots for the frame group. Prior to the poll, an unacknowledged reservation request (no RACK or slot assignment received) may be replaced by a new reservation request with an equal or smaller size requirement and a higher priority using the slotted ALOHA reservation request retransmission procedure.

D4: Polling by the Ground Station

When an aircraft is polled by the ground station with a Poll Request message in a M_up burst, the airborne MAC sublayer will send a MAC_poll.IND primitive to the DLE through the DLM if the T1 timer is inactive, otherwise, a dummy poll response (no reservation request) will be prepared by the MAC.
Upon receiving a MAC_poll.IND primitive, the DLE should immediately forward the frame or frame subgroup that requires acknowledgment at the top of its output queue to the DLM, where frame group will be generated and sent to the MAC sublayer via the MAC_data.REQ protocol primitive. The MAC sublayer will prepare a poll response (a dedicated reservation request) for the received frame group. This will allow the replacement of any unacknowledged reservation request (of a lower priority) by that of the newly arrived frame group (of a higher priority). If the DLM has nothing to send, the MAC should prepare a dummy poll response regardless of its T1 timer status.

D5: Reservation Request Acknowledgment from the Ground Station

If the reservation request for a downlink data transmission cannot be satisfied by the ground station in a timely fashion, the ground station should initiate a RACK via M_up burst to the requesting aircraft at the earliest possible opportunity. If a RACK cannot be transmitted before a scheduled poll request, the poll/poll response will take precedence. In this case, no RACK will be transmitted. Upon receiving a RACK, the aircraft terminates the slotted ALOHA procedure and waits for either the next poll or its downlink data slot assignment.

D6: Reservation Request Response from the Ground Station

The data slots allocated to an aircraft are conveyed in a Reservation Response message to the requesting aircraft through the M_up management slot in the MAC cycle preceding the first assigned data slot.

D7: MAC Burst Sequence Transmission

Upon receiving the Reservation Response message from the ground station in a M_up slot, the aircraft transmits the associated MAC burst sequence in consecutive MAC burst segments using the assigned data slots starting in the next MAC cycle. Upon the arrival of a downlink MAC burst sequence assignment, the MAC sublayer will inform the DLE through the DLM using the MAC_xmit.IND protocol primitive conveying priority, ACK (Y or N), and size of the transmitted frame subgroup. This protocol primitive is needed regardless whether or not the ACK parameter is Y or N so that the DLM can prepare a new frame group for the next media access event. However, the MAC_xmit.IND protocol primitive will be forwarded to the DLE by the DLM only when its ACK parameter is set to Y(es). Upon receiving the MAC_xmit.IND protocol primitive the transmitted frame group will be discarded by the DLM. The frame subgroup will be kept at DLE until acknowledged.

D8: T1 Timer Initialization

If the frame group transmitted in D7 requires acknowledgment, namely, it arrived at the MAC sublayer with the parameter ACK=Y(es), the MAC sublayer will start its T1 timer. If the uplink ACK fails to arrive before the T1 timer expires a new transmission will be initiated.

D9: Burst Sequence Arrival
The ground station receives the downlink MAC burst sequence and performs FEC. The ground MAC will remove the MAC burst headers and forwards the received frame group to the DLM, only if all burst segments of the burst sequence have passed the FEC.

D10: **DLS Frame FCS Checking**

Upon receiving the downlink frame group from the MAC sublayer, the ground DLM will ungroup the received frame group into its component DLS frames, including ungrouping the frame subgroup into DLS frames. FCS checking will be performed on individual DLS frames to determine whether or not the DLS frames can be accepted. If all discretely addressed DLS INFO frames are accepted, the ground DLM forwards the individual DLS frame to the appropriate destination DLE or DLEs; else all discretely addressed INFO frames are discarded. The ground DLM will also accept other frames (such as CTRL frames) and forward them to their destination DLE if they passed the FCS checking.

D11: **DLS Frame Acknowledgment**

If all the discretely addressed DLS frames in the received frame group that require acknowledgment are accepted, the receiving ground DLE sends an acknowledgment frame to the ground DLM for inclusion in the next uplink frame group.

D12: **Expedited Uplink DLS Acknowledgment Frames**

The ground station DLM receives acknowledgment frames from all the DLEs. The DLS acknowledgment frames are grouped (possibly with other DLS CTRL frames or one of the discretely addressed DLS INFO frame subgroups) as a frame group at the ground station DLM. The DLS acknowledgment frames receive expedited service by the DLM; they are included in the frame group before all other types of frames. The frame group is forwarded to the MAC sublayer with the MAC_data.REQ protocol primitive. The ground station MAC sublayer receives the frame group, insert the MAC burst headers, perform the frame group to MAC burst sequence mapping, and transmit the MAC burst sequence using its assigned uplink data slots. Upon receiving the acknowledgment frame, the aircraft MAC sublayer performs FEC and removes all burst headers and forwards the DLS frame group to the DLM using the MAC_data.IND protocol primitive. The aircraft DLM performs frame ungrouping, FCS checking, and forwards the accepted DLS frames including the acknowledgment frame to the destination DLE.

D13: **T1 Timer Cancellation**

The aircraft DLE accepts the acknowledgment frame, discards its copy of the frame subgroup that has been acknowledged, and responds with a MAC_cancel_t1.REQ primitive to the MAC sublayer through the DLM. A new frame subgroup at the top of the DLE output queue is also sent to the DLM, where the frame subgroup will be further grouped with DLS frames that require no acknowledgment to generate a new frame group. The new frame group is sent to the aircraft MAC to initiate a new transmission via the MAC_data.REQ protocol primitive.

D14: **DLS Frame Group Retransmission**
If the T1 timer expires without receiving the MAC_cancel_t1.REQ primitive, the MAC will declare a time-out for the outstanding frame group by sending a MAC_time_out.IND protocol primitive to the DLE through the DLM. Upon receiving the MAC_time_out.IND, the DLE will terminate its WAIT state for the acknowledgment frame and initiate a MAC_data.REQ protocol primitive which carries the highest priority frame subgroup (a new frame subgroup or the outstanding frame subgroup) to the DLM immediately. The DLM will generate a new frame group and send the new frame group to the MAC sublayer. Upon receiving the new frame group the aircraft MAC sublayer will prepare a reservation request for the received frame group.

D15: New Downlink Media Access Event

Any new frame group received at the MAC sublayer, as in Step D2, will trigger the next downlink media access event and will follow the procedures described in Steps D3 to D14. Note that all DLS frames with ACK=N(0) will be discarded at DLM once they are transmitted by the MAC sublayer and that untransmitted DLM frames or frame subgroup from the DLE may be regrouped by the DLM when MAC_poll.IND or MAC_time_out.IND is received by the DLM.

5.7.3 Operations of an Uplink MAC Sublayer Media Access Event

The following sequence of operations describes a normal uplink MAC media access event:

U1: DLS Frame Grouping

When a ground station DLE is awaiting an acknowledgment for a previously transmitted frame group, new DLS frames of a given priority that require acknowledgment are grouped at the DLE to form a Frame Subgroup on a first-come-first-served basis. Frame subgrouping at DLE must satisfy the maximum frame or frame group constraints. If no acknowledgment is outstanding, a DLS frame subgroup from a ground station DLE are passed to the DLM when it becomes available. There is one DLE associated with each aircraft at the ground station (Figure 5-1). DLS frames that do not require acknowledgment are passed individually from the DLE to the DLM when they become available.

U2: Forward DLS Frame Group to MAC

With multiple DLS frames and frame subgroups arriving at the ground DLM from multiple DLEs, the ground station DLM will construct a frame group for uplink transmission. The frame group may be constructed by grouping all untransmitted DLS acknowledgment frames, followed by DLS CTRL frames, and possibly end with the highest priority frame subgroup. The frame group may also include non-discretely addressed DLS broadcast frames of the same or higher priority than that of the highest priority frame subgroup. The maximum size of an uplink frame group is subjected to the same size constraint associated with a single media access event as a downlink frame group. The DLM will forward a MAC_data.REQ primitive containing uplink frame group to the MAC sublayer under the following conditions:

a) There is no uplink frame group awaiting acknowledgment from the same destination aircraft, i.e., the MAC sublayer does not have an active T1 timer for the associated
source ground station DLE, and the MAC sublayer does not have an outstanding (without a burst sequence assigned) uplink frame subgroup from the same source DLE.

b) There is no uplink frame group awaiting acknowledgment to the same destination aircraft, i.e., the MAC sublayer does not have an active T1 timer for the associated source ground station DLE, and the MAC sublayer does have an outstanding uplink frame subgroup (without a burst sequence assigned) from the same source DLE with priority lower than that of the highest priority frame subgroup from the same source DLE.

c) A new DLS frame subgroup arrives at the DLM from a ground station DLE in response to a MAC_time_out.IND protocol primitive from the MAC sublayer, i.e., the T1 timer associated with a ground station DLE has just expired at the MAC sublayer.

For a frame group that requires acknowledgment, a MAC_data.REQ will be sent with an ACK parameter set to Y(es) to inform the MAC sublayer that a T1 timer associated with the aircraft DLE that originates the frame subgroup should be started upon completion of the transmission of the associated MAC burst sequence. For a frame group that does not require acknowledgment, the ACK parameter will be set to N(o) and the originating DLEs will remove those DLS frames from their output queues upon their transmission to the DLM. Any frame subgrouping for the uplink data with ACK = Y(es) will be done by the ground station DLEs. Any further frame grouping for uplink DLS frames with ACK = N(o) will be done by the DLM.

U3: Replacing Uplink Frame Group Prior to Scheduling for the Uplink Burst Sequence

Prior to an uplink burst sequence is scheduled, the next uplink frame group at the ground station MAC sublayer may be replaced by a newly arrived frame group from the DLM with higher priority DLS frames from one or more ground station DLEs. Other uplink frame groups without burst sequences assigned may also be replaced at any time when a frame group of higher priority from the same source DLE has arrived. (The ground station MAC must keep as many outstanding MAC_data.REQ requests through the DLM from different source DLEs to compete with downlink reservation requests or the assignment of uplink burst sequences).

U4: Uplink DLS Frame Group Transmission

When an uplink DLS frame group with a given priority is received at the ground station MAC sublayer prior to receiving any downlink reservation request with lower or same priority, the ground station MAC will assign the next available time slot(s) to the uplink frame group and transmit the associated burst sequence. Once an uplink burst sequence is assigned, the ground MAC sublayer will inform the ground DLM with the MAC_xmit.IND protocol primitive conveying priority, ACK(Y or N), DLE identifier(s), and size of the transmitted uplink DLS frame group. The DLM will use this information to uniquely identify which frame subgroup and its DLE is waiting for acknowledgment. For frame subgroup requiring acknowledgment, DLE
should be the ultimate keeper of the frame subgroup prior to the arrival of its acknowledgment. Upon receiving the MAC_xmit.IND protocol primitive the associated frame group will be discarded by the DLM.

**U5: T1 Timer Initialization**

If the uplink frame group transmitted in U4 requires acknowledgment, namely, it arrived at the MAC sublayer with ACK=Y(es) from the DLM, the ground station MAC starts a T1 timer, which is associated with the only discretely addressed frame subgroup that requires acknowledgment. If the downlink ACK associated with the T1 timer fails to arrive before the T1 timer expires a new transmission will be initiated.

**U6: Burst Sequence Arrival**

All aircraft within the signal range receive the uplink frame group and perform FEC. Each aircraft MAC will remove the MAC burst headers and forward the received frame group to the DLM only if all burst segments of the burst sequence have passed the FEC.

**U7: DLS Frame FCS Checking**

Upon receiving the uplink frame group from the MAC, the aircraft DLM performs ungrouping of the received frame group into individual DLS frames. FCS checking will be performed for individual DLS frames to check data integrity of the received DLS frames. If all the DLS frames are accepted, the DLM forwards all the pertinent-addressed DLS frames to the DLE; all other DLS frames received are discarded. Pertinent address refers to a frame with the DLE discrete address or non-discretely addressed data frames (such as broadcast frames) and CTRL frames (such as XID).

**U8: DLS Frame Subgroup Acknowledgment**

If all of the discretely addressed DLS frame subgroup that requires acknowledgment are accepted, the aircraft DLE sends an acknowledgment frame without delay to the MAC sublayer through DLM using MAC_ack.REQ primitive.

**U9: Expedited Downlink DLS Acknowledgment Frame Transmission**

The aircraft MAC sublayer receives and sends the acknowledgment frame using the reserved M_RA slot uniquely associated with the uplink MAC burst sequence transmission to the ground station MAC sublayer. Upon receiving the acknowledgment frame, the ground station MAC forwards it to the source DLE through DLM.

**U10: T1 Timer Cancellation**

The source DLE accepts the acknowledgment frame, discards the frame subgroup that has been acknowledged, and responds with a MAC_cancel_t1.REQ protocol primitive to the ground station MAC sublayer through the DLM; any new frame subgroup at the top of the ground station source DLE output queue is also sent to the ground station MAC sublayer through DLM. Upon receiving the
MAC_cancel_t1.REQ primitive, the ground station MAC sublayer cancels the associated T1 timer. Note that the ground station MAC must keep a T1 timer for each ground station DLE with respect to individual aircraft for which an acknowledgment frame is pending. Following the delivery of the MAC_cancel_t1.REQ protocol primitive to the MAC sublayer through the DLM, any frame or frame subgroup at the top the source DLE is also forwarded immediately to the MAC sublayer through the DLM using the MAC_data.REQ protocol primitive.

U11: **DLS Frame Group Retransmission**

If the T1 timer expires prior to receiving the MAC_cancel_t1.REQ primitive, the ground station MAC will declare a time-out for the outstanding frame group by sending a MAC_time_out.IND protocol primitive to the source DLE through the DLM. Upon receiving the MAC_time_out.IND, the DLE will terminate its WAIT state for the acknowledgment frame and initiate a MAC_data.REQ protocol primitive which carries the highest priority frame subgroup (a new frame subgroup or the outstanding frame subgroup) to the DLM immediately. The DLM will generate a new frame group and send it to the MAC sublayer. The ground station MAC will prepare itself for the transmission of the frame group.

U12: **New Uplink Media Access Event**

Any new DLS frame group received as in Step U2 at the MAC sublayer will trigger the next uplink media access event and will follow the procedures described in Steps U3 to U12. Note that all DLS frames with ACK=N(o) will be discarded at DLM once they are transmitted by the MAC sublayer and that untransmitted DLM frames and frame group from the DLEs may be regrouped by the DLM when MAC_time_out.IND from the MAC sublayer is received by the DLM.

5.7.4 **Timing Constraints**

Timing is critical for the VDL Mode 3 DLS-MAC interface. The following timing constraints are identified. Violation of these timing constraints will lead to redundant MAC burst sequence transmission and/or degraded service.

\[
D13-D8 < T1, D14-D3 = 0, U10-U5 < T1, U12-U3 = 0, D11=U8= 0, U8-U7 < 210 \text{ ms.}
\]

In addition, the time between a poll (M_up) and its response (M_down) is 120 ms or one half of a MAC cycle in all VDL Mode 3 system configurations. Therefore, event D4 must be completed within the window of 120 ms. In other words, if a specific implementation includes MAC and DLS in physically separated entities, interconnected with copper wires for instance, they must be tightly coupled together such that two interlayer protocol primitives can be exchanged within half a MAC cycle of 120 ms. For example, in D4 a MAC_poll.IND will be followed by a DL_data.REQ.
SECTION 6

6.  3T CONFIGURATION

In 3T, the slot usage is different from the other configurations in that the first time slot in each frame (labeled A) is used entirely for M channel functions. Another special feature of 3T is that voice and data are on a much more equal footing—both voice and data transmission can proceed only after a slot allocation has been negotiated using the M channels. Also, in 3T all users are considered to be in one user group, regardless of Group ID. Group ID is used to control polling only, as described in Section 6.2.3. Below (in Section 6.1) the new formats associated with 3T will be described. In Section 6.2 the protocol changes included in 3T are noted.

6.1  Formats (3T)

In 3T the basic message structure remains the same as in other configurations; there are V/D messages and uplink and downlink M channel messages.

6.1.1  V/D Formats

The V/D messages contain 24 bits of header and 576 bits of V/D. There is no truncated voice mode in 3T.

The voice header contains 12 bits of information arranged in fields just like in the other configurations.

The data header is identical to the data header of the other configurations.

6.1.2  M Uplink Format

The uplink M channel message consists of 384 bits, of which 192 are information bits. These are arranged into 16 Golay words, whose structures are the same as those listed in Section 3.3. The Golay words are arranged as follows:

1  Beacon 1 (B)  12 bits
2  Beacon 2    12 bits
3  Message (B)  12 bits
4  Message (B)  12 bits
5  Beacon 1 (C) 12 bits
6  Message (C)  12 bits
7  Message (C)  12 bits
8  Beacon 1 (D) 12 bits
9  Message (D)  12 bits
10 Message (D)  12 bits
11 Reservation #1 12 bits
In this structure, the last six words constitute a reservation pool that can be shared by all users, independent of whether their Local ID begins with B, C, or D. Words 1, 3, and 4 are used to control activities of users with Local ID prefix B. Thus, Beacon 1 (B) controls the polling access for all “B” users. The fields labeled Message (B) can be either Entry messages or Next Net messages for “B” users. Similarly, words 5, 6, and 7 are devoted to “C” users; and words 8, 9, and 10 are devoted to “D” users. The second word (Beacon 2) contains general information that is the same for all users and is not expected to change often.

In addition to the uplink M channel, the same time slot also contains another special message called the Handoff Check message, whose format is given below:

```
Handoff Check          (MID = 0101)

Beacon 3          12 bits
GSA+Frequency #1   12 bits
Frequency #2       12 bits
Frequency #3       12 bits
Frequency #4       12 bits
```

Beacon 3 is a special word that is similar to Beacon 1. Its format is as follows:

```
Beacon 3

Message ID          4 bits
Ground Station Code  3 bits
Spare               1 bit
Ground Subnetwork Address (bits 1-4) 4 bits
```

The Frequency word is similar to the Next Net 1 word:

```
Frequency #N

Spare       2 bits
Frequency   10 bits
```

The GSA+Frequency word is similar to the Frequency word, except that the spare bits contain the most significant bits of the Ground Subnetwork Address:

```
GSA+ Frequency #N
```
6.1.3 M Downlink Formats

The formats for downlink M channels are very similar to the formats in other configurations. The major difference is that in the 3T configurations, the first time slot in each cycle is devoted to providing four separate downlink M channel opportunities. As described in the section on protocols, the second, third and fourth opportunities are associated with “B”, “C” and “D” users, respectively, for polling.

6.1.4 Message Format Summary

The new message formats introduced by 3T are summarized in Table 4-1 (for uplink M channel messages). Downlink M channel message formats and V/D formats remain unchanged.

6.2 Protocols (3T)

Many of the protocols associated with 3T are similar to protocols associated with the other configurations. Major changes include the way voice and data slots are allocated to the various users. Changes, where appropriate, are noted below.

6.2.1 Link Establishment

As in all other configurations, all airborne users must perform link establishment before participating.
Table 6-1. Burst Format Summary (M Channel Uplink: 3T)

<table>
<thead>
<tr>
<th>Type</th>
<th>Message ID</th>
<th>Sync</th>
<th>Burst Format</th>
</tr>
</thead>
<tbody>
<tr>
<td>¾</td>
<td>**</td>
<td>S₂*</td>
<td>{Beacon 1 (B): 12} {Beacon 2: 12} {Message (B): 12} {Message (B): 12}</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>{Beacon 1 (C): 12} {Message (C): 12} {Message (C): 12}</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>{Beacon 1 (D): 12} {Message (D): 12} {Message (D): 12}</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>{Reservation #1: 12} {Reservation #2: 12} {Reservation #3: 12}</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>{Reservation #4: 12} {Reservation #5: 12} {Reservation #6: 12}</td>
</tr>
<tr>
<td></td>
<td>0101</td>
<td>S₂*</td>
<td>{Beacon 3: 12} {GSA+ Frequency #1: 12} {Frequency #2: 12} {Frequency #3: 12}</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>{Frequency #4: 12}</td>
</tr>
</tbody>
</table>

**Message IDs for Beacon 1 (B), Beacon 1 (C), and Beacon 1 (D) are independent.**
Message (¾) can be a Net Entry Response, Next Net, or net entry confirmation (Reservation/RACK) message.

{Beacon 3: 12} = { (Message ID: 4)(Ground Station Code: 3)(Spare:1)(Ground Subnetwork Address (bits 1-4): 4) }
{GSA+Frequency #1: 12} = { (Ground Subnetwork Address (bits 5+6):2)(Spare:1)(Frequency:10) }
{Frequency #N: 12} = { (Spare:2)(Frequency: 10) }
6.2.1.1  **Net Initialization**

Net initialization operates essentially the same way in all configurations. However, for 3T, the Slot Number may *not* agree with the Group ID of the entrant. Instead, the Slot Number must always be “A.”

6.2.1.2  **Net Entry**

To operate fully in a 3T net, an airborne radio must sign in if it wishes to do anything more than listen to activities on the net. Normally, a radio will begin the sign-in procedure by transmitting a Net Entry Request message in an available RA slot. The rules for choosing a particular slot are found in Section 4.10.

For polling purposes, the ground station will assign to an entrant a Group ID corresponding to the (fictitious) group with the least participants. For voice access, the Group IDs B, C, D will be treated as one large user group. Other rules for net entry are the same as in Section 4.1.2. Note that for 3T the maximum number of assignable airborne addresses is 180 (60 each for Group IDs B, C, and D).

6.2.2  **Acquisition Window/Squelch Window/Validity Window**

The Squelch Window field is contained in the uplink M channel in word Beacon 2. There is only one squelch window size for all users trunked together on a net. The use of the squelch window is the same as in all other configurations.

6.2.3  **Polling**

The 3T configurations can be thought of as encompassing three separate nets, associated with Group IDs prefixes B, C and D, which are trunked together in terms of their voice and data traffic. As far as polling is concerned, however, the three nets remain separated. Polling for “B” users is controlled using the first Beacon 1 in the uplink M channel. Likewise, polling activities for “C” and “D” users are controlled by the second and third Beacon 1, respectively. Polling responses for “B”, “C” and “D” users must be transmitted in the downlink M channel “A” slot using the second, third, and fourth opportunities, respectively. For polling commands, the use of the M channels is completely separate for B, C and D. The rules for scheduling polling messages is the same as found in Section 4.3.

6.2.4  **Net Exit**

The net exit procedure in 3T is essentially the same as in any other configuration.

6.2.4.1  **Leaving Net Message**

The leaving Net Message is exactly the same as in any other configuration.

6.2.4.2  **Next Net Message**
The Next Net message in 3T is the same as it is in all other configurations. The message must be sent in the appropriate part of the uplink M channel message. For example, the Next Net message for “D” users must be sent in the ninth and tenth words.

6.2.5 **Airborne Voice Transmission**

When PTT is activated on an airborne radio, the radio must obtain a time slot allocation before voice transmission can begin. To initiate the process, the airborne radio will transmit a downlink M channel Reservation Request message with the Voice Access bits changed to 01 (Routine Request). This request will be received by the ground station and slots will be allocated according to an algorithm described below.

A pair of slots per cycle must be allocated to the voice link, and the slots must always be D slots. This allows the airborne radio to have a periodic voice slot allocation without conflicts.

The uplink M channel message that provides the voice reservation will contain the user’s Local ID and the Reserved Frame bits will be 1110 or 1111 depending on whether the first usable slot is in the even or odd frame of the next cycle. Also, during the time when the downlink voice is transmitted, the Voice Signal field of the appropriate Beacon 1 will be set to 01 (occupied by airborne user). At this point, the voice transmission operates as in other configurations (see Section 4.5).

When the airborne PTT is deactivated, the header will have EOM = 1 in the last time slot to contain at least one full vocoder frame. Upon receiving this signal, the ground radio will return the reserved slots to the available slot pool and set the Voice Signal field of Beacon 1 back to 10. As in the other configurations, it may happen that the EOM is missed by the ground receiver. If the ground radio misses [4] consecutive voice time slots it will consider the voice message lost and operate as if an EOM had been received.

Note that the 3T configuration provides “party line” connectivity within a user group just as in any other configuration; however, all users comprise one user group, regardless of Group ID.

6.2.5.1 **Truncated Voice Mode**

There is no truncated voice mode in the 3T configuration.

6.2.6 **Ground Voice Transmission**

When the PTT of a ground radio is activated, the radio must determine (1) whether there is an airborne user from the same user group already transmitting voice, and (2) whether there is a pair of slots per cycle available. If there is no prior voice user and if there are appropriate slots available, then the ground radio will begin transmitting the uplink voice message. In addition to transmitting the message, the ground radio will set the Voice Signal field of the appropriate Beacon 1 to 00 (ground access).

If there is already an airborne voice message from the same user group, then the ground radio must first “remove” the airborne user prior to voice transmission. To accomplish this the ground radio
transmits an uplink M channel message with the Voice Signal field of the appropriate Beacon 1 set to 00. The uplink voice message will begin in the next cycle. It is the responsibility of the airborne radio to cease transmission by the end of the cycle in which it receives the ground access indication. The uplink voice message will be sent in the slots previously reserved for the downlink voice message, i.e., the D slots.

If there is a prior airborne message but no slots are available, then the voice transmission must wait until appropriate slots are available. The scheduling of slots in configuration 3T is described below.

6.2.7 Airborne Data Transmission

From the point of view of an airborne radio, data transmission in configuration 3T is nearly identical to the process in the other configurations. Minor changes include the following:

C The airborne radio can generally choose from a larger number of RA slots for its Reservation Request message.

C The reservation is provided in the reservation pool in the uplink M channel message.

All other procedures are the same.

6.2.8 Ground Data Transmission

Uplink data messages are processed in 3T in a way that is almost identical to the way they are processed in the other configurations. The only difference is in the way the uplink data slots are scheduled, as described in the next section.

6.2.9 Data/Voice Scheduling

In configuration 3T, the scheduling of V/D time slots is very similar to the scheduling processes in the other configurations, with some modifications to account for the larger number of slots available and for the inclusion of voice in the process.

At the end of each cycle, the ground radio will catalog all the voice and data slot requests received up to that point. Voice requests and data requests are treated separately; and all voice communications take place using the D slots. Access to these slots is adjudicated according to the following algorithm.

First, uplink voice and downlink voice are treated separately, with the uplink having priority. At the end of each cycle the ground station will catalog all voice requests received up to that point. If there is an uplink request pending at the beginning of cycle N, the algorithm will check to see if there are D slots available in N + 1. If the answer is yes, the ground user’s voice message will begin to be transmitted in the first available D slot in that cycle. If D slots are not available in the next cycle because of a prior reservation for an airborne data message, the uplink voice message will begin in the first available D slot after the completion of the data reservation. If voice slots are not available because of a preexisting downlink voice message, the uplink voice will preempt it. To accomplish this, the ground station will first change the Voice
Signal bits in the third Beacon 1 word (the one related to the D slots) in the uplink M burst in cycle N to 00 (i.e., ground access). The ground voice message will begin to be transmitted in cycle $N + 1$. Once a ground user has been given voice access to D slots, its reservation will continue until PTT is released and the last voice burst (with EOM) is transmitted.

If there are airborne voice requests pending, they will be arranged by the ground station in the order in which they are received. If the D slots in the next cycle are not already scheduled for data or voice bursts then the voice message at the head of the airborne voice queue will be given access to the D slots starting in the cycle $N + 1$. The ground station will send a reservation addressed to the appropriate user with Reserved Slot = 1110 or 1111. If the D slots in the next cycle are occupied, no voice reservation can be given at that time. The ground station can, however, send a RACK if an unused reservation word is available for this function. When an airborne user is given a voice reservation, the duration of reservation is unrestricted (except for a possible time out after 35 seconds). The reservation will normally end only after PTT is deactivated and EOM is transmitted with the last voice burst. Data cannot preempt a preexisting voice message; but a ground voice message can preempt an airborne voice message.

Except for the changes necessary to accommodate voice messages, the processing of data requests is nearly identical to the data scheduling in other configurations. As in the other configurations, there are separate priority queues which are each ordered according to time-of-arrival of the requests. As before the higher priority messages are served first and uplink acknowledgments are given expedited service. A reservation delivered to a particular user tells it to start transmitting on a particular slot in the next cycle and to continue transmitting until the reservation (for up to 15 slots) is completed. This is basically the same as the process in other configurations (except there are more slots per cycle available). The major exception for 3T is that the ground will tell an airborne user to skip the D slots for its data message if the D slots in the next cycle are scheduled for voice. Note that even if the voice message ends while a data transmission is ongoing. The data burst will continue to avoid the D slots until its reservation has completed.

As in the other configurations, whenever the ground station receives a Reservation Request via random access but cannot immediately grant a reservation, it can transmit a RACK using any unused Reservation word. Note that it is possible that a Reservation Request can be used to request slots for both voice and data messages at once. The ground station can transmit a RACK if it cannot immediately grant any slots for either function. If the ground can grant a reservation for one function (e.g., voice) than the airborne user should interpret that reservation as a RACK for the other function (e.g., data). As in the other configuration, any unsatisfied reservation request (voice and/or data) must be renewed when an airborne user is polled, or the request will be dropped. Again, a poll response is an opportunity to issue a request for an increased number of data slots while a request is pending.

This algorithm has the following properties.

- Uplink voice messages and downlink data messages that have already begun are never preempted.
- Voice has priority over data for the use of the D slots.
- An uplink voice will preempt a downlink voice.
C Only one voice message at a time is allowed.

C Data messages are sent sequentially. One must be completed before another can begin.

C In the absence of other traffic, a data message can use all six slots in one cycle. This provides a maximum (peak) information rate of 12400 bps transported from MAC layer to MAC layer. (Overhead due to addressing, error detection, etc., can lower this throughput rate).

6.2.9.1 Resolving Reservation Scheduling Conflicts

Because the uplink M channel message is quite long in the 3T configuration, there are fewer possibilities for Reservation conflicts then those described in Section 4.9.1. In particular, the Net Entry Response messages, Reservations or RACKs confirming net entry completion, and Next Net messages are transmitted in the “message” portions as described in Section 4.1.2 and Table 4-1. Thus, the only potential type of conflict is between ordinary Reservations and RACKs. In this case, the Reservation messages have precedence.
SECTION 7

7. WIDE AREA COVERAGE CONFIGURATIONS

The 3S configuration is a special 3-slot configuration which is designed to allow for coverage of a large volume of airspace by 3 ground stations. The 2S1X configuration is a special 3-slot configuration where two of the slots are used for a single wide area coverage domain of coverage and the last slot is used for an independent circuit. This might be necessary in geographical areas where a single ground station cannot provide coverage of a service volume due to adverse propagation conditions. The 3S and 2S1X configuration supports voice, and not data, communications.

Multiple ground stations operating in wide area coverage configurations are all coordinated in time (as described in Section 8). Each ground station (up to 3) uses a separate time slot. A separate uplink M channel beacon signal is transmitted in each slot. The different beacons will have different Slot Number designations, but will have the same GSC. When a ground user activates PTT, the resulting digital voice bit stream will be transmitted concurrently from each ground station using its own time slot.

Each airborne user will have the responsibility of selecting which beacon information to use and which voice message to process and to present to the operator. These choices can be made using a link quality estimating algorithm as described below. In other words, the airborne radio will “connect” itself to the ground station which is perceived to deliver the “best” signal. As the airborne radio travels through a wide area coverage sector, it may, from time to time, change its master ground station from one site to another.

When an airborne radio transmits, it will transmit in only one time slot per frame. The airborne radio will always transmit in slot A. Note that all of the collision avoidance and ground use precedence protocols that apply to other configurations apply here also. Thus, for example, an airborne user “connected” to slot C cannot transmit on slot A if another airborne user is already transmitting. An airborne radio will receive ground transmissions only in the slot to which it is connected; however, it will receive airborne transmissions only in slot A.

7.1 Ground Transmission Timing

Although the same voice bit stream is transmitted by each of the wide area coverage ground stations, the throughput delay can be minimized if the vocoder frames are staggered when they are inserted into the VDL Mode 3 bursts in the different time slots. In order to provide an example, it is convenient to assume that the vocoder frames are 20 ms. Thus, there are normally 6 vocoder frames per burst. If the vocoder frames are numbered consecutively, then the frames transmitted in slot A might be (M, M + 1, M + 2, M + 3, M + 4, M + 5). If that is the case, then the vocoder frames transmitted in slots B and C should be (M + 2, M + 3, M + 4, M + 5, M + 6, M + 7) and (M + 4, M + 5, M + 6, M + 7, M + 8, M + 9), respectively. Transmitting the voice bits in this way, as opposed to transmitting the slot A sequence in the other slots, will eliminate the necessity that communication over slots B and C will experience excess delays of 40 ms and 80 ms with respect to slot A.
Note.—that in the above example it was assumed that the ground vocoder was located at a central location and that the voice bits were distributed to the remote ground stations from this single source. In an architecture with a separate vocoder for each ground radio, the same vocoder timing issues do not arise.

7.2 Channel Quality Measurement

In order to choose which ground station should be its master, an airborne radio needs a means of assessing which ground station provides the “best” signal. This choice must be made based on the information available to the airborne radio. Examples of possible metrics include:

1. Signal strength estimated from the receiver AGC.

2. Signal quality based on synchronization sequence correlation measurement.

3. Signal quality based on the number of bit errors estimated by the Golay decoding process.

Other, more sophisticated metrics are also possible.

The slot selection algorithm implemented during validation trials was based on received power level. It included 2 dB of hysteresis to prevent continuous re-selection between comparable slots due to transient noise. The algorithm used for slot selection could be summarized as follows:

The aircraft station monitors the received power level of the M Uplink bursts from each of the ground stations assigned to the wide area coverage net (LBACs 7, 9, and 11 for 3S or LBACs 4 and 6 for 2S1X).

Although slot selection is being assessed every MAC, when the aircraft station transmits or receives a voice signal, the Voice Unit utilizes the same slot for the duration of the PTT event.

The received power level was calculated based on Receive Signal Strength Indication (RSSI), as the average power level at the symbol instances over the System Data segment of the M Uplink Burst.

7.3 Mixed Configuration to Improve Spectrum Efficiency with Area Coverage

This section describes a method by which two voice circuits may be supported on a single frequency, one of which provides 2-station wide area coverage (i.e. One voice circuit for 2-station wide area coverage) using the 2S1X system configuration and the second circuit provides independent 3V use within the same coverage region.
7.3.1 **Introduction**

In some regions multiple DSB-AM radios are employed to control sectors whose area cannot be covered by single ground station radio due to line of sight limitations.

VDL Mode 3 will meet the requirement for wide area coverage through the use of System Configuration 3S. Since all three slots are used to support a single wide area coverage voice circuit, it does not provide an increase in voice capacity over the existing AM system. However in many instances, the required coverage can be achieved from only 2-ground stations. As a result the unused slot capacity in a Standard 3S would be wasted. Ground stations can be configured to use the third slot in a 2-ground station wide area coverage sector and thus increase overall system capacity by providing an additional voice circuit.

7.3.2 **Configuration**

The configuration is as follows:

C Two radios operating under System Configuration 2S1X utilizing Slots A and C would support User Group A for wide area coverage.

C A third radio operating independently under System Configuration 3V on Slot B would support User Group B.
This arrangement is shown in Figure 7-1.

**Figure 7-1. 2S1X & 3V Channel Utilization**

7.3.3 **Operation**

With reference to Figure 7-1, an airborne user who tunes to User Group A will reject transmissions on Slot B since the System Configuration/Slot ID in the M Uplink Burst indicates that is for User Group C. Similarly tuning to User Group B will cause the radio to reject transmissions on Slots A and C since the System Configuration/Slot ID in the M Uplink Burst indicates those are for User Group A.

This procedure is covered in the SARPs Section 5.7.2.1.1 Net Initialization that states:

*Note.— The first part of the link establishment procedure shall be the acquisition of the M uplink burst associated with the specified user group identifier.*
7.3.3.1 **Configuration Options**

Referring to Figure 7-1, GS3 need not be spatially separated from GS1 or GS2. Furthermore, providing a radio can support more than one User Group, then GS1 or GS2 could be used to support the 3V User Group B as well as being part of the wide area net.
§ 8. TIME MAINTENANCE

Because VDL Mode 3 is a time slotted system, timing is of critical importance. Within a particular user group, the timing of the airborne radios is slaved to their ground station. The architecture includes sufficient guard time to allow for up to 200 nmi range in the 4-slot configurations and 609 nmi range in the 3-slot configurations. The guard time also includes an allowance for the airborne radio timing to have an additional error of ±1 symbol period beyond the offset due to propagation delay. If an airborne radio cannot guarantee such precision, it must initiate special procedures as described in Section 8.2.

In some cases the timing of the ground stations is relatively unimportant. For instance, if all the time slots on a channel are used by a single ground station, then the absolute time of that station, and its timing with respect to other stations, is unimportant. However, in cases where different ground stations share the different time slots on a single frequency channel, the relative timing of the ground stations is critical. Relative time is also important between different ground stations implementing the Handoff Check Message in the 3T configuration.

To facilitate the time coordination of ground stations, it is assumed that ground stations can be slaved to an absolute time standard. Universal Coordinated Time (UTC) is an example of such a standard. Because of the fact that UTC may contain leap seconds, it is not easily usable by VDL Mode 3 as a standard. The standard for VDL Mode 3 will be equivalent to UTC, but without leap seconds. This type of time is used elsewhere. In particular, the Global Positioning System (GPS) uses (internally) a time standard called GPS system time, which was aligned to UTC on 6 January 1980, but is now different by an integral number (12 in August 1997) of omitted leap seconds. A GPS receiver internally calculates GPS system time and corrects it to UTC by adding the appropriate number of leap seconds. (The number is part of the GPS navigation message.)

The discussion of GPS should not be construed as a requirement that GPS be used as a time source. The only requirement is to use timing equivalent to GPS system time. In particular, in order to avoid explicit reference to GPS, the standard time reference could be International Atomic Time (TAI). If VDL Mode 3 time is defined as TAI - 19 seconds, it will coincide with GPS system time.

8.1 Ground Station Timing Procedures

It is anticipated that an external time source providing “absolute” time to a VDL Mode 3 ground station will provide a timing strobe once per second. It is also assumed that each strobe will be labeled with its time-of-day. Note that since the VDL Mode 3 MAC cycle time is 0.24 seconds, the MAC cycles will “line up” with the one second time strobes only once each 6 seconds. Thus, it was convenient to define the 6-second epoch in Section 1.1. In an ordinary day (i.e., one without a leap second) there are an integral number of epochs (14400). To maintain a simple transition at midnight, leap seconds are omitted from VDL Mode 3 system time (as described in the previous section). The remainder of this section describes a possible way to maintain the time interface between a time source and a VDL Mode 3 ground radio.
For convenience all times are measured in units of symbol periods. A MAC cycle is 2520 symbol periods long. Within a MAC cycle the time when the “center” of the first symbol of the synchronization sequence of the uplink M channel beacon is transmitted defines the point 0. Thus, the centers of the symbols within a cycle are located in the range -1260 to +1259. Note that within a particular radio different units (for example, sample periods) can be used.

As stated previously it is assumed that the 1-second strobes are labeled with time of day, which may include hours, minutes, seconds, etc. However, only the “seconds” units really matter. In particular, only the seconds modulo 6 have any significance. Thus, it is assumed that the strobes are labeled with a parameter called Strobe Number (SN) and that

\[ 0 \leq SN \leq 5. \]

Given these definitions it is easy to determine that strobes are expected to be received at times:

\[ TS (\text{expected}) = (420 \times SN + 1260) \mod 2520 - 1260. \]

In practice, the actual strobes may be received at times which differ slightly from the expected times. If \( TS (\text{actual}) \) is the measured strobe time, then the ground station timing error is given by

\[ \Delta = (TS (\text{actual}) - TS (\text{expected}) + 1260) \mod 2520 - 1260. \]

An appropriate algorithm to correct such errors needs to be developed. Note that under a normal operating environment the internal clock of the ground station should have an accuracy of 2 parts per million (ppm). Thus, the drift per strobe should be less than 0.02 symbol periods. Ground time should be relatively easy to maintain.

If the ground station, which has been configured to receive external time, fails to do so, it should report this failure after 5 missed strobes. This reporting can occur during routine remote maintenance or by some other means to be determined. At that point the system may (as an option) switch over to an alternate time source, or to an alternate ground site which has good time. In either case, the total time error with respect to TAI should be no greater than 1 symbol period.

8.2 Airborne Timing Procedures

Figure 8-1 is a simplified picture illustrating various ways that time can be distributed in the VDL Mode 3 architecture (with emphasis on the upper left airborne radio in User Group A). The boxes labeled “External Clock” are assumed to be reliable sources of time as described in Section 6.1. The boxes labeled “Internal Frequency Source/Clock” are assumed to be clocks controlled by the internal oscillators of the radios. The primary path of timing information is from the ground to the airborne radio via the uplink M channel beacons, as shown. However, the figure shows that there are alternate means of receiving time. (Note that all of these timing signals are uniquely identified by including the synchronization sequence \( S_2 \).) These are discussed below.
The normal operation of the VDL Mode 3 system assumes that the airborne radios receive time from the ground stations to which they are “connected.” The timing of an airborne radio is expected to be delayed with respect to its ground station by an amount equal to $R/c$, where $R$ is the air-ground range and $c$ is the speed of light. Airborne radios must maintain this time to within an accuracy of $\pm 1$ symbol period ($T_s$).

### 8.2.1 Coast Time Counters

In order to maintain time, the airborne radios must keep track of three separate counters:

1. Coast Time Counter 1 (CTC1) is the number of MAC cycles since the last successful reception of an uplink M channel beacon. Thus, whenever a beacon is missed CTC1 is incremented by 1. Otherwise, CTC1 is reset to 0. A successful beacon reception
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consists of the reception of the synchronization sequence and the Beacon 2 word. The Slot Number and GSC fields must correspond to the airborne radio’s net. In order to qualify as a valid beacon signal the beacon must also contain the same information in Beacon 2 and have the same timing (within ±1 symbol period) as the previous beacon signal.

(2) Coast Time Counter 2 (CTC2) is the number of MAC cycles since the last time the airborne radio accepted new timing information. This information could come from a beacon reception, but it could also come from the reception of an Alternate Timing Signal (ATS). ATS’s are Poll Responses from airborne radios (except in the 3T configuration) and beacons in slots other than the one controlling the airborne radio’s User Group. Different User Groups sharing a common channel may be controlled by geographically separated ground stations. However, the separate ground stations will have the same GSC. Airborne radios will accept the timing information of an ATS only if it obeys certain timing constraints described below in rule (2) of Section 8.2.2. If a beacon is not received and if the timing is not updated by an ATS then CTC2 is incremented by 1. Otherwise, CTC2 is reset to zero.

(3) Coast Time Counter 3 (CTC3) is the number of MAC cycles since the last reception of a beacon or any Poll Response whether or not it was used for updating time. If none of the above signal types is received during a MAC cycle, CTC3 is incremented by 1. Otherwise, CTC3 is reset to 0.

Note.— that, based on the definitions stated above,

\[ CTC1 \geq CTC2 \geq CTC3 \geq 0. \]

Also, note that (in order to avoid a software overflow condition) these counters can cease to be incremented at some level, which is higher than any anticipated threshold (e.g., at 1023).

These counters control, among other things, the “timing state” of a particular airborne radio. There are four operational timing states:

(1) Timing State 0 (TS0). This special state applies to airborne radios prior to net initialization, and to configuration 3T under certain conditions. In this state an airborne transmitter cannot transmit.

(2) Timing State 1 (TS1). This is the normal state of VDL Mode 3. In this state an airborne transmitter can transmit full-length voice messages, data messages, and downlink M channel messages.

(3) Timing State 2 (TS2). This is the truncated voice mode. In this state an airborne radio can transmit only truncated voice messages. Transmissions of data messages and downlink M channel messages are not permitted.
(4) Timing State 3 (TS3). This is the free-running voice mode, which is the preferred state when there are no ground stations present. Operationally, an airborne radio will enter TS3 when it determines that there are no ground stations visible to any aircraft within line-of-sight. While in TS3 airborne radios can transmit full-length voice messages only if there are no preexisting voice messages on the channel. Transmissions of data messages and downlink M channel messages are not permitted. In TS3, all the airborne users on a frequency channel coalesce into a single large User Group, i.e., Group ID’s in V/D headers are ignored.

In order to facilitate the efficient use of airborne radios, it may be possible to indicate to the users (by a means to be determined) their current timing states.

8.2.2 Transition Rules

This section will describe the rules whereby the Coast Time Counters (CTCs) are used to control the transitions from one timing state to another and the timing updates using the ATSs. In order to derive these rules certain assumptions about the system parameters were made.

(1) The stability of the airborne clock is the same as the airborne frequency stability, i.e., 5 ppm.

(2) The ground stations are normally locked to an external time source. Under very rare circumstances the ground radio may have a timing accuracy equivalent to its frequency stability, i.e., 2 ppm.

(3) An additional source of time error is the movement of the airborne radio with respect to the ground station. For a Mach 1 aircraft this is 1 ppm.

(4) One type of ATS is the polling response. In the worst case of a fully loaded 4V configuration, the longest possible polling cycle is 120 MAC cycles (plus some allowance for net entrants).

The first three assumptions are used to determine the threshold for the transition from TS1 to TS2 and to suggest an appropriate value for the timing update criterion (see below). The fourth assumption is used to suggest an appropriate value for the threshold for the transition from TS2 to TS3.

Given these assumptions, the following rules for airborne radios which have already entered a net (and are not in the 3T configuration) can be generated:

(1) When CTC1 \( t \) (default =50), a radio will change from TS1 to TS2.

(2) While in TS2, a radio will accept time from an ATS if and only if

\[ T_r < T_a + 0.04 \cdot CTC2 \cdot T_s. \]
Here, $T_a$ is the expected time of an ATS as determined by the airborne radio’s clock; and $T_i$ is the actual time of arrival of the ATS with respect to the airborne radio’s clock. $T_s$ is a symbol period.

If CTC2 is greater than 800, all ATS time updates will be accepted. If the time is updated, CTC2 is reset to 0.

(3) When CTC3 $\geq f$ (default =250), a radio will change to TS3.

(4) While in TS3, a radio will accept time from any ATS and enter TS2.

(5) Any radio in TS2 or TS3 will immediately revert to TS1 upon reception of a valid beacon signal. Time will be updated to agree with that of the beacon.

Thus, CTC1 and CTC3 control a radio’s timing state whereas the role of CTC2 is to control the timing update mechanism while a radio is in TS2. A “state diagram” based on these rules is shown in Figure 8-2.

Rule (1) is based on the time it would take for an airborne receiver to accumulate a timing error of $T_s$, given the worst-case drift assumptions. The worst case would correspond to the addition of the maximum rates due to the airborne and ground clocks and the aircraft’s movement (5 ppm + 2 ppm + 1 ppm = 8 ppm).

Rule (2) is designed to allow an airborne radio to accept time preferentially from sources with the least excess path delay. Thus, a radio will accept time from an ATS only if it appears “earlier” than the time predicted by its own internal clock. The factor with CTC2 is included to allow for the case where an airborne radio’s clock is fast with respect to the correct time. The net result is that, when there are a number of ATSs available, an airborne radio will tend to have its time controlled in such a way as to minimize its excess path delay. This will greatly reduce the chance that a radio in TS2 will ever violate its time slot boundaries.

Rule (3) is designed to allow a radio to enter TS3 whenever at least two whole polling cycles have passed without receiving any poll responses. It is considered very unlikely that this will occur unless the
ground station has ceased to poll its airborne radios. The only reason a ground station would cease polling is if it were inoperable. Under this condition, TS3 is the preferred state.

**Figure 8-2. Timing State Diagram**

Rule (4) is designed to ensure that if there is any evidence that at least one ground station (on channel) within line of sight is operable, all radios in the area will be in TS1 or TS2, ensuring that time slot boundaries are respected.

Rule (5) ensures that radios will return to TS1 as quickly as possible whenever the appropriate ground timing is available.

### 8.2.3 Special Rules for Net Initialization

Radios, which have not yet entered a net, have some special considerations when uplink beacons are not available. Such radios can be considered to be in a special timing state, called TS0, where transmission is not allowed. Radios in this state have no information as to the local configuration of the system, and they initially have no information as to why beacon signals are not available. The ground station could be operating but out of line of sight, or the ground station could be inoperable. To deal with this uncertainty, the following rule applies. The airborne radio will not transmit until one of the following happens:

1. The radio receives a valid beacon signal. In this case the word “valid” signifies that the information in Beacon 2 is the same and the timing is the same (within ±1 symbol period) as the last successful beacon reception. In this case the radio will enter TS1 and proceed to net entry if desired.
(2) The radio receives an ATS. The ATS will contain enough information (see Section 3.4) to tell the airborne radio whether the local configuration is a three-slot or four-slot configuration. With this information the radio can enter TS2 and determine the correct time for transmitting truncated voice messages.

(3) The radio’s CTC3 counter reaches the value f. In this case the radio enters TS3. In order to shorten the time it takes to reach TS3 under these circumstances, the CTCn are initially set to max(f-50,t) at the onset of link establishment. Using the default values of f=250 and t=50 gives 200 as the starting value of CTCn. In this case an airborne radio will enter TS3 in 12 seconds when no beacon is present.

Note that if a radio enters TS2 or TS3 in this way, it does not have an opportunity to complete net entry. The net entry procedure can be completed only after successful reception of uplink beacon signals begins. Note also that, except in the case of radio start-up, the user always has the option to return to the previous net if ground connectivity with the next net is not achieved quickly.

8.2.4 Truncated Voice Mode

For all configurations (except 3T) the airborne radios enter the truncated voice mode whenever they are in TS2. To accommodate this condition of increased timing uncertainty, the V/D (voice) burst are shortened by 32 symbol periods. These shortened bursts are shifted by 16 symbol periods in order to provide more guard time, enhancing the probability that the airborne transmissions will obey slot boundaries.

To allow for the shortened bursts of the truncated voice mode, the effective vocoder bit rate must be reduced from 4800 bps to 4000 bps. This will be accomplished by adjusting the vocoder clock rate so that there is one 96-bit vocoder frame per 24 milliseconds. Thus, there will be five such frames per TDMA frame. The number of bits per TDMA frame is five times 96, or 480.

It is assumed that a particular transmission will adopt the voice mode applicable at the activation of PTT, which will remain constant for that PTT event. If the timing state should change during a particular transmission, the voice mode will temporarily remain unchanged until EOM. Nevertheless, the vocoder must be able to switch from one rate to the other on a slot-by-slot basis to account for the possibility that a voice message in one mode is quickly replaced by a voice message in the other.

8.2.5 3T Configuration

The 3T configuration is a rather special case vis-à-vis ground timing. For 3T all communications, including voice, are scheduled by the ground station. Thus, TS2 is of little or no value in 3T. When CTC1 exceeds the threshold of 50, the radio enters TS0 and all airborne transmission ceases until CTC3 exceeds 250 and the airborne radios enter TS3. This will create a potentially long gap when voice transmission is not allowed. It is assumed that this is acceptable in a sector governed by a configuration such as 3T, which treats voice and data more equally than other configurations. In other words, it is expected that 3T will only be used where data is the primary means of communication and voice is a back-up mode.
Note that in 3T there are no valid ATS’s since there are no alternative uplink M channel beacons and the Poll Responses are identified as not being suitable for timing (see Section 2.4). However, the Poll Responses do serve to reset CTC3 to zero whenever they are received. A potential net entrant entering into a 3T area will never have the opportunity to enter via TS2 since no ATS’s are available. It will either enter normally in TS1 or go directly to TS3 after waiting up to 1 minute.

8.2.6 **Squelch Windows**

In Section 4.2 the squelch windows for airborne radios in TS1 were discussed briefly. To account for the numerous possibilities encompassed by the different timing states and configurations, the squelch windows for voice communications are summarized in Tables 8-1 and 8-2. The columns indicate the state of the receiving radio, and the rows indicate the type of voice message being received. The windows are measured in symbol periods relative to the time when the receiving radio would have transmitted its own voice message.

8.2.7 **Scenarios**

To clarify how the proposed timing rules will work, three possible “lost timing” scenarios are considered.

(1) Single lost radio. In this scenario a single airborne radio in a user group loses connectivity with the ground station due to some type of adverse propagation condition. All (or most) other users remain connected. In this case the lost radio will coast for 12 seconds and then enter TS2, the truncated voice mode. While in this mode, it can maintain voice communication with some of the other airborne radios. It will also receive poll responses from some of the radios. The radio will update its timing based on the “closest” relay radios available. (Closest connotes, in this case, radios, which are most nearly in line with the ground radio and the lost radio. These will have the smallest excess path delay.) This will, with very high probability, keep the truncated voice transmissions within their proper time slot boundaries. Also, the quasiperiodic reception of ATSs will keep the lost radio from ever entering TS3. In most cases, the lost radio will eventually reestablish its connection with the ground. Reception of the ground beacon will reset all CTCs to zero and send the radio into TS1.

<table>
<thead>
<tr>
<th>Table 8-1. Source Filtering Squelch Window Matrix for 4-Slot Configurations</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Message Type</strong></td>
</tr>
<tr>
<td>------------------</td>
</tr>
<tr>
<td><strong>State</strong></td>
</tr>
<tr>
<td>Uplink voice</td>
</tr>
<tr>
<td>Downlink voice: TS1</td>
</tr>
</tbody>
</table>
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#### Table

<table>
<thead>
<tr>
<th>Downlink voice: TS2</th>
<th>-2 to +4(n+9)</th>
<th>-34 to +4(n+9)</th>
<th>Wide Open</th>
<th>-1 to +(4n+35)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Downlink voice: TS3</td>
<td>Wide Open (Note 4)</td>
<td>Wide Open (Note 4)</td>
<td>Wide Open</td>
<td>Wide Open (Note 4)</td>
</tr>
</tbody>
</table>

**Note 1.** — Each squelch window is defined relative to the nominal burst time in symbols.

**Note 2.** — \( n \) = Squelch Window parameter.

**Note 3.** — If \( n \) is unknown, then the default value is 6.

**Note 4.** — Receive any such message with “correct” Group ID if not already receiving a voice message.

**Note 5.** — In this column, “Wide Open” implies that an airborne radio will receive any voice message, without regard to Group ID.
Table 8-2. Source Filtering Squelch Window Matrix for 3-Slot Configurations

<table>
<thead>
<tr>
<th>State</th>
<th>Airborne Receiver State Squelch Window (Note 1)</th>
<th>Ground Receiver State Squelch Window (Note 1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Uplink voice</td>
<td>TS1 (Note 2)</td>
<td>NA (Note 2)</td>
</tr>
<tr>
<td>Downlink voice: TS1</td>
<td>-2 to +8(n+1)</td>
<td>-1 to +8(n+7)</td>
</tr>
<tr>
<td>Downlink voice: TS2</td>
<td>-2 to +8(n+5)</td>
<td>-1 to +8(n+39)</td>
</tr>
<tr>
<td>Downlink voice: TS3</td>
<td>Wide Open (Note 4)</td>
<td>Wide Open (Note 4)</td>
</tr>
</tbody>
</table>

Note 1.— Each squelch window is defined relative to the nominal burst time in symbols.

Note 2.— n = Squelch Window parameter.

Note 3.— If n is unknown, then the default value is 7.

Note 4.— Receive any such message with “correct” Group ID if not already receiving a voice message.

Note 5.— In this column, “Wide Open” implies that an airborne radio will receive any voice message, without regard to Group ID.

(2) Massive Ground Failure. In this scenario the ground station and all possible back-ups fail simultaneously. When this happens, the CTC1’s of all airborne radios will begin to increment once per cycle. After 12 seconds all the radios will enter TS2. Also, all CTC3 counters will continue to increment. After about 60 seconds, all the radios will enter TS3 and all user groups will coalesce into one large user group. At no time is air-to-air voice communication prevented. Also, if and when the ground stations are operable and begin transmitting beacons, the airborne radios will all return to TS1.

(3) Oceanic. In this case, which might apply over the ocean or in any area with no ground infrastructure, there are never any beacon signals. The only correct timing state is TS3. In this case any entering radio will wait 12 seconds for its CTC3 to reach 250, and it will then remain in TS3 indefinitely.
8.2.8 Dummy Poll Responses

The overall system timing architecture relies on air-to-air time transfer provided by quasiperiodic Poll Responses. In particular, the CTC3 thresholds for entering TS3 are determined based on assumptions concerning typical polling cycle times. However, there exist certain configurations in which polling may not be implemented. These configurations are the voice-only configurations: 4V, 3V, 3S, and 2S1X. If a ground radio in one of these configurations does not support polling, it will transmit the value 61 or 62 in the Aircraft ID (Poll) field of its uplink M channel message. This informs the airborne radios that discrete addressing is not supported.

In order to support the time transfer architecture, airborne radios must transmit “Poll Responses” even though they are never actually polled (except possibly for certain airborne radios which are placed in a passive, listen-only mode). To accomplish this, an airborne radio will transmit dummy Poll Responses using the value 61 in the Aircraft ID field. It will transmit them in MAC cycles chosen by the following algorithm:

Immediately after entering TS1, after determining that the uplink Beacon contains Aircraft ID = 61 or 62, divide all further MAC cycles into groups of 25. Within each group, choose one MAC cycle at random in which to transmit a dummy Poll Response. Continue to transmit dummy Poll Responses for as long as the airborne radio remains in TS1.

Analysis and simulation have shown that, unless the number of airborne radios is extremely large, the probability that at least one MAC cycle out of 25 contains one and only one dummy Poll Response is very close to 1. In other words, this algorithm will, with very high probability, provide an interference free dummy poll response at least once per 25 MAC cycles (i.e., once per epoch). Since the threshold for entering TS3 is 250 MAC cycles, the likelihood of proper operation should be quite high.

8.2.9 Summary

This section has described a set of very simple rules, based on the reception of timing information available on the M channel, which will successfully guide airborne radios among the possible timing states. The same simple rules apply to every system configuration and can successfully cope with any type of air/ground connectivity scenario, including the complete absence of any ground infrastructure. All of the rules governing time maintenance are summarized in the flow chart shown in Figure 8-3. (Note that the boxes with rounded edges come into play only in the 3T configuration.)

Note also that an airborne radio attempting net initialization first sets counter CTC 1 to at least 50. This prevents the radio from entering TS1 until it receives a valid beacon. The box labeled “Beacon Changed” indicates that a beacon is considered valid only if the information in the Beacon 2 word is unchanged from the last successful reception of the beacon. In order to be valid the timing of the beacon message must also be within ±1 symbol period of the last received beacon. This means that an initializing radio cannot enter TS1 (and proceed to net entry) until it has received 2 beacons. Also, any change to a beacon or beacon timing will be confirmed before taking effect.
Finally, note that the nominal waiting time for a radio attempting net initialization to enter TS3 is reduced substantially by resetting the default CTC3 to a nonzero value in the rectangular box at the top of Figure 8-3.

Figure 8-3. Timing Logic Flow Chart (Airborne Radio). Default values of parameters f and t are assumed.
SECTION 9

9. MISCELLANEOUS

9.1 Random Number Generator

Certain functions of the radio system related to RA require the generation of a “random” number. For instance, in all configurations the radio normally must choose which slot to use for a Net Entry Request. To ensure that different radios generate different numbers, the algorithm for generating random numbers is based on the unique 24-bit ICAO address.

The algorithm generates a new 12-bit number at each access as follows. First, the 24-bit address is broken into 2 12-bit pieces \( a(0) \) and \( a(1) \) so that

\[
ICAO\ Address = 4096 \cdot (a(1) + a(0))
\]

These are used to generate two sequences of numbers using the recursion relations

\[
M(n) = (4093 \cdot M(n-1) + a(0) + 1) \mod 4111
\]

\[
N(n) = (4021 \cdot N(n-1) + a(1) + 1) \mod 4099,
\]

with \( M(0) = N(0) = 0 \). These are then combined to give a single random number

\[
K(n) = (M(n) + N(n)) \mod 4099.
\]

This ensures that two radios will not choose the same pseudorandom sequence.

This algorithm produces \( 2^{24} \) unique sequences, each of which is nearly uniform in distribution. These sequences can be used to derive sequences of numbers drawn from a smaller alphabet. Suppose, for example, that a sequence of numbers between 0 and 8 (inclusive) must be generated for random access in configuration 2V2D. Such a number can be derived from \( K(n) \) by invoking the formula

\[
R(n) = \text{Int}\left(\frac{K(n)}{4099} \cdot 9\right)
\]

where \( \text{Int}(\ ) \) means the integer part of the argument.
9.2 Slot Timing

For the sake of completeness, detailed diagrams of the various time slot structures are shown in Figures 7-1 and 7-2. In these figures, S signifies the synchronization sequence, H is the header, R is the Reservation word, and F is the Frequency word. B1, B2, and B3 are Beacon 1, Beacon 2, and Beacon 3, respectively. The horizontal scale is given in units of symbol periods. The V/D (voice) bursts are drawn using the assumption that each normal burst consists of six 96-bit vocoder frames, so that each vocoder frame carries 20 ms of voice information. The truncated voice modes are drawn as 5 96-bit frames. The reduction from 6 to 5 frames is accomplished by increasing the vocoder frame from 20 ms to 24 ms while retaining 96 bits per frame by slowing the vocoder clock.

9.3 Ground Station User List

In order to manage the interface between the VDL Mode 3 radio network and the ground network, the ground station maintains a list of current active users on each net. This list consists of a record of the unique relationship between an airborne user’s 24-bit ICAO address and its 8-bit Local ID. Since the radio access is controlled by the Local ID and network access is controlled by the ICAO address, a translation must sometimes be made at the interface. For example, during an airborne voice transmission, the identity of the speaker can be sent to the ground controller by translating the Local ID in the V/D header into the corresponding ICAO address. The ICAO address can, in turn, be translated into the aircraft’s call sign if that information is available to the ground network.

Whenever a user is added to or deleted from the user list, an appropriate message is sent to a higher-level protocol in the ground system. A user is added to the list during the net entry procedure whenever a ground radio successfully receives the first Poll Response message during net entry. A user is deleted from the list whenever the ground station receives a Leaving Net message. A user can also be deleted from the list if it fails to respond to a specified number (3) of poll commands. This type of purging can either be automatic or manual, depending on the ground system implementation.

Note that the user list can also be used to avoid ambiguities that could arise if a user who is already in a net should try to reenter it. (This could happen if a net entrant failed to receive a Reservation message immediately following the first Poll Response.) In that case, the “entrant” will be reissued the Local ID that is already in the list.
Figure 9-1. Four-Slot Configuration Timing Diagrams (One TDMA Frame)
Figure 9-2. Three-Slot Configuration Timing Diagrams (One TDMA Frame)
9.4 Missed Messages/Incorrect Messages

This section deals with the consequences of possible errors in M channel messages. In the postulated channel bit error rate (BER) environment of $10^{-3}$ such errors are very unlikely (see Table 9-1). (Note that the synchronization performance is based on the algorithm discussed in reference 3.) Nevertheless, errors are possible, so it is important to verify that there are no significant failure modes. A partial catalogue of message errors is contained in the following subsections.

<table>
<thead>
<tr>
<th>Table 9-1. M Channel Performance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Channel BER = 10-3</td>
</tr>
<tr>
<td>Probability of no synchronization</td>
</tr>
<tr>
<td>Golay word error rate</td>
</tr>
<tr>
<td>Golay word error rate (undetected)</td>
</tr>
</tbody>
</table>

9.4.1 Link Establishment

The link establishment procedure consists of several steps. In the net initialization phase, the entrant must receive an uplink beacon twice in a row with the identical (correct) information in the Beacon 2 word before it can begin the net entry phase. Note that this word contains a GSC, which should virtually eliminate the possibility of entering a nearby net using the same frequency as the correct net.

The net entry procedure begins with the entrant transmitting its 24-bit ICAO address. For the purpose of verification, the ICAO address is echoed back to the entrant along with the entrant’s Local ID number. If either of the ICAO address transfers is erroneous, the round trip message is not verified and the entrant will reinitiate the entry procedure. It is extremely unlikely that the two ICAO address transfers will both be in error and have canceling errors.

When the entrant receives the Net Entry message with its new Local ID number, it echoes back this number in an immediate Poll Response. If this response contains the correct Local ID, the ground station will assume that the entire entry process is successfully completed. As a type of acknowledgment, the ground station will send a Reservation message to the entrant in the next cycle. If the entrant does not receive this poll command, it will reinitiate the entry procedure.

All the crucial information transfers involve redundant messages, which need to agree with one another. The probability of multiple errors leading to incorrect verification is exceedingly small. Thus, it is almost certain that an entrant will enter only the intended net and will receive a valid Local ID.
9.4.2 Beacon Reception

An airborne radio may fail to receive a beacon message or it may receive an obviously erroneous one. When an airborne radio fails to receive a designated number of beacons consecutively, it goes into timing state TS2 and the truncated voice mode. Truncation prevents an airborne radio from transmitting in ways that would disrupt the remainder of the system.

9.4.3 Poll Responses

A ground station may fail to correctly receive poll responses when they are commanded. This may be due to the fact that the airborne radio has left the net. After three consecutive missed poll responses, the ground radio will notify a higher-level protocol and the airborne radio will be a candidate for purging.

9.4.4 Leaving Net Messages

A ground station may fail to correctly receive a Leaving Net message. In this case, the airborne user will remain in the Ground Station User List, but will no longer respond to polling commands. Thus, it will eventually be purged by the procedure outlined in Section 9.4.3.

There is a small, but finite, chance that a Leaving Net message will be received erroneously. It may happen that the received message has an incorrect Local ID that corresponds to another user on the net. If this happens, the user will incorrectly be dropped from the net and deleted from the Ground Station User List. When it is dropped from the net, the user will stop receiving poll commands; however, it can reenter the net using the procedures described in Section 9.4.5.

9.4.5 Poll Command

If an airborne user ceases receiving valid poll commands while it is still receiving beacon signals, it may have inadvertently been dropped from its net. After receiving no poll command for TL4 (default = 120) consecutive cycles, it can try to reenter the net by the net entry procedure.

9.4.6 Reservation Request

A ground station may miss a Reservation Request. In this case, no reservation will be given and the airborne user will have to repeat its request. A ground station may also receive an erroneous message. The consequences of an error include the possibility of giving slots to a user who hadn’t requested any or giving the wrong number of slots. Such errors will give rise to a small decrease in system throughput, but will have no other adverse effect.

9.4.7 Acknowledgment

A ground station may fail to receive a downlink M channel Acknowledgment message. In such a case, the ground station will have to repeat a data transmission. Such errors will give rise to a small decrease in system throughput.
9.4.8 **Reservation**

An airborne user may fail to receive a reservation intended for it. Also, a user may misinterpret a message meant for another user as meant for itself. In either case, the correct message will either not be sent or will fail due to a collision. The upper level protocols will detect such errors. The net result will be the need to reschedule the transmission and a small decrease in system throughput.

9.4.9 **Next Net**

An airborne radio may fail to receive one or two of a pair of Next Net messages directed to it. In that case, the airborne radio will not respond with a Next Net ACK the next time it is polled; and the ground station can transmit another Next Net pair. If the Next Net message is received erroneously the airborne radio may enter an incorrect net. If that happens, the airborne operator must reenter the previous net and request a retransmission of the Next Net message. It should be noted, however, that the two identical Next Net messages must be received in order to be loaded into the recipient’s memory. The chance of two identical erroneous receptions is very small.

9.5 **Distant Airborne Radios**

It is possible that an airborne radio which is separated from a ground station by a range exceeding that implied by the Squelch Window parameter will nevertheless try to enter that ground station’s net or otherwise attempt to communicate. This could negatively affect overall system performance, particularly if the airborne range would cause its transmissions to violate time slot boundaries as seen by some receivers. However, the protocols contain mechanisms which greatly reduce the probability of this happening.

The first mechanism relies on the fact that the ground station has a validity window for downlink M channel messages which is the same size as the squelch window. Thus, if an airborne entrant’s range is substantially beyond the sector size, its Net Entry Request will not be valid, and the ground will not respond. Thus, the airborne radio will not be able to enter the net and will not be allowed to transmit Reservation Requests, V/D (data) messages, etc. Nevertheless, the airborne radio could still attempt to transmit V/D (voice) messages using the dummy Local ID (=61 or 62).

The second protocol mechanism helps reduce such voice message traffic. In Section 4.5, it is pointed out that an airborne transmitter expects to see the Voice Signal field = 01 soon after it begins transmitting. However, a V/D (voice) message which falls outside the squelch window will not cause such a change in the field. Thus, the “distant” airborne radio would cease transmitting soon after it began, and potential interference would be limited.

9.6 **Back-up Ground Sites**

For a variety of reasons, it may happen that the ground site that controls a particular user group will change abruptly. This might occur, for example, if there were a failure at a primary site which caused the ground infrastructure to switch to a back-up radio site. If the back-up site is far from the primary site, the new beacon signals may appear (at some airborne receivers) to be outside of the ±1 symbol period validity window. Thus, the first such beacon will be declared invalid, and CTC1 and CTC2 will be
incremented. (CTC3 will reset to 0.) However, if the next received beacon has the same time offset, it will be declared valid since the information (in this case the timing information) is the same.

Thus, whenever an airborne radio receives two successive beacon signals with timing information which is substantially different from its previous information, the timing of the airborne radio should be changed. This will allow the airborne radio to quickly adapt to the new geometry with a minimal likelihood of false time adjustment. Note that by this same mechanism other information contained in the beacon, such as the Squelch Window parameter or the Configuration can be changed.

9.7 Ground Station Code Management

In VDL Mode 3 the Ground Station Code (GSC) is used to provide extra insurance that an airborne user does not receive unintended messages from nearby sectors using the same frequency as the desired sector. Such incorrect messages can be disruptive, particularly during net initialization.

Normally, it can be expected that frequency reuse criteria will ensure that the signal level from nearby cochannel users will be reduced in power by at least 20 dB. This power difference should provide an excellent discriminator between correct and incorrect signals; however, unusual propagation phenomena (e.g., ducting) may cause distant signal sources to deliver excess power to some locations. If the GSCs are distributed so that neighboring cochannel sectors have different designations, then the probability of confusion will be reduced. In other words, the GSCs should be geographically arranged so that incorrect signals from sectors using the same frequency and the same GSC as the correct signal will be reduced in power by significantly more than 20 dB.

If all neighboring sectors sharing a frequency were separated by the same distance (D), they would form a perfect hexagonal grid. It would then be possible to number the hexagons in a cellular pattern with GSCs ranging from 1 to 7 so that the distance between hexagons with the same GSC would be $\sqrt{7}$ D. This would provide an extra 8.5 dB of power difference assuming free-space propagation. In practice, the extra margin would often be even greater if the frequency and GSC reuse sector was over the radio horizon.

It is not likely that the distribution of ground stations will allow for a perfectly symmetrical cellular arrangement. Thus, the improvement by 8.5 dB may not be realizable. However, it appears to be very likely that it will be possible to avoid using the same GSC in adjacent cochannel sectors. This is roughly equivalent to the situation with only 3 GSCs, which would lead to a minimum reuse distance of $\sqrt{3}$ D. This would give a power ratio improvement of at least 4.8 dB with free-space propagation.

Thus, the minimum improvement will be in the range between 4.8 dB and 8.5 dB. In many cases the sector reusing both frequency and GSC will be over the horizon, and the protection will be much greater. It is assumed that these techniques will effectively eliminate the possibility of entering an incorrect net or receiving incorrect data.
SECTION 10

10. SIMULATED DATA LINK PERFORMANCE

Computer simulation has been used to verify protocols and obtain preliminary performance data of the VDL Mode 3 defined in the draft Standards and Recommended Practices (SARPs). The simulation is written using MIL3’s Optimized Network Engineering Tool (OPNET). Two simulation models have been developed: subnetwork model and integrated model. The subnetwork model contains only lower layer protocols specific to VDL Mode 3 such as MAC, DLS, LME, and partial physical layer. The integrated model includes all higher layer protocols up to the application layer. It performs connection management, Interdomain Routing Protocol (IDRP) function, Connection-less Network Protocol (CLNP) function, and Connection Oriented Transport Protocol (COTP) function, which can significantly affect system (network) performance. The simulation work involves integration of the VDL Mode 3 subnetwork simulation model with MITRE’s Aeronautical Telecommunication Network (ATN) simulation model. The ATN simulation model contains high-fidelity models of ATN protocols including IDRP, CLNP, and COTP. The integrated model is expected to validate full end-to-end system operation and accurately assess system performance. Simulation is planned to be carried out in two phases. Phase 1 models a single ground station in a single routing domain (i.e., a single ground station attached to a single router) whereas Phase 2 models two ground stations in a single routing domain (i.e., two ground stations attached to a single router). While description of the model generally applies to both phases, the current simulation is performed for Phase 1.

Simulation will collect both subnetwork and integration related parameter measurements. Major performance parameters of interest are (applications) transit end-to-end delays, channel throughputs (with delay constraints), overall IDRP connection establishment time (i.e. how long it takes to establish communication between an airborne and a ground router), and protocol overhead resulting from the use of various upper layer protocol data units.

10.1 Traffic Model

The Aeronautical Mobile Communications Panel (AMCP) Working Group D (WG-D) and RTCA SC-172 have adopted a terminal domain application traffic model for simulation efforts as summarized in Table 10-1. This traffic model includes four applications, whose characteristics are described by message size, message rate, arrival pattern, and priority. These traffic characteristics are assumed to be equal for all aircraft. Note that the combined uplink and downlink Air/Ground data link traffic in Table 10-1 is used as a reference “Load Factor” of 1.0. The load factor and number of aircraft served per channel (or per user group) are the parameters that are varied to assess capacity. The total loading of the air/ground communications link therefore depends on the number of aircraft as well as the load factor. Each load factor defines one set of packet arrival rates. The simulation model is then run for different combinations of number of aircraft and Load Factor. The range of Load Factors used for the two models is somewhat different: 0.2 to 8.0 (including 1.0) for the subnetwork model; and 1.0 and 2.0 for the integrated model.
### Table 10-1. Terminal Domain Application Message Traffic Model

<table>
<thead>
<tr>
<th>Message Distribution</th>
<th>Priority (Note 7)</th>
<th>Uplink</th>
<th>Downlink</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>average message rate in steady state</td>
<td>average size in bits</td>
</tr>
<tr>
<td>Exponential inter-arrival with Poisson message size</td>
<td>High</td>
<td>0.017</td>
<td>137</td>
</tr>
<tr>
<td></td>
<td>Medium</td>
<td>0.0017</td>
<td>198</td>
</tr>
<tr>
<td></td>
<td>Low</td>
<td>0.001</td>
<td>2400</td>
</tr>
<tr>
<td>Constant (Notes 4 &amp; 5)</td>
<td>Low</td>
<td>0.017</td>
<td>3325</td>
</tr>
</tbody>
</table>

Notes:  
1. Rates are in number of messages per second per aircraft  
2. Each message is acknowledged at Data Link Sublayer except broadcast  
3. Ack of uplink message uses downlink M Subchannels; ack of downlink message requires 4 octets conveyed in the V/D (data) subchannels  
4. Broadcast service provided for constant uplink messages  
5. Periodic fixed size downlink meteorological observations  
6. All traffic collectively represents a Load Factor of 1  
7. Each priority has its own COTP connection

### 10.2 Simulation Models

#### 10.2.1 Subnetwork (VDL Mode 3) Simulation Model

This section describes simulation aspects of the subnetwork model with emphasis on MAC-DLS operations/protocols presented in Section 5. A description of this model and results of studies performed with it have been reported in [5, 6]. MAC/DLS simulation has been performed to optimize various parameters with two performance criteria: message end-to-end delay and maximum channel throughput. Parameters obtained with this process are expected to achieve near optimal channel performance that maximizes throughput while minimizing end-to-end message delays for both the 2V2D and 3T system configurations.

#### 10.2.1.1 Simulation Objectives

Modeling of the subnetwork simulation is proceeded to achieve several objectives:

C To verify MAC and DLS protocol operations: It is important to verify the correctness and robustness of the proposed MAC and DLS protocols, their parameter settings, error recovery procedures, operations, and control. This objective can be achieved partially with extensive simulation that mimics the protocol operations provided in Section 5 and VDL Mode 3 SARPs.
C To evaluate “what if” modifications to MAC and DLS protocol operations under various loading scenarios: With simulation, it is possible to increase gradually the traffic intensity to a point where a channel is overloaded and the worst case delay scenarios become realized. The worst case scenarios can provide insight for protocol enhancement that might be hidden otherwise.

C To obtain channel performance reference: A VDL Mode 3 subnetwork consisting of one ground station and 80 aircraft is used as the reference network model. For the 2V2D system configuration, the 80 aircraft are equally split into two independent user groups, whereas in the 3T system configuration, the 80 aircraft are randomly assigned into three disjoint user groups. Channel performance reference is established in terms of resource (i.e., various subchannels) utilization and end-to-end message delays versus throughput.

10.2.1.2 DLS-MAC Simulation Model

Subnetwork simulation modeling is focused on two specific configurations: 2V2D and 3T. Each slot in a 2V2D frame is split into a management subchannel (M) and a voice and data (V/D) subchannel. Simulation captures a variety of functions provided by the management subchannels in the VDL Mode 3 subnetwork protocol. Three types of management subchannels are used: 1) random access (M_RA) subchannel for air-to-ground reservation requests, 2) ground-to-air (M_up) response to reservation requests, and 3) air-to-ground (M_down) response to polling which is part of the M_up messages. Portions of M_RA subchannels are also reserved for the acknowledgment of ground-to-air message transmissions on a non contention basis (M_ack). Usage (i.e., access and application) of the management subchannels varies depending on the activity in the previous MAC cycle.

Each node in the VDL Mode 3 subnetwork model, either the ground station or an airborne radio, is represented by a node diagram as shown in Figure 10-1. It contains message source/sink, DLS layer, MAC layer, and physical layer consisting of a transceiver (transmitter and receiver) and an antenna. Note that in this subnetwork model, the DLS is directly connected to the message source/sink (i.e., application layer).

The MAC and DLS protocol simulation models are written to emulate protocol operations described in Section 5 (as well as appropriate paragraphs in the VDL Mode 3 SARPs). Procedures that generate the corresponding TDMA timing reference points in each system configuration were used to provide the basic clock ticks for the simulation of protocol cycles. Prioritized queues are maintained at both the DLS and MAC sublayers for data subchannel reservation, message segmentation, multiplexing, and acknowledgment. Under priority queuing, an outstanding downlink reservation request may be replaced at the DLS or MAC sublayer by another newly arrived request with a higher priority.

Both the ground station and the airborne radio nodes share the same DLS layer which consists of priority queuing, requests for data subchannels, and the acknowledgment of received packets. MAC layers of the ground station and the airborne radio function differently, so two distinct MAC layers are used for them. The ground station MAC handles uplink data transmission, data subchannel assignment, and polling of airborne radios, whereas the airborne MAC deals with reservation requests, net entry, downlink data
transmission, and response to polls. (Uplink and downlink data transmission may be done with or without acknowledgment.)

Figure 10-1. VDL Mode 3 Node Diagram

The number of active aircraft involved during a simulation run, N, is fixed at a certain value such as N = 80 (aircraft) per channel (31.5 kbps). A network model of one ground station and 80 aircraft (per channel) is used as a reference model. Different values of N such as 60 and 40 are also used for general evaluation. As mentioned above, the 80 aircraft are split into two independent user groups (i.e., 40 aircraft per user group) for the 2V2D configuration and randomly assigned into three disjoint user groups for the 3T configuration. Note that N = 40, 60, and 80 per channel is equivalent, respectively, to N = 20, 30, and 40 per user group for the 2V2D configuration.

Statistics of both end-to-end delays (for each priority class in each direction) and the utilization of every subchannel with an increasing traffic intensity may now be collected through a series of individual simulations.

10.2.2 Integrated Simulation Model

10.2.2.1 Model Overview

The integrated model environment consists of 4 major logical components.

1. The VDL subnetwork model — a description of this model was presented in Section 10.2.1. This model supports a high fidelity simulation of the VDL Mode 3 subnetwork up through the DLS sublayer.
2. **ATN and VDL Mode 3 Interface** — this portion provides a model of the upper layers (i.e., Transport and above), the function of CLNP header compression, and aspects associated with the Intermediate Systems (Routers).

3. **Application Message Traffic Generator** — this portion supplies the input message leading to the model on a per aircraft basis.

4. **Aircraft Mobility Model** — this portion controls the arrival and departure rates of aircraft into and out of a VDL Mode 3 ground station’s service volume.

Figure 10-2 gives an overview of the integrated model environment. The paragraphs below give more detail on these components (except the VDL subnetwork model).

**Legend:**

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>AOC</td>
<td>Aeronautical Operational Control</td>
</tr>
<tr>
<td>ATC</td>
<td>Air Traffic Control</td>
</tr>
<tr>
<td>ACSE</td>
<td>Association Control Service Element</td>
</tr>
<tr>
<td>COTP</td>
<td>Connection-Oriented Transport Protocol</td>
</tr>
<tr>
<td>DLS</td>
<td>Data Link Service Sublayer</td>
</tr>
<tr>
<td>ES-IS</td>
<td>End-System to Intermediate system</td>
</tr>
</tbody>
</table>
10.2.2.1.1 ATN and Mode 3 Interface

The current VDL Mode 3 SARPs allows both ISO 8208 and non-ISO 8208 for ATN/Mode 3 interface. It stipulates that compression/decompression be performed to all ATN CLNP packets unless the Network Support Capability parameter indicates no compression for CLNP packets. In the ISO 8208 architecture, compression takes place in the Subnetwork Dependent Convergence Function (SNDCF) of the ATN routers. The non-ISO 8208 architecture, the approach taken in this simulation, moves the header compression function from the SNDCF of the ATN routers to the VDL Mode 3 subnetwork and supports broadcast traffic. Two candidate schemes are known for compression. One is the Local Reference (LREF) scheme specified in the ATN SARPs and the other is a simplex compression scheme that can be used for two-way or broadcast traffic. The current simulation employs the former—LREF scheme of the ATN SARPs.

10.2.2.1.2 Application Message Traffic Generator

The same traffic model used in the subnetwork model (Section 10.1) is also used for the integrated model. The simulation will collect application message’s subnetwork (channel) utilization, i.e., what percent of subnetwork is used by application messages. The integrated model employs Load Factors of 1.0 and 2.0. Each of three exponentially arriving (Application) messages (shown in Table 10-1) with different priorities—high priority, medium priority, and low priority (indicated by P3, P2, and P1, respectively, in Figure 10-2)—requires distinct Transport connection as depicted in Figure 10-2. Another low priority message with constant rate arrival, which is used for broadcast service, directly interacts with the DLS layer and is not shown.

10.2.2.1.3 Aircraft Mobility Model

Aircraft traffic in the ATN simulation model is provided by a set of external text files known as flight files. Each simulated aircraft is modeled as having its own mobility model or flight plan for traversing the airspace. The purpose of the mobility model is only emulating aircraft interactions with the ground station (i.e., aircraft arrivals to and departures from ground station service volume) rather than accurate flight modeling. The model for flight files is taken as a random walk through the specific ground station’s service volume (SV) that appears in the scenario being run. In a general multiple SV model, an aircraft starts in one of the SVs and spends a random amount of time (exponentially distributed) in that SV based on the average flying time within a SV. Average flight length per SV is 12 minutes, which reflects typical flight times in sectors in the United States. The goal of aircraft traffic generation is to achieve a target (average) number of aircraft in the air within each SV during the data collection portion of the simulation run. Connection management procedures are triggered by each entry of the aircraft as specified in the flight files.
Simulation runs of the VDL Mode 3/ATN model require a warm-up period to allow the simulation to reach “steady state” before data recording begins. Warm-up period should be long enough to ensure that measurements of data statistics (e.g., end-to-end transit delays) are not dependent on the “ initialization bias” error. Total simulation time is 5 hours. The simulation reaches a steady state level of approximately constant number of aircraft (per user group) \( (N) \) after 3 hours of warm-up period. Output performance data are taken over 2 hours of the steady-state period. A number of different network models were designed to deal with different values of \( N \). Note that in the subnetwork model, simulations were run using \( N = 20, 30, \) and 40 (per user group). The same values of \( N \) are used for the integrated model. Aircraft arrival rate is approximately 31, 45, and 56 per hour for \( N = 20, 30, \) and 40, respectively. Aircraft departure rate is kept close to aircraft arrival rate during the steady state run.

10.2.2.2 Operating Concept

The ATN/VDL Mode 3 integrated system simulation consists of a ground network and a number of aircraft. In the simulation the arrival of each new aircraft at the ground station’s service volume is required to go through a complete connection establishment at all levels (i.e., net entry through IDRPs).

Figure 10-3 is a block diagram representation of the system laid out for OPNET simulation. It shows two major nodes representing End Systems and ATN routers—Ground End System/ATN Router and Aircraft End System/ATN Router—plus two ground station nodes. Each of these nodes consists of a stack of OSI protocols. The Ground End System/ATN Router on the left connects to 2 ground stations (Phase 2 structure is shown here) via CMPRS and DLS. These ground stations communicate with the aircraft node (Aircraft End System/ATN Router) shown on the right of the diagram.

Each block in Figure 10-3 is called “process” in OPNET terminology. This diagram is a simplified ATN protocol model which was derived from the OSI Reference Model. The block “Appl” on top of the nodes indicates the Application layer which contains the message traffic model described in Section 10.1. The traffic model (shown in Table 10-1) consists of four different application traffic depending on priority—high, medium, and low—and whether it is point-to-point or broadcast. (Low priority broadcast application, which directly interface with the DLS, is not shown in the figure. Also, the Context Management (CM) application, which facilitates the exchange of address information, is not included in the current simulation. The CM application service is considered a strategic function, and its communications delays are not as critical.) These application messages go through the Association Control Service Element (ACSE), which establishes, maintains, and releases (i.e., controls) associations between these applications. The Connection-Oriented Transport Protocol (COTP) dictates that transport layers (or entities) be connected first before any communications can occur between application entities. When applications have different priorities, each priority will have its own COTP connection. CLNP (ISO 8473) is used to forward messages between routers. Subnetwork/ATN connection depends on what manner the CLNP packets are transferred over the VDL Mode 3 system. Two options exist for the Mode 3 subnetwork and ATN interface: ISO 8208 and CLNP (ISO 8473). The current simulation employs the latter, CLNP interface. For this interface, network packet (i.e., CLNP packet) compression is performed in the (Mode 3) subnetwork. Note that the subnetwork also includes DLS and MAC sublayers.
The End System to Intermediate System (ES-IS) Routing Information Exchange Protocol is used to initialize air-to-ground (or ground-to-air) IDRP connection. With its connection established, IDRP distributes Routes to aircraft. The interactions between these protocols require a pre-existing subnetwork connection between the airborne and air/ground ATN routers and are summarized as follows.

At the beginning of the flight, the aircraft initiates and establishes link and subnetwork connection(s) with the available ground stations using time information in the flight files. (The time information in flight files dictates how long an aircraft will stay in a certain service volume while the aircraft transmits and receives messages.) As the aircraft moves from one service volume to another, a handoff procedure is executed to maintain VDL communication. The handoff will require a new IDRP connection assuming the new ground station (serving the new service volume) is not connected to the same router that the old ground station is connected to. A new IDRP connection is initialized with the help of ES-IS.

**Figure 10-3. Block Diagram Representation of the Integrated Model**

Handoff between the old and new ground stations is completed when IDRP connection is re-established. As soon as the new IDRP connection is established (and thus Routes are distributed), TP connections are set up. When transport entities are connected, a transport connect confirm is notified (to applications) and the applications begin sending data. A simplified time-line for this procedure is shown in Figure 10-4. (Note: Although applications can begin sending data as soon as IDRP connection is established, the current simulation is set up in such a way that applications send data only after COTP connection is established as Figure 10-4 shows.)
10.3 System Performance

10.3.1 Subnetwork (Data Link) Model Performance

Measures of performance for the data link service include channel throughput and message delays. Channel throughput is determined by system configuration, number of active aircraft served by the channel, and message traffic intensity (i.e., Load Factor). Message delay is determined by system configuration, channel throughput, and message priority. Channel throughput, end-to-end message delays, and channel resource utilization of each system configuration and data traffic scenario can be determined by simulation.

Note.— IDRP connection involves exchange of IDRP OPEN and UPDATE Protocol Data Units (PDUs) including exchange of ES-IS Intermediate System Hello (ISH) PDUs

Figure 10-4. Time line leading to total connection establishment

Maximum channel throughput theoretically possible (i.e., upper bound) for a given system configuration may not be achievable in practice. Other constraints such as the (subnetwork) end-to-end 95th percentile delay requirement further reduce the achievable channel throughput. With prioritized data link service, it is possible to meet specific message delay requirements (for top priority messages) while maintaining relatively high level of channel throughput.

End-to-end message delay performance of the top priority messages that meets the delay requirements are summarized in Table 10-2 (for 2V2D and 3T system configurations). The maximum sustainable channel throughput ranges from 7 kbps to 10.2 kbps. End-to-end delay values apparently meet the message delay requirements (i.e., 5 seconds and 3 seconds for 95th percentile and mean, respectively) at average channel throughput of 2.5 kbps with 80 aircraft per channel (or 40 aircraft per user group) and a Load Factor of 1 for the 2V2D configuration, and at average channel throughput of 4.5 kbps with 80 to 160 aircraft per channel and a Load Factor of 2 or less for the 3T configuration. The baseline end-to-end delay values are achieved by using fine-tuned DLS and MAC service system parameters.
The major performance measures are IDRP connection establishment delay in seconds, end-to-end (ETE) delay in seconds, and channel (or data) throughput in kilo-bits per second (kbps). A wide range of message delay performance is expected due to the variability in system configuration, number of active aircraft participated, data message traffic intensity (i.e., load factor), and difference in message priority. ETE delays will be obtained for combinations of various parameters such as different numbers of aircraft and different traffic intensities with various overhead and timers as intrinsic parameters. Both mean and 95th percentile delay values for both uplink and downlink will be collected. Simulations are to be run for operating conditions similar to but less aggressive than the subnetwork simulation:

C  System configuration: 2V2D
C  Number of aircraft per user group: 20, 30, 40
C  Traffic intensity (Load Factor): 1.0, 2.0.

Baseline performance, which involves only the subnetwork model (Section 10.3.1), is used as a reference to evaluate the integrated model. Whenever appropriate, ETE delay performance of the integrated model will be compared to that of the baseline model. To do so, simulation output results will be collected to generate a number of tables reflecting various parameters and overhead.

### Table 10-2 Baseline VDL Mode 3 Data Link Message Delay Performance

#### Integrated Model Performance

<table>
<thead>
<tr>
<th>Channel Configuration</th>
<th>Absolute Upper bound Capacity</th>
<th>Maximum Channel Throughput Achieved By Simulation</th>
<th>Effective Channel Throughput with Delay Constraints</th>
<th>Baseline End-to-End Delay (uplink)</th>
<th>Baseline End-to-End Delay (downlink)</th>
<th>number of aircraft per 25 kHz channel and Load Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>2V2D</td>
<td>8.2 kbps</td>
<td>7 kbps</td>
<td>2.5 kbps</td>
<td>0.52</td>
<td>1.5</td>
<td>1.0 3.5 80 aircraft with Load Factor of 1</td>
</tr>
<tr>
<td>3T</td>
<td>12.4 kbps</td>
<td>10.2 kbps</td>
<td>4.5 kbps</td>
<td>0.23</td>
<td>0.48</td>
<td>0.75 2.8 80 aircraft with Load Factor of 2 or 160 aircraft with Load Factor of 1</td>
</tr>
</tbody>
</table>

Note: Baseline End-to-End Message Delays are in seconds (top priority message only)
SECTION 11

11. GROUND NETWORK IMPLICATIONS

11.1 Architecture

There are a variety of alternative architectures that may be considered for implementation of the VDL Mode 3 ground system. Selection of the optimum architecture for a State will depend on numerous factors including the state of their current infrastructure as well as the telecommunications infrastructure between the control site and the ground station site. It should be advised that it is undesirable to place a different low rate vocoder in the voice path to the radio. Tandem connections that require converting between compressed voice algorithms should be avoided in the ground network.

Figure 11-1 illustrates a voice-only architecture where a separate subnetwork is providing data services. It employs a remote vocoder installation to minimize impact to the existing infrastructure.

Figure 11-1. Voice-only Ground Network Architecture
Appendix C to the Report on Agenda Item 1
Figure 11-2 illustrates a ground infrastructure with remote vocoding and separate voice and data communications paths. The Ground Network Interface (GNI) interfaces with the data subnetwork and with the network management system. The advantage of this approach is that there is no change to the voice path beyond a new VHF radio. The primary disadvantage is the number of ground telecommunications lines required to remote the radio.

Figure 11-2. Voice and Data Ground Network Architecture with Remote Vocoding
Figure 11-3 illustrates voice compression at the control site to attempt to reduce ground telecommunications costs. The disadvantage is that it requires the most changed in the ground infrastructure.

Figure 11-3. Voice and Data Ground Network Architecture with Voice Compression at the Control Site
11.2  **Vocoder Placement**

It may be desirable for a ground service provider to place the vocoders at the control site to take advantage of the data compression to reduce the bandwidth requirements between the control site and remote ground station. With a 4800 bps vocoder, it is possible to compress 4 voice circuits into a 26.6 kbps synchronous data bitstream. The disadvantage of this approach is that the control site must time track the ground radio timing to minimize the end-to-end delay and to prevent underflow of the data between the vocoder and ground station.

11.3  **End-to-End Voice Delay**

The VDL Mode 3 system has a requirement to support a maximum end-to-end voice delay of 250 ms. Depending on the ground system implementation, this may or may not be achievable.

The voice delay budget for which the system was designed is as follows:

<table>
<thead>
<tr>
<th>Processing</th>
<th>Delay (ms)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voice Switch</td>
<td>15</td>
</tr>
<tr>
<td>Voice sampling</td>
<td>20</td>
</tr>
<tr>
<td>Vocoder analysis</td>
<td>A</td>
</tr>
<tr>
<td>TDMA framing</td>
<td>104.76</td>
</tr>
<tr>
<td>Modem/CSU/DSU</td>
<td>10</td>
</tr>
<tr>
<td>Ground transmission</td>
<td>20</td>
</tr>
<tr>
<td>Buffer delay</td>
<td>0.42</td>
</tr>
<tr>
<td>RF transmission</td>
<td>1.33</td>
</tr>
<tr>
<td>Airborne network</td>
<td>2</td>
</tr>
<tr>
<td>TDMA decoding</td>
<td>12.05</td>
</tr>
<tr>
<td>Vocoder processing &amp; synthesis</td>
<td>60-A</td>
</tr>
<tr>
<td><strong>Total Voice Delay</strong></td>
<td><strong>245.56</strong></td>
</tr>
</tbody>
</table>

If the ground infrastructure has appreciable delay in communicating between the control and radio sites, the 250 ms end-to-end delay requirement may not be achieved. It is up to each State to determine the acceptability of this.

11.4  **Cross-coupling**

During periods of low traffic loading, it is common practice in some States to collapse two or more ATC sectors onto a single controller position in order to provide staff savings. To continue to support ATC communications, the frequencies may be cross-coupled so that aircraft transmissions on one frequency
are rebroadcast onto other frequencies in the cross-coupling group. For ground transmissions, the controller transmits on all frequencies within the group.

Even with good communications discipline, simultaneous transmissions, otherwise known as 'step-on', can occur. This step-on is because a finite time exists between one aircraft or controller attempting to seize the channel and all other users of the channel becoming aware that the channel is busy. The probability of step-on occurring is a function of the channel loading and the duration of the delay between a PTT event and all other users realizing that the channel is busy.

11.4.1 Alternative Architectures

Three architectural alternatives are considered to support cross-coupling of radios for maintaining party-line capabilities across multiple frequencies of operation:

1. Voice Switching and Control Equipment (VSCE) switching
2. Ground Network Interface (GNI) switching
3. Direct switching between remote radio sites

11.4.1.1 VSCE Switching

This alternative assumes that the rerouting of the analog voice communication is performed at the control site by the voice switch. This assumes the aircraft transmits a voice communication. The ground system receives the signal, and returns the downlink analog voice signal to the voice switch. The voice switch then determines to which radio the downlink voice needs to be forwarded and sends it to the appropriate GNI port for transmission.

11.4.1.2 GNI Switching

This alternative assumes that the rerouting of the digital voice communication is performed at the control site by the GNI. This assumes the aircraft transmits a voice communication. The ground system receives the signal, and returns the downlink digital voice signal to the GNI. The GNI then determines to which radio the downlink voice needs to be forwarded and sends it to the appropriate radio for transmission. It is assumed that the vocoding function is performed within the GNI to minimize delays and to more efficiently utilize ground transmission media.

11.4.1.3 Direct Switching

This alternative assumes a remote voice and data multiplexing function and a mesh telecommunications network supporting the ground network system to enable the radio sites to directly route the downlinked voice communication to the appropriate radio site(s). This assumes the aircraft transmits a voice communication. The ground remote site receives the signal, and forwards it to the appropriate remote radio site(s) for retransmission.
11.4.2  Delay Analysis

11.4.2.1  Assumptions

The voice switch delay number is based on field measurements of the U.S. FAA's Voice Switching and Control System (VSCS). VDL Mode 3 processing allocations are based on lessons learned from one of the validation prototype implementations and FAA's current implementation plans for the NEXCOM program. For just-in-time processing, the vocoder encode 20ms frame timing is aligned with the TDMA frame timing such that the last vocoder frame in a voice burst is ready for transmission just prior to when it is modulated, with a few milliseconds allocated for processing and for clocking data out of the vocoder (for hardware vocoder implementations). It is convenient to align the 20 ms vocoder frame timing with the start of a VDL Mode 3 time slot in 4-slot configurations. This arrangement provides 4.2ms for the radio to clock-out vocoder data and format the last (sixth) voice frame for transmission. If the vocoder algorithm is implemented in software, all 4.2 ms could be allocated to formatting the sixth voice frame.

For the worst case assumptions, less efficient processing is provided for, such as additional buffering of vocoder frames while forming the TDMA frame. Also, a slow serial clocking of the vocoder is assumed. Depending on a State's implementation, these delay inefficiencies may provide margin to accommodate other additional delays not accounted for in this analysis if the State utilizes the more efficient means to minimize delays. Examples of additional delays could be longer ground telecommunications delays or longer voice switch delays.

Assumptions are 3.05ms (32 D8PSK symbol periods) per received vocoder frame, 256kbps fractional-T1 HDLC rate from Multimode Digital Radio (MDR) to Radio Interface Unit (RIU), and 56k/1.544M/9.6k bps rates for RIU-to-GNI landline for the Typical/Minimum/Maximum cases, respectively. For the GNI case, relay messages are sent over 2 MDR/RIU fractional-T1 lines and 2 RIU/GNI lines. For the Direct case, relay messages are sent over 2 MDR/RIU fractional-T1 lines and 1 RIU/GNI line (assumes relay uplink RIU can multiplex in a voice stream from another radio without having to go to a GNI. This only effects the Max Direct case, and if you were to count the slow 9600bps RIU/GNI line twice it would add 20ms to the Direct Max delay case only. The other Max delays would be the same.). Also, for simplicity of analysis, all ground stations are assumed to be time synchronized.
## Cross-Couple Delay — VSCE Switching

### VDL3 Audio Throughput Delay

<table>
<thead>
<tr>
<th>Component</th>
<th>Likely</th>
<th>Min</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>Airborne network delay</td>
<td>4.00 ms</td>
<td>2.00 ms</td>
<td>4.00 ms (COMPLETE GUESS)</td>
</tr>
<tr>
<td>Analysis</td>
<td>60.00 ms</td>
<td>60.00 ms</td>
<td>60.00 ms (dependent on vocoder frame size)</td>
</tr>
<tr>
<td>Clock out of vocoder</td>
<td>2.60 ms</td>
<td>1.25 ms</td>
<td>20.00 ms (4/8bit Parallel @ 9600Hz / Serial @ 4800Hz)</td>
</tr>
<tr>
<td>TDMA Framing delay</td>
<td>84.76 ms</td>
<td>84.76 ms</td>
<td>103.05 ms (Just in time processing for voc. frame 6)</td>
</tr>
<tr>
<td>Processing delay</td>
<td>4.57 ms</td>
<td>3.00 ms</td>
<td>6.00 ms</td>
</tr>
<tr>
<td></td>
<td>155.94 ms</td>
<td>151.01 ms</td>
<td>193.05 ms (Aircraft Tx)</td>
</tr>
<tr>
<td>Receive slot overhead</td>
<td>10.19 ms</td>
<td>5.62 ms</td>
<td>13.14 ms (Vocoder frame tx + squelch offset. Includes Propagation)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>4Slot TS2 vs. 4Slot TS1 vs. 3Slot TS2</td>
</tr>
<tr>
<td>Processing delay</td>
<td>6 ms</td>
<td>5.30 ms</td>
<td>9.00 ms</td>
</tr>
<tr>
<td>RIU/MDR Line Blockage</td>
<td>2.19 ms</td>
<td>0.00 ms</td>
<td>2.19 ms (No blockage vs. Max size packet just started)</td>
</tr>
<tr>
<td></td>
<td>18.38 ms</td>
<td>10.92 ms</td>
<td>24.33 ms (MDR Rx)</td>
</tr>
<tr>
<td>Transfer delay</td>
<td>0.75 ms</td>
<td>0.75 ms</td>
<td>2.63 ms (1 vocoder frames in HDLC packet - Max 6 frames)</td>
</tr>
<tr>
<td>Processing delay</td>
<td>6.28 ms</td>
<td>3.00 ms</td>
<td>6.28 ms</td>
</tr>
<tr>
<td>Modem Transfer delay</td>
<td>1.71 ms</td>
<td>0.06 ms</td>
<td>10.00 ms (56k/T1-1.544M/9.6k)</td>
</tr>
<tr>
<td></td>
<td>8.74 ms</td>
<td>3.81 ms</td>
<td>18.91 ms (RIU Rx)</td>
</tr>
<tr>
<td>Maximum Telco delay</td>
<td>14.00 ms</td>
<td>5.00 ms</td>
<td>25.00 ms (LINCS: MAX 50 ms spec'd - 18.88 ms max likely)</td>
</tr>
<tr>
<td>Clock data into vocoder</td>
<td>2.67 ms</td>
<td>1.25 ms</td>
<td>20.00 ms 28 symbols</td>
</tr>
<tr>
<td>Vocoder Synthesis</td>
<td>20.00 ms</td>
<td>20.00 ms</td>
<td>20.00 ms (dependent on vocoder frame size)</td>
</tr>
<tr>
<td>Processing delay</td>
<td>4.00 ms</td>
<td>2.00 ms</td>
<td>4.00 ms</td>
</tr>
<tr>
<td></td>
<td>26.67 ms</td>
<td>23.25 ms</td>
<td>44.00 ms (GNI Rx)</td>
</tr>
<tr>
<td>Voice switch delay</td>
<td>2.40 ms</td>
<td>2.40 ms</td>
<td>4.00 ms (2 x Measured from field - VSCS)</td>
</tr>
<tr>
<td>Analysis</td>
<td>60.00 ms</td>
<td>60.00 ms</td>
<td>60.00 ms (dependent on vocoder frame size)</td>
</tr>
<tr>
<td>Processing delay</td>
<td>4.00 ms</td>
<td>2.00 ms</td>
<td>4.00 ms</td>
</tr>
<tr>
<td>Clock out of vocoder</td>
<td>2.60 ms</td>
<td>1.25 ms</td>
<td>20.00 ms (4/8bit Parallel @ 9600Hz / Serial @ 4800Hz)</td>
</tr>
<tr>
<td>TDMA Framing delay</td>
<td>8.95 ms</td>
<td>8.95 ms</td>
<td>8.95 ms (94 symbols into slot for First Vocoder Frame TS1)</td>
</tr>
<tr>
<td>VDL3 Audio Throughput Delay</td>
<td>Likely</td>
<td>Min</td>
<td>Max</td>
</tr>
<tr>
<td>----------------------------</td>
<td>--------</td>
<td>-----</td>
<td>-----</td>
</tr>
<tr>
<td>Modem Transfer delay</td>
<td>1.71 ms</td>
<td>0.06 ms</td>
<td>10.00 ms (56k/T1-1.544M/9.6k)</td>
</tr>
<tr>
<td></td>
<td>77.27 ms</td>
<td>72.26 ms</td>
<td>102.95 ms GNI Tx</td>
</tr>
<tr>
<td>Maximum Telco delay</td>
<td>14.00 ms</td>
<td>5.00 ms</td>
<td>25.00 ms (LINCS: MAX 50 ms spec'd - 18.88 ms max likely)</td>
</tr>
<tr>
<td></td>
<td>93.67 ms</td>
<td>79.66 ms</td>
<td>131.95 ms Ground System (VSCE + GNI + Telco)</td>
</tr>
<tr>
<td>Processing delay</td>
<td>4.00 ms</td>
<td>2.00 ms</td>
<td>4.00 ms</td>
</tr>
<tr>
<td>RIU/MDR Line Blockage</td>
<td>2.19 ms</td>
<td>0.00 ms</td>
<td>2.19 ms No blockage vs. Max size packet just started</td>
</tr>
<tr>
<td></td>
<td>6.19 ms</td>
<td>2.00 ms</td>
<td>6.19 ms RIU Tx</td>
</tr>
<tr>
<td>Transfer delay</td>
<td>0.75 ms</td>
<td>0.75 ms</td>
<td>2.63 ms (1 vocoder frames in HDLC packet - Max 6 frames)</td>
</tr>
<tr>
<td>Processing delay</td>
<td>6.00 ms</td>
<td>3.00 ms</td>
<td>6.00 ms</td>
</tr>
<tr>
<td></td>
<td>6.75 ms</td>
<td>5.75 ms</td>
<td>14.81 ms MDR Tx</td>
</tr>
<tr>
<td></td>
<td>174.40 ms</td>
<td>130.40 ms</td>
<td>265.19 ms Rx to Tx</td>
</tr>
<tr>
<td>Vocoder Frame Padding</td>
<td>20.00 ms</td>
<td>0.00 ms</td>
<td>0.00 ms (if necessary)</td>
</tr>
<tr>
<td></td>
<td>260.00 ms</td>
<td>240.00 ms</td>
<td>360.00 ms TDMA Frame boundary alignment</td>
</tr>
<tr>
<td>Processing delay</td>
<td>6.28 ms</td>
<td>3.00 ms</td>
<td>6.28 ms</td>
</tr>
<tr>
<td>Receive slot overhead</td>
<td>4.38 ms</td>
<td>4.38 ms</td>
<td>5.42 ms (Vocoder frame tx + squelch offset + Propagation)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>4Slot TS1 vs. 3Slot TS1</td>
</tr>
<tr>
<td>Clock data into vocoder</td>
<td>2.67 ms</td>
<td>1.25 ms</td>
<td>2.67 ms 28 symbols</td>
</tr>
<tr>
<td>Vocoder Synthesis</td>
<td>20.00 ms</td>
<td>20.00 ms</td>
<td>20.00 ms (dependent on vocoder frame size)</td>
</tr>
<tr>
<td>Airborne network delay</td>
<td>4.00 ms</td>
<td>2.00 ms</td>
<td>4.00 ms (COMPLETE GUESS)</td>
</tr>
<tr>
<td></td>
<td>37.32 ms</td>
<td>30.63 ms</td>
<td>38.37 ms Aircraft Rx</td>
</tr>
<tr>
<td>Total</td>
<td>453.26 ms</td>
<td>421.64 ms</td>
<td>591.42 ms</td>
</tr>
</tbody>
</table>

The time delay from the start of the time slot in which voice was received to the time when the first relayed vocoder frame is available at the ground transmitter is:

Typ: 174.40 ms
Min: 130.40 ms
Max: 265.19 ms
11.4.2.2.1 VSCE Typical Case

For this case, the next TDMA frame available for relay is 240 ms from the one in which voice was received. The delta T is 240 ms – 174.40 = 65.60 ms. The ground system can process 3-additional voice frames before the 240ms deadline which marks the start of the time slot in which voice is re-transmitted. At the start of the relay time slot, the ground transmitter should have 5-vocoder frames, but since only 4 are available, the system will have to pad with 1 vocoder silence frame which will add 20ms to the 240ms frame delay for a total of 260ms additional delay.

The Typical end-end delay is then:

<table>
<thead>
<tr>
<th>Time (ms)</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>155.94</td>
<td>Aircraft Transmission</td>
</tr>
<tr>
<td>260.00</td>
<td>Ground Relay</td>
</tr>
<tr>
<td>37.32</td>
<td>Aircraft Reception</td>
</tr>
<tr>
<td><strong>453.26</strong></td>
<td>Total Typical</td>
</tr>
</tbody>
</table>

11.4.2.2.2 VSCE Minimum Case

For this case, the next TDMA frame available for relay is 240 ms from the one in which voice was received. The delta T is 240 ms – 130.40 = 109.60 ms. The ground system can process 5-additional voice frames before the 240ms deadline which marks the start of the time slot in which voice is re-transmitted. At the start of the relay time slot all 6-frames are available, so no silence padding is required and the total additional delay is 240 ms.

The Minimum end-end delay is then:

<table>
<thead>
<tr>
<th>Time (ms)</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>151.01</td>
<td>Aircraft Transmission</td>
</tr>
<tr>
<td>240.00</td>
<td>Ground Relay</td>
</tr>
<tr>
<td>30.63</td>
<td>Aircraft Reception</td>
</tr>
<tr>
<td><strong>421.64</strong></td>
<td>Total Min.</td>
</tr>
</tbody>
</table>

11.4.2.2.3 VSCE Maximum Case

For this case, the next TDMA frame available for relay is 360 ms from the one in which voice was received. The delta T is 360 ms – 265.19 = 94.81 ms. The ground system can process 4-additional voice frames before the 360ms deadline which marks the start of the time slot in which voice is re-transmitted. At the start of the relay time slot 5-frames are available, so no silence padding is required and the total additional delay is 360 ms.
The Maximum end-end delay is then:

193.05 ms  Aircraft Transmission
360.00 ms  Ground Relay
38.37 ms   Aircraft Reception

591.42 ms  Total Max.
### VDL3 Audio Throughput Delay

<table>
<thead>
<tr>
<th></th>
<th>Likely</th>
<th>Min</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>Airborne network delay</td>
<td>4.00 ms</td>
<td>2.00 ms</td>
<td>4.00 ms (COMPLETE GUESS)</td>
</tr>
<tr>
<td>Analysis</td>
<td>60.00 ms</td>
<td>60.00 ms</td>
<td>60.00 ms (dependent on vocoder frame size)</td>
</tr>
<tr>
<td>Clock out of vocoder</td>
<td>2.60 ms</td>
<td>1.25 ms</td>
<td>20.00 ms (4/8bit Parallel @ 9600Hz / Serial @ 4800Hz)</td>
</tr>
<tr>
<td>TDMA Framing delay</td>
<td>84.76 ms</td>
<td>84.76 ms</td>
<td>103.05 ms (Just in time processing for voc. frame 6)</td>
</tr>
<tr>
<td>Processing delay</td>
<td>4.57 ms</td>
<td>3.00 ms</td>
<td>6.00 ms</td>
</tr>
<tr>
<td></td>
<td>155.94 ms</td>
<td>151.01 ms</td>
<td>193.05 ms</td>
</tr>
<tr>
<td>Receive slot overhead</td>
<td>10.19 ms</td>
<td>5.62 ms</td>
<td>13.14 ms (Vocoder frame tx + squelch offset. Includes Propagation)</td>
</tr>
<tr>
<td>Processing delay</td>
<td>6.00 ms</td>
<td>5.30 ms</td>
<td>9.00 ms</td>
</tr>
<tr>
<td>RIU/MDR Line Blockage</td>
<td>2.19 ms</td>
<td>0.00 ms</td>
<td>2.19 ms (No blockage vs. Max size packet just started)</td>
</tr>
<tr>
<td></td>
<td>18.38 ms</td>
<td>10.92 ms</td>
<td>24.33 ms</td>
</tr>
<tr>
<td>Transfer delay</td>
<td>0.75 ms</td>
<td>0.75 ms</td>
<td>2.63 ms (1 vocoder frames in HDLC packet - Max 6 frames)</td>
</tr>
<tr>
<td>Processing delay</td>
<td>6.28 ms</td>
<td>3.00 ms</td>
<td>6.28 ms</td>
</tr>
<tr>
<td>Modem Transfer delay</td>
<td>1.71 ms</td>
<td>0.06 ms</td>
<td>10.00 ms (56k/T1-1.544M/9.6k)</td>
</tr>
<tr>
<td></td>
<td>8.74 ms</td>
<td>3.81 ms</td>
<td>18.91 ms</td>
</tr>
<tr>
<td>Maximum Telco delay</td>
<td>14.00 ms</td>
<td>5.00 ms</td>
<td>25.00 ms (LINCS: MAX 50 ms spec'd - 18.88 ms max likely)</td>
</tr>
<tr>
<td>Processing delay</td>
<td>4.00 ms</td>
<td>2.00 ms</td>
<td>4.00 ms</td>
</tr>
<tr>
<td>TDMA Framing delay</td>
<td>8.95 ms</td>
<td>8.95 ms</td>
<td>8.95 ms (94 symbols into slot for First Vocoder Frame TS1)</td>
</tr>
<tr>
<td>Modem Transfer delay</td>
<td>1.71 ms</td>
<td>0.06 ms</td>
<td>10.00 ms (56k/T1-1.544M/9.6k)</td>
</tr>
<tr>
<td></td>
<td>14.67 ms</td>
<td>11.01 ms</td>
<td>22.95 ms</td>
</tr>
<tr>
<td>Maximum Telco delay</td>
<td>14.00 ms</td>
<td>5.00 ms</td>
<td>25.00 ms (LINCS: MAX 50 ms spec'd - 18.88 ms max likely)</td>
</tr>
<tr>
<td>Processing delay</td>
<td>4.00 ms</td>
<td>2.00 ms</td>
<td>4.00 ms</td>
</tr>
<tr>
<td>RIU/MDR Line Blockage</td>
<td>2.19 ms</td>
<td>0.00 ms</td>
<td>2.19 ms (No blockage vs. Max size packet just started)</td>
</tr>
<tr>
<td></td>
<td>6.19 ms</td>
<td>2.00 ms</td>
<td>6.19 ms</td>
</tr>
</tbody>
</table>

---

**11.4.2.3 Cross-Couple Delay — GNI Switching**

- **Airborne network delay**: Likely 4.00 ms, Min 2.00 ms, Max 4.00 ms (COMPLETE GUESS)
- **Analysis**: 60.00 ms, Min 60.00 ms, Max 60.00 ms (dependent on vocoder frame size)
- **Clock out of vocoder**: Likely 2.60 ms, Min 1.25 ms, Max 20.00 ms (4/8-bit Parallel @ 9600Hz / Serial @ 4800Hz)
- **TDMA Framing delay**: Likely 84.76 ms, Min 84.76 ms, Max 103.05 ms (Just in time processing for voc. frame 6)
- **Processing delay**: Likely 4.57 ms, Min 3.00 ms, Max 6.00 ms
- **Receive slot overhead**: Likely 10.19 ms, Min 5.62 ms, Max 13.14 ms (Vocoder frame tx + squelch offset. Includes Propagation)
- **Processing delay** for 4Slot TS2 vs. 4Slot TS1 vs. 3Slot TS2
- **RIU/MDR Line Blockage**: Likely 2.19 ms, Min 0.00 ms, Max 2.19 ms (No blockage vs. Max size packet just started)
- **Transfer delay**: Likely 0.75 ms, Min 0.75 ms, Max 2.63 ms (1 vocoder frames in HDLC packet - Max 6 frames)
- **Processing delay** for 4Slot TS2 vs. 4Slot TS1 vs. 3Slot TS2
- **Modem Transfer delay**: Likely 1.71 ms, Min 0.06 ms, Max 10.00 ms (56k/T1-1.544M/9.6k)
- **Maximum Telco delay**: Likely 14.00 ms, Min 5.00 ms, Max 25.00 ms (LINCS: MAX 50 ms spec’d - 18.88 ms max likely)
- **Processing delay** for 4Slot TS2 vs. 4Slot TS1 vs. 3Slot TS2
- **TDMA Framing delay**: Likely 8.95 ms, Min 8.95 ms, Max 8.95 ms (94 symbols into slot for First Vocoder Frame TS1)
- **Modem Transfer delay**: Likely 1.71 ms, Min 0.06 ms, Max 10.00 ms (56k/T1-1.544M/9.6k)
- **Maximum Telco delay**: Likely 14.00 ms, Min 5.00 ms, Max 25.00 ms (LINCS: MAX 50 ms spec’d - 18.88 ms max likely)
- **Processing delay** for 4Slot TS2 vs. 4Slot TS1 vs. 3Slot TS2
- **RIU/MDR Line Blockage**: Likely 2.19 ms, Min 0.00 ms, Max 2.19 ms (No blockage vs. Max size packet just started)
- **Transfer delay**: Likely 0.75 ms, Min 0.75 ms, Max 2.63 ms (1 vocoder frames in HDLC packet - Max 6 frames)
- **Processing delay** for 4Slot TS2 vs. 4Slot TS1 vs. 3Slot TS2
- **Modem Transfer delay**: Likely 1.71 ms, Min 0.06 ms, Max 10.00 ms (56k/T1-1.544M/9.6k)
- **Maximum Telco delay**: Likely 14.00 ms, Min 5.00 ms, Max 25.00 ms (LINCS: MAX 50 ms spec’d - 18.88 ms max likely)
- **Processing delay** for 4Slot TS2 vs. 4Slot TS1 vs. 3Slot TS2
- **RIU/MDR Line Blockage**: Likely 2.19 ms, Min 0.00 ms, Max 2.19 ms (No blockage vs. Max size packet just started)
### Table 1: Time Delay Components

<table>
<thead>
<tr>
<th>Component</th>
<th>Min</th>
<th>Typ</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transfer delay</td>
<td>0.75 ms</td>
<td>0.75 ms</td>
<td>2.63 ms</td>
</tr>
<tr>
<td>(1 vocoder frames in HDLC packet - Max 6 frames)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Processing delay</td>
<td>6.00 ms</td>
<td>3.00 ms</td>
<td>6.00 ms</td>
</tr>
<tr>
<td>Vocoder Frame Padding</td>
<td>0.00 ms</td>
<td>0.00 ms</td>
<td>0.00 ms</td>
</tr>
<tr>
<td>(if necessary)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Receive slot overhead</td>
<td>4.38 ms</td>
<td>4.38 ms</td>
<td>5.42 ms</td>
</tr>
<tr>
<td>(Vocoder frame tx + squelch offset + Propagation)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Clock data into vocoder</td>
<td>2.67 ms</td>
<td>1.25 ms</td>
<td>2.67 ms</td>
</tr>
<tr>
<td>Vocoder Synthesis</td>
<td>20.00 ms</td>
<td>20.00 ms</td>
<td>20.00 ms</td>
</tr>
<tr>
<td>(dependent on vocoder frame size)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Airborne network delay</td>
<td>4.00 ms</td>
<td>2.00 ms</td>
<td>4.00 ms</td>
</tr>
<tr>
<td>Aircraft Rx</td>
<td>37.32 ms</td>
<td>30.63 ms</td>
<td>38.37 ms</td>
</tr>
<tr>
<td>Total</td>
<td>313.26 ms</td>
<td>301.64 ms</td>
<td>471.42 ms</td>
</tr>
</tbody>
</table>

The time delay from the start of the time slot in which voice was received to the time when the first relayed vocoder frame is available at the ground transmitter is:

- **Typ:** 86.73 ms
- **Min:** 45.50 ms
- **Max:** 141.19 ms
11.4.2.3.1 **GNI Typical Case**

For this case, the next TDMA frame available for relay is 120 ms from the one in which voice was received. The delta T is 120 ms – 86.73 = 33.27 ms. The ground system can process 4-additional voice frames (takes 29.54ms) before the 120ms deadline which marks the start of the time slot in which voice is re-transmitted. This is based on the vocoder frame duration at the VDL Mode 3 channel rate and the ground telecommunications transmission rates discussed in Section 11.4.2.1. At the start of the relay time slot 5-vocoder frames are available, so no silence frame padding is necessary and the total additional delay is 120ms.

The Typical end-end delay is then:

155.94 ms Aircraft Transmission  
120.00 ms Ground Relay  
37.32 ms Aircraft Reception  

**313.26 ms** Total Typical

11.4.2.3.2 **GNI Minimum Case**

For this case, the next TDMA frame available for relay is 120 ms from the one in which voice was received. The delta T is 120 ms – 45.50 = 74.50 ms. The ground system can process all remaining vocoder voice frames (takes 20.37ms) before the 120ms deadline which marks the start of the time slot in which voice is re-transmitted. Therefore, the additional delay is 120ms.

The Minimum end-end delay is then:

151.01 ms Aircraft Transmission  
120.00 ms Ground Relay  
30.63 ms Aircraft Reception  

**301.64 ms** Total Min.

11.4.2.3.3 **GNI Maximum Case**

For this case, the next TDMA frame available for relay is 240 ms from the one in which voice was received. The delta T is 240 ms – 141.19 = 98.81 ms. The ground system can process 4-additional voice frames (takes 95.94ms) before the 240ms deadline which marks the start of the time slot in which voice is re-transmitted. At the start of the relay time slot 5-frames are available, so no silence padding is required and the total additional delay is 240 ms.

The Maximum end-end delay is then:

193.05 ms Aircraft Transmission  
240.00 ms Ground Relay  
41.42 ms Aircraft Reception
474.47 ms Total Max.
## Cross-Coupling Delay — Direct Analysis

### VDL3 Audio Throughput Delay

<table>
<thead>
<tr>
<th>Delay Type</th>
<th>Likely</th>
<th>Min</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>Airborne network delay</td>
<td>4.00 ms</td>
<td>2.00 ms</td>
<td>4.00 ms</td>
</tr>
<tr>
<td>Analysis</td>
<td>60.00 ms</td>
<td>60.00 ms</td>
<td>60.00 ms</td>
</tr>
<tr>
<td>Clock out of vocoder</td>
<td>2.60 ms</td>
<td>1.25 ms</td>
<td>20.00 ms</td>
</tr>
<tr>
<td>TDMA Framing delay</td>
<td>84.76 ms</td>
<td>84.76 ms</td>
<td>103.05 ms</td>
</tr>
<tr>
<td>Processing delay</td>
<td>4.57 ms</td>
<td>3.00 ms</td>
<td>6.00 ms</td>
</tr>
<tr>
<td></td>
<td>155.94 ms</td>
<td>151.01 ms</td>
<td>193.05 ms</td>
</tr>
<tr>
<td>Receive slot overhead</td>
<td>10.19 ms</td>
<td>5.62 ms</td>
<td>13.14 ms</td>
</tr>
<tr>
<td>Processing delay</td>
<td>6.00 ms</td>
<td>5.30 ms</td>
<td>9.00 ms</td>
</tr>
<tr>
<td>RIU/MDR Line Blockage</td>
<td>2.19 ms</td>
<td>0.00 ms</td>
<td>2.19 ms</td>
</tr>
<tr>
<td></td>
<td>18.38 ms</td>
<td>10.92 ms</td>
<td>24.33 ms</td>
</tr>
<tr>
<td>Transfer delay</td>
<td>0.75 ms</td>
<td>0.75 ms</td>
<td>2.63 ms</td>
</tr>
<tr>
<td>Processing delay</td>
<td>6.28 ms</td>
<td>3.00 ms</td>
<td>6.28 ms</td>
</tr>
<tr>
<td>Modem Transfer delay</td>
<td>1.71 ms</td>
<td>0.06 ms</td>
<td>10.00 ms</td>
</tr>
<tr>
<td></td>
<td>8.74 ms</td>
<td>3.81 ms</td>
<td>18.91 ms</td>
</tr>
<tr>
<td>Maximum Telco delay</td>
<td>14.00 ms</td>
<td>5.00 ms</td>
<td>25.00 ms</td>
</tr>
<tr>
<td>Processing delay</td>
<td>4.00 ms</td>
<td>2.00 ms</td>
<td>4.00 ms</td>
</tr>
<tr>
<td>TDMA Framing delay</td>
<td>8.95 ms</td>
<td>8.95 ms</td>
<td>8.95 ms</td>
</tr>
<tr>
<td>RIU/MDR Line Blockage</td>
<td>2.19 ms</td>
<td>0.00 ms</td>
<td>2.19 ms</td>
</tr>
<tr>
<td></td>
<td>15.14 ms</td>
<td>10.95 ms</td>
<td>15.14 ms</td>
</tr>
<tr>
<td>Transfer delay</td>
<td>0.75 ms</td>
<td>0.75 ms</td>
<td>2.63 ms</td>
</tr>
<tr>
<td>Processing delay</td>
<td>6.00 ms</td>
<td>3.00 ms</td>
<td>6.00 ms</td>
</tr>
<tr>
<td></td>
<td>6.75 ms</td>
<td>3.75 ms</td>
<td>8.63 ms</td>
</tr>
<tr>
<td></td>
<td>63.01 ms</td>
<td>34.43 ms</td>
<td>92.00 ms</td>
</tr>
<tr>
<td>Vocoder Frame Padding</td>
<td>0.00 ms</td>
<td>0.00 ms</td>
<td>60.00 ms</td>
</tr>
<tr>
<td></td>
<td>120.00 ms</td>
<td>120.00 ms</td>
<td>180.00 ms</td>
</tr>
<tr>
<td>Processing delay</td>
<td>6.28 ms</td>
<td>3.00 ms</td>
<td>6.28 ms</td>
</tr>
<tr>
<td></td>
<td>4.38 ms</td>
<td>4.38 ms</td>
<td>5.42 ms</td>
</tr>
<tr>
<td>----------------------</td>
<td>---------</td>
<td>---------</td>
<td>---------</td>
</tr>
<tr>
<td><strong>Receive slot overhead</strong></td>
<td>(Vocoder frame tx + squelch offset + Propagation)</td>
<td>4Slot TS1 vs. 3Slot TS1</td>
<td></td>
</tr>
<tr>
<td><strong>Clock data into vocoder</strong></td>
<td>2.67 ms</td>
<td>1.25 ms</td>
<td>2.67 ms</td>
</tr>
<tr>
<td><strong>Vocoder Synthesis</strong></td>
<td>20.00 ms</td>
<td>20.00 ms</td>
<td>20.00 ms</td>
</tr>
<tr>
<td><strong>Airborne network delay</strong></td>
<td>4.00 ms</td>
<td>2.00 ms</td>
<td>4.00 ms</td>
</tr>
<tr>
<td></td>
<td>37.32 ms</td>
<td>30.63 ms</td>
<td>38.37 ms</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>313.26 ms</td>
<td>301.64 ms</td>
<td>411.42 ms</td>
</tr>
</tbody>
</table>

The time delay from the start of the time slot in which voice was received to the time when the first relayed vocoder frame is available at the ground transmitter is:

Typ: 63.01 ms
Min: 34.43 ms
Max: 92.00 ms
11.4.2.4.1 **Direct Typical Case**

For this case, the next TDMA frame available for relay is 120 ms from the one in which voice was received. The delta T is 120 ms – 63.01 = 56.99 ms. The ground system can process all additional voice frames before the 120ms deadline which marks the start of the time slot in which voice is re-transmitted. Therefore, the additional delay is 120ms.

The Typical end-end delay is then:

- 155.94 ms Aircraft Transmission
- 120.00 ms Ground Relay
- 37.32 ms Aircraft Reception

**313.26 ms** Total Typical

11.4.2.4.2 **Direct Minimum Case**

For this case, the next TDMA frame available for relay is 120 ms from the one in which voice was received. The delta T is 120 ms – 34.43 = 85.57 ms. The ground system can process all additional voice frames before the 120ms deadline which marks the start of the time slot in which voice is re-transmitted. Therefore, the additional delay is 120ms.

The Minimum end-end delay is then:

- 151.01 ms Aircraft Transmission
- 120.00 ms Ground Relay
- 30.63 ms Aircraft Reception

**301.64 ms** Total Min.

11.4.2.4.3 **Direct Maximum Case**

For this case, the next TDMA frame available for relay is 120 ms from the one in which voice was received. The delta T is 120 ms – 92.00 = 28.00 ms. The ground system can process a single additional voice frame (takes 14.55ms) before the 120ms deadline which marks the start of the time slot in which voice is re-transmitted. At the start of the relay time slot 2-frames are available, so the ground system will need to pad with 3 silence frames (60ms) and the total additional delay is 180 ms.

The Maximum end-end delay is then:

- 193.05 ms Aircraft Transmission
- 180.00 ms Ground Relay
- 38.37 ms Aircraft Reception

**411.42 ms** Total Max.
11.4.3 Step-on Reduction Via Signaling

The VDL Mode 3 also provides the means to control access to the voice channel via the voice signaling field of its uplink beacon. This capability can be utilized to reduce the likelihood of a step-on by allowing the ground site receiving the downlink aircraft transmission to immediately send a message to all of the ground stations in the cross-coupling group, as soon as the receiving station determines a valid V/D (voice) header is received. When the other ground stations receive this signal, they can either indicate an aircraft is talking to block new users from the channel, or utilize ground pre-emption and indicate the ground user is talking. Care should be taken by States to ensure that race conditions do not occur with the signaling if this optional functionality is deployed.

11.5 Ground Station Synchronization

If it is desired to have different slots on the same frequency to be operating from diversely located ground station sites, it will be necessary to synchronize the timing between these ground stations to prevent inter-slot interference. As such, the ground station radio equipment should be designed to accept an external timing source signal to allow the uplink beacons to be synchronized with each other.

11.6 GNI Hierarchy

Depending on the scale of a State’s VDL Mode 3 implementation, it may be necessary to implement some form of hierarchy of GNIs to limit the number of ports being used from the ATN routers. To prevent excess IDRPU updates, it is desirable to restrict the change of ATN ports between sector boundaries to be an infrequent event. This will create the establishment of Primary and Secondary GNIs. Primary GNIs (GNI_p) are directly connected to ATN router ports, while Secondary GNIs (GNI_s) must be routed through a Primary GNI to reach the router, as per Figure 11-4.
11.7 Make-Before-Break and IDRP

Due to the significant number of messages that must be exchanged to initialize the Interdomain Routing Protocol (IDRP), some States may determine that the data channel will be blocked from communications for longer than is desirable. As such, the VDL link layer header includes a Ground Subnetwork Address to allow subnetwork routing of packets to the previous GNI during the establishment of the new IDRP connection to maintain continuity of communications during a handoff between routers. The termination of the old IDRP connection is a local issue.

When an aircraft establishes a connection, the CTRL_CMD frame includes a Ground Subnetwork Address of 000000. The ground station will respond with the address assigned to it. The address may be associated with a router port or some smaller element depending on the ground architecture.

11.7.1 The Problem

Make-before-Break (MbB) is the term applied to a class of solutions that maintain uninterrupted network communication over a mobile link during changes in link connectivity. MbB is needed only when the change in link connectivity corresponds to a change in ground ATN routers. When this occurs,
depending on the link involved, represent a significant outage for user communications. In order to ameliorate
the problem, the concept of initializing IDRP before the link interruption occurs was advanced. This concept
works very well when the mobile link allows simultaneous communication between two ground ATN routers.
Mode S and VDL Mode 2 are examples of data links which operate in this way, mainly because the
frequency used for communication (with the ATN routers) is the same for both the old and the new routers.
(Note that this is not always the case for VDL Mode 2). In Mode S and VDL Mode 2, any new ground ATN
router can be in the process of initialization while the earlier ground ATN router is still transferring user data.
This is not allowed for VDL Mode 3 because the contact frequency will always be different between the
earlier and latest ATN ground routers. Simultaneous transfer of messages with both the new and old routers
— IDRP initialization messages with the new router and user messages with the older router — is not
possible for Mode 3.

11.7.2 The VDL Mode 3 Solution

The VDL Mode 3 solution to this problem is to provide a communication path between the
new VDL ground system (which uses the new frequency) and the old VDL ground system (which cannot
be directly contacted by the aircraft). In this way data can flow between the old ATN ground router and
aircraft, bypassing the new ATN router, until it has been initialized. Data from the aircraft is transferred to
the new VDL Mode 3 ground network interface equipment (GNI), which in turns sends the data to the former
GNI, which in turn sends it to its local ATN router. (The GNIs involved in this procedure are only those that
are associated with different ATN routers). Data flow to the aircraft proceeds in the reverse path: From the
former ATN router to its local GNI and then to the new GNI and thence to the aircraft. While this is
occurring, the ATN router attached to the new GNI is sending initialization messages. This is really a Break
and Maintain approach to the uninterrupted service requirement. But since it solves the same problem as MbB
does, it is put into this classification.

The implementation of the solution involves three phases, a request phase, an initialization
phase, and the operating phase. The request phase begins when an aircraft downlinks the last GNI used for
communication to the present GNI. This provides the present GNI with the following information: (1) the
aircraft is capable of MbB operations; and (2) of the many connected GNIs, the GNI formerly servicing the
aircraft. If the present GNI has MbB connectivity with the last, it agrees with this request and informs the
aircraft. This concludes the request phase. The initialization phase consists of the present GNI informing the
last GNI that it will be performing MbB operation for the aircraft. The former and present GNIs now have
sufficient information to act as switches. The operation phase can now begin. Packets, addressed to the
aircraft in question, received by the former GNI, and originating from its locally attached router, are
encapsulated into frames and sent to the new GNI for delivery. Similarly, frames sent by the aircraft and
received by the operative GNI are examined. Any frames addressed to the former GNI are delivered to the
identified GNI. The switching of frames by the GNI is possible because each frame contains a frame ground
subnetwork address, indicating the GNI to use. It is not necessary for the VDL Mode 3 avionics to keep track
of which packet goes to which GNI. The airborne ATN router, as part of normal packet forwarding functions,
keeps track of which GNI to use. It is the equivalent of a PC keeping track of the correspondence between
ethernet address and host system when connected to an ethernet. The GNI switching operation for an aircraft
ceases based on a timer. After which it is assumed that IDRP initialization has occurred.
11.7.3 Technical Aspects of the VDL Mode 3 Solution

It is assumed that all ground network interface units (GNIs) which are associated with the same ATN router are grouped and connected to that router via a “master” GNI, denoted the primary ground network interface or GNI\(_P\). Each GNI\(_P\) is assigned a non-zero identifier that is unique with respect to the set of GNI\(_P\)s that an aircraft can contact at any one time.

The Make-before-Break process occurs on an aircraft by aircraft basis. MbB operations for an aircraft begins when an aircraft wishing to participate in MbB operations downlinks the identifier of the last GNI\(_P\) capable of supporting MbB operations as an XID parameter during initial link negotiation. The last GNI\(_P\) capable of supporting MbB operations is defined to be the last GNI\(_P\) that participated in MbB XID negotiations within a predefined time period. If no such GNI\(_P\) is identified, the corresponding XID parameter is set to zero. This XID parameter identifies the “former_GNI\(_P\”).

Each GNI\(_P\) keeps a list of all surrounding GNI\(_P\)s with which it is capable of communicating for the purposes of MbB. Whenever, an aircraft begins the net entry protocol and the GNI\(_P\) sends a Net Entry Response of type “no previous link (section 5.7.2.1.2 of the Manual for VDL Technical Specifications), the GNI\(_P\) will examine the downlinked former_GNI\(_P\) XID parameter. If the parameter value matches a GNI\(_P\) identifier on the MbB list, the GNI\(_P\) will set the MbB_Operations_Permitted XID parameter to TRUE. Otherwise this parameter’s value is FALSE. The MbB parameter set is then uplinked according to the XID procedures defined in section 5.7.2.1.3.2 of the VDL Technical Manual. The MbB parameters set is defined as: (1) the identifier of the communicating GNI\(_P\), (2) the value of the aircraft_TMbB timer in seconds, and (3) the MbB_Operations_Permitted parameter. The GNI\(_P\) which performs this uplink is denoted the “operative_GNI\(_P\)”.

An aircraft receiving an MbB_Operations_Permitted XID parameter value of TRUE will participate in MbB operations. Once the aircraft has determined that it is participating in MbB operations the following occurs.

C The aircraft delays the generation of a Leave Event Message for the former_GNI\(_P\) until one of the following occur:

1. Aircraft_TMbB (system timer) seconds pass after the receipt of the timer value; or,

2. A new MbB parameter set is received via an XID transfer that does not contain a GNI\(_P\) identifier matching the operative_GNI\(_P\); or,

3. The MbB_Operations_Permitted parameter value is FALSE as a result of the uplink of a new MbB parameter set.

C Each subnetwork packet received from the local ATN router will be encapsulated in a frame header, as defined in section 5.6.2.1 of the Manual on VDL Technical Specifications. The Ground Subnetwork Address field in the DLS sublayer frame header will be set to the next hop link address value accompanying the packet received from the ATN router.
Note 1.— For MbB operations to succeed, the airborne ATN router must have the correspondence between the NET of the remote ground router and the attached GNI ground network address. The following methods are possible.

1. Join Event messages are generated and sent to the local ATN router, whenever the CTRL_RSP_LE frame is received following the receipt of a Net Entry Response M burst message of type “no previous link”. The link address, provided within the Join Event message, is that of the provided operative_GNI_p XID parameter. The ATN router will subsequently send an ISH packet with the destination field defined as the ground subnetwork address, i.e., the operative_GNI_p. This elicits an ISH from the ground ATN router, which is received by the airborne router. The NET of the ground router contained in the ISH packet can now be associated with the initiating Join Event message and its accompanying ground subnetwork address.

2. The VDL Mode 3 avionics supplies the ground subnetwork address of the encapsulating frame for all packets transferred to the local ATN router.

3. The NET of the remote router includes within the system identifier field sufficient information to deduce the ground subnetwork address.

Using one of the above procedures, the airborne ATN router has sufficient information to provide, with each packet forwarded to the VDL Mode 3 avionics system by the local ATN router, the next hop destination address to use. The next hop destination defines the ground subnetwork address field in each VDL Mode 3 frame. In this way established and newly required end-system communications will use the path corresponding to the former_GNI_p. While IDRP initialization will occur using the path corresponding to the operative_GNI_p. Once IDRP has initialized, both former and operative GNI_p paths will be used until the aircraft_TMbB timer expires and the former GNI_p path is withdrawn.

Note 2.— The airborne CLNP compression utility must be provided the ground subnetwork address for each packet, so as to assure the uniqueness of the reference number for each GNI_p.

Upon successful MbB parameter transfer, the operative_GNI_p performs the following initialization actions.

C Supercedes any existing switching information involving the aircraft with the more recent information,

C (Re)initializes the operative_TMbB timer.

C Sends a message to the former_GNI_p identified in the net initialization XID exchange. This message informs the former_GNI_p of the operative_GNI_p for the aircraft.

C The former_GNI_p will perform the following actions on receipt of this message.
C Supercede any existing switching information involving the aircraft with the more recent information and reinitialize the former_TMbB timer.

C Delay the generation of a Leave Event Message until the former_TMbB timer expires (see Note 3).

C Confirm the receipt of the message with the new (operative) GNI_p.

C Compress any packets addressed to the aircraft as required, and send the resulting compressed packet and corresponding frames to the operative_GNI_p. The ground subnetwork address field in the frame header is set to the value associated with the former_GNI_p.

C De-encapsulate frames received from the operative_GNI_p, decompress the resulting packets, and deliver the uncompressed packet to the local ATN router associated with the former_GNI_p.

C Cease MbB operations after former_TMbB seconds

In addition to the requirements formerly listed, the operative_GNI_p will perform the following functions in support of MbB operation.

C Provide complete A-CLDL functions for all frames transmitted or received from the aircraft, whatever the ground subnetwork address value.

C Deliver each frame successfully received from the A-CLDL function to the GNI_p identified in the ground subnetwork address field of the frame header.

C Compress packets received from the locally attached ATN router and encapsulate the result in a DLS sublayer frame. The ground subnetwork address value associated with the operative_GNI_p is used when constructing the frame header associated with each packet.

C Decompress packets received from the aircraft (i.e., packets contained in frames with a ground subnetwork address value of the operative_GNI_p), as required and forward to the local ATN router.

C Forward frames received from the former_GNI_p to the aircraft identified in the frame header, providing all necessary DLS support.

C In the event that the local ATN router notifies the operative_GNI_p that IDRP has completed initialization, modify the MbB_Operations_Permitted parameter to FALSE and uplink the new value in a XID frame.

C After operative_TMbB seconds, cease MbB operations for the aircraft in question.
Note 3.— While the ATN router is initializing using the operative\textsubscript{GNI\_p}, the ATN will be advertising one path to the aircraft. This will be the path through the former\textsubscript{GNI\_p}. During this time, any data transmitted to the aircraft from any location in the ATN will be forwarded to the ATN router connected to the former\textsubscript{GNI\_p}, which in turn will deliver the data to the operative\textsubscript{GNI\_p}. When IDR\textsubscript{p} has finished initializing, and the former\textsubscript{TMbB} timer has not expired, two paths to the aircraft will be advertised throughout the ATN; one using the ATN router attached to the former\textsubscript{GNI\_p}, the other the ATN router attached to the operative\textsubscript{GNI\_p}. Each path will have a different quality of service associated with it, distinguished by the path distance, or hop count. For this reason, messages to be sent to the aircraft and originating in a control center associated with the operative\textsubscript{GNI\_p} will be sent to the ATN router attached to the operative\textsubscript{GNI\_p}. Because, the hop count will be at least one less than that of the path to the ATN router attached to the former\textsubscript{GNI\_p}. Most, if not all, ATC messages will thus be using the operative\textsubscript{GNI\_p} when the former\textsubscript{TMbB} timer expires. When the timer does expire, the path associated with the former\textsubscript{GNI\_p} will be withdrawn, as a result of the generation of a Leave Event Message by the former\textsubscript{GNI\_p}. At this point, all data will use the operative\textsubscript{GNI\_p}, as its associated ATN router is the only one being advertised as capable of reaching the aircraft in question.

Note 4.— The value of the aircraft\textsubscript{TMbB} timer must be larger than the expected time it takes the IDR\textsubscript{p} protocol to initialize and for the subsequent new router to be advertised throughout the ATN. The relationship of the 3 timers must be as follows.

\[
\text{operative\textsubscript{TMbB}} > > \text{former\textsubscript{TMbB}} > > \text{aircraft\textsubscript{TMbB}}
\]

Continued switching operation by the GNI\textsubscript{p}s after IDR\textsubscript{p} has initialized is not detrimental to the system. All CLNP packets will be routed correctly, if not efficiently. Thus, the operative\textsubscript{TMbB} and former\textsubscript{TMbB} timers’ primary use is to flush the involved GNI\textsubscript{p}s switching tables of dated information.
12. DATA BURST EXAMPLES

In this document care has been taken to define each burst component as exactly as possible. Nevertheless, there may be some ambiguity as to the order in which the different pieces are assembled and the order of the bits (or symbols) within the pieces. To help remove such ambiguity, an example of a particular downlink V/D(data) message is provided. Such a message contains all types of burst components including a synchronization sequence, a Golay code word, and a Reed Solomon (RS) code word.

It is assumed for the sake of this exercise that a data frame comprising exactly 62 bytes (octets) of information is being sent. This means that the entire message consists of one, and only one, burst. It is also assumed that the airborne radio making the transmission is connected to a ground site whose Ground Station Code (GSC) is 010.

Throughout this section, numerous examples of bit or symbol sequences are presented in tabular form. These are always read from left to right, and then from top to bottom (exactly as one would read this text). Ultimately, the information is transmitted in this left-to-right fashion. For all MAC sublayer and physical layer processing, the most significant bit (MSB) of any field is placed to the left and the least significant bit (LSB) is placed to the right.

The different components of a burst will be treated separately in the following sections. Then the pieces will be put together, and the further processing needed to create the final Differential 8-ary Phase Shift Key (D8PSK) transmission will be described.

12.1 Power Stabilization

It is assumed that every burst begins with a sequence of three symbols with information 000. The purpose of this sequence is to provide a more or less constant signal to allow a receiver’s Automatic Gain Control (AGC) to stabilize prior to receiving the first symbol of the synchronization sequence. This corresponds to the 9-bit sequence shown in Figure 12-1.

0 0 0 0 0 0 0 0 0

Figure 12-1. Power Stabilization Sequence

12.2 Synchronization Sequence

The synchronization sequence for all V/D (data) bursts is $S_1$ (as described in Section 3.1), which is shown in Figure 12-2.

| 0 | 0 | 0 | 1 | 1 | 1 | 0 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 |
| 1 | 0 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 1 | 1 |
12.3 **Header**

As described in Section 2.2, the V/D(data) header has the following format:

\{(Message ID:3)(Ground Station Code:3)(Segment Number:4)(Spare:1)(EOM:1)\}

In this case the fields have the following values:

- **Message ID = 101** Downlink data
- **GSC = 010** By assumption
- **Segment Number = 0001** Data frame is one burst long
- **Spare = 0** All spare bits are set to 0
- **EOM = 1** Data frame is one burst long

Thus, the header for this particular burst is

```
1 0 1 0 1 0 0 0 0 1 0 1
```

This header is protected by a (24,12) Golay code which can be implemented by multiplying the previous 12-element vector by a particular 12 x 24 matrix to yield figure 12-3. Note that in this case the Golay parity bits are affixed *ahead* of the original header bits.

```
0 1 1 0 0 0 0 0 0 1 0 1 0 1 0 0 0 0 1 0
```

**Figure 12-3. Golay Coded Header Sequence**

12.4 **Data and RS Error Coding**

For this example it is assumed that the data (as interpreted by the RS encoder) consist of the following 62 bytes of information (in hexadecimal notation):

```
00 01 02
03 04 05
06 07 08
09 0 0B
A
0C 0 0E
D
0F 10 11
12 13 14
```
For convenience, it has been assumed that the 62 bytes are just the ascending sequence of numbers from 0 to 61 (in decimal notation); an actual data frame would not be likely to have such a simple form. Note, also, that in this example the data frame consists of exactly 62 bytes. If there had been less data, then it would have been padded with zeros until the total length was 62 bytes. These padded zeros are always appended to the end (i.e., to the right) of the data and transmitted along with the rest of the message. All V/D(data) bursts are the same length.

The RS encoding process generates 10 bytes of parity information. For the input above, the parity bytes are (0E, DC, 13, 63, E7, 4A, 6D, 3E, 1D, A2). These are affixed to the end of the data. Thus, the entire 72-byte RS word is
This is expressed in terms of bits in Figure 12-4.

```
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 1 0 1
0 0 0 0 0 0 1 1 0 0 0 0 0 0 1 0 0 0 0 0 0 0 1 0 1
0 0 0 0 0 1 1 0 0 0 0 0 0 0 1 1 1 0 0 0 0 0 1 0 0 0
0 0 0 0 1 0 0 1 0 0 0 0 0 1 0 1 0 0 0 0 0 0 1 0 1
0 0 0 0 1 1 1 0 0 0 0 0 0 1 1 1 1 0 0 0 0 0 1 1 1 0
0 0 0 0 1 1 1 1 0 0 0 1 0 0 0 0 0 0 0 0 1 0 0 0 1
0 0 0 1 0 0 1 0 0 0 0 0 0 0 1 1 0 0 0 1 0 1 0 0 0
0 0 0 1 0 1 0 1 0 0 0 1 0 1 1 0 0 0 0 1 0 1 1 1
0 0 0 1 1 1 0 0 0 0 0 0 1 1 1 0 0 1 0 0 0 1 1 1 0
0 0 0 1 1 0 1 1 0 0 0 1 1 1 0 0 0 0 1 1 1 0 1 0 1
0 0 0 1 1 0 1 1 0 0 0 1 1 1 1 0 0 0 0 1 1 1 0 1 1
```

It should be emphasized that the purpose of the RS encoding and decoding process is to ensure that the 496 bits of data carried by the burst are delivered as reliably as possible from the Data Link Service (DLS) sublayer of the transmitter to the DLS sublayer of the receiver. The fact that the RS coder and RS decoder interpret these bits as a sequence of 62 bytes with the MSB on the left does not have any relevance at all to how these bits may be interpreted by the upper layers of the transmitting and receiving protocol stacks. The bits are simply delivered in the order in which they are received.

12.5 Bit Scrambling

The payload of every VDL Mode 3 burst is subject to bit scrambling. Bit scrambling consists of bit-by-bit modulo 2 addition with a particular sequence of bits. The sequence is part of an m-sequence defined by the characteristic polynomial

\[ x^{15} + x + 1 \]

Equivalently, the sequence is defined by the recursion relation

\[ s(n) = s(n - 1) + s(n - 15) \]

with a seed \((s(1), s(2), \ldots, s(15))\) equal to \((1,0,0,1,1,0,1,0,1,0,0,0,1,0,1)\). The scrambling bits are then given by \(s(16)\) through \(s(615)\) as shown in Figure 12-5. This 600-bit sequence is fixed; and every burst is scrambled using this same sequence. The V/D(data) and normal V/D(voice) bursts are the longest ones, and they use all 600 bits in the sequence. Other types of VDL Mode 3 bursts are shorter; and they use only as many of the scrambler bits as are needed, starting at the beginning of the sequence.
Figure 12-5. Bit Scrambler Sequence

| 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 |
| 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 1 | 1 |
| 0 | 0 | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| 0 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 1 | 1 | 0 |
| 0 | 0 | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 1 | 1 | 1 |
| 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 1 | 0 |
| 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 |
| 0 | 0 | 0 | 1 | 1 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 1 | 1 | 0 |

In the case of the current example, the payload consists of the header plus the RS-encoded data as shown in Figure 12-6. When the payload and the scrambling sequences are added together, the result is shown in Figure 12-7.
Figure 12-6. Payload Sequence
Figure 12-7. Scrambled Payload
12.6 Phase Change Sequence

The final sequence of the previous section is nearly ready to be translated into a sequence of phase changes for the D8PSK modulator. However, prior to that step the power stabilization and synchronization sequences must be added to the head of the transmitted bit stream. When this is done, the result is

\[
\Delta \varphi_i = \pi x_i / 4
\]

where the angle change, \( \Delta \varphi_i \), is measured in radians. In this notation, the table is given by Table 8-1. Note that this table can also be expressed as a simple equation. Using the same notation, \( x_i \) is given by

\[
x_i = 4(y_i(1)) + 2(y_i(1) \oplus y_i(2)) + (y_i(1) \oplus y_i(2) \oplus y_i(3))
\]

This sequence is finally in a form which can be used to generate a sequence of phase changes. This is done by dividing the bit sequence in groups of three (e.g., \( y_i(1), y_i(2), y_i(3) \)) and using a look-up table which maps 3-bit symbols into phase changes. For convenience the phase changes are described in terms of a sequence of \( x_i \) as follows:

\[
x_i = 4(y_i(1)) + 2(y_i(1) \oplus y_i(2)) + (y_i(1) \oplus y_i(2) \oplus y_i(3))
\]
where the symbol $\oplus$ represents modulo 2 summation and the symbol + represents ordinary summation.

Table 12-1. Data Encoding

<table>
<thead>
<tr>
<th>$y_i(1)$</th>
<th>$y_i(2)$</th>
<th>$y_i(3)$</th>
<th>$x_i$</th>
</tr>
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<tbody>
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<td>7</td>
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</table>

Figure 12-8 shows the sequence of phase changes in this notation. The first row is the power stabilization component. The next two lines comprise the synchronization sequence. The next row is the header; and the remaining 24 rows are the RS data word.
12.7 Phase Sequence

The sequence of phase changes derived in the previous section can be converted into a sequence of phases by summing all the $x_i$ up to a particular point. The final sequence is given by figure 12-9 (assuming that the starting phase is zero radians). If the numbers in the figure are labeled $z_i$, then the sequence of phases is given by

$$\phi_i = \pi z_i / 4$$

where the angle, $\phi_i$, is given in radians. This sequence defines the trajectory of the complex waveform as it passes through the space of I and Q. In other words, these angles define specific sequences of (I,Q) pairs,

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<td>5</td>
<td>7</td>
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<td>4</td>
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<td>7</td>
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<td>2</td>
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<tr>
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<td>5</td>
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<td>3</td>
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<tr>
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<td>6</td>
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<tr>
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<td>5</td>
<td>6</td>
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<td>7</td>
<td>1</td>
<td></td>
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</tr>
</tbody>
</table>

which are passed through appropriate Nyquist filters to generate the waveform that is sent to the radio’s modulator.
Figure 12-9. Final Phase Sequence
13. STATE TRANSITION DIAGRAMS

13.1 Introduction

The state diagrams in this document provide an overview of VDL Mode 3 MAC and DLS simulation in Opnet completed at MITRE for VDL Mode 3 performance analysis and validation. The state diagrams illustrate the transitions of both the DLS and MAC sublayers protocol finite state machines under normal and recovery operations.

13.2 Clock State Transitions

At the center of VDL Mode 3 MAC operations are the TDMA MAC cycles which consist of a sequence of bursts of fixed time duration. External events occur spontaneously while internal events always occur at the beginning of each cycle and individual burst. Actions are performed or scheduled for future clock states in a cyclic and deterministic fashion by the MAC sublayer. Figure 13-1 illustrates the state diagram of the TDMA clock process of the VDL Mode 3 Opnet simulation model. The state transitions for Figure 13-1 are tabulated in Table 13-1.

CLOCK (Aircraft and the Ground Station)

NEW_CYCLE (c1, interrupt)
NEW_BURST (c2, interrupt)
(M_up, M_RA, M_down, and Data)

WAIT/IDLE (c3)

Figure 13.1. A State Diagram for VDL Mode 3 Clock

Table 13.1. VDL Mode 3 MAC Clock State Transitions

<table>
<thead>
<tr>
<th>State</th>
<th>Actions</th>
<th>Next State</th>
</tr>
</thead>
<tbody>
<tr>
<td>c1</td>
<td>Start a new MAC cycle</td>
<td>c2</td>
</tr>
<tr>
<td>c2</td>
<td>Start a new burst type</td>
<td>c3</td>
</tr>
</tbody>
</table>
13.3 DLS State Transitions

VDL Mode 3 DLS adopts an acknowledged-connectionless data link protocol (A-CLDL). The state diagram for such a data link layer in Opnet is illustrated in Figure 13-2. The state transitions are tabulated in Table 13-2.

DLS (Aircraft and the Ground Station)

LME_INIT (d1)
SET_UP
  Aircraft (d2)
    (Net_Entry_Request, Send_XID)
Ground Station (d3)
    (Net_Entry_Response, XID_Response)
READY (wait) (d4)
UPPER_LAYERS_ARRIVAL (d5 interrupt)
MAC_ARRIVAL (interrupt)

Frame arrival (d6)
ACK Frame arrival (d7)

Figure 13.2. A State Diagram for VDL Mode 3 DLS Sublayer

<table>
<thead>
<tr>
<th>State</th>
<th>Action</th>
<th>Next State</th>
</tr>
</thead>
<tbody>
<tr>
<td>d1</td>
<td>LME Initialization</td>
<td>d2 (aircraft), or d3 (ground)</td>
</tr>
<tr>
<td>d2</td>
<td>Send Net_Entry_Request Send XID</td>
<td>d4 (ready)</td>
</tr>
<tr>
<td>d3</td>
<td>Send Net_Entry_Response</td>
<td>d4 (ready)</td>
</tr>
<tr>
<td>State</td>
<td>Action</td>
<td>Next State</td>
</tr>
<tr>
<td>-------</td>
<td>--------</td>
<td>------------</td>
</tr>
<tr>
<td>Send XID Response</td>
<td></td>
<td></td>
</tr>
<tr>
<td>d4</td>
<td>Handle arrivals (MAC and upper layers) Initiate recovery process</td>
<td>d1, d5, d6, or d7</td>
</tr>
<tr>
<td>d5</td>
<td>Handle upper layer arrivals (forward frames to MAC)</td>
<td>d4 (ready)</td>
</tr>
<tr>
<td>d6</td>
<td>Handle MAC frame arrivals (generate ACK frame)</td>
<td>d4 (ready)</td>
</tr>
<tr>
<td>d7</td>
<td>Handle MAC ACK arrivals (discard ACKed frame)</td>
<td>d4 (ready)</td>
</tr>
</tbody>
</table>

13.4 **Ground Station MAC Sublayer State Transitions**

VDL Mode 3 MAC sublayer functionalities are not identical between the ground station and the aircraft and result in different MAC sublayer state diagrams. This is due to the unique role the ground station plays in managing all the available channel resources. Figure 13-3 details the MAC state diagram simulated for the ground station; its state transitions are tabulated in Table 13-3.

MAC (Ground Station)

READY/IDLE (wait g1)

Mac_Ack_Arrival (M_RA Interrupt)

Mac_Frm_Arrival (M_RA, M_down, And Data Interrupts)

M_UP_BURST (g2 interrupt)
DATA_BURST (g3 interrupt)
T1_TIME_OUT (g4 interrupt)
DLS_ARRIVALS (g5 interrupt and queuing)
PHY_ARRIVALS (g6 interrupt)
MAC_RESET (g7 interrupt)
Table 13.3. VDL Mode 3 Ground Station MAC Sublayer State Transitions

<table>
<thead>
<tr>
<th>State</th>
<th>Actions</th>
<th>Next State</th>
</tr>
</thead>
<tbody>
<tr>
<td>g1 (Idle)</td>
<td>Process frame arrival and handle external and internal interrupts</td>
<td>g2, g3, g4, g5, g6, or g7</td>
</tr>
<tr>
<td>g2 (M_up)</td>
<td>Poll aircraft, assign data slots, and transmit M_up bursts</td>
<td>g1 (Idle/Ready)</td>
</tr>
<tr>
<td>g3 (Data)</td>
<td>Process downlink frames and transmit uplink frames</td>
<td>g1 (Idle/Ready)</td>
</tr>
<tr>
<td>g4 (T1_Time-Out)</td>
<td>Uplink frame retransmission</td>
<td>g1 (Idle/Ready)</td>
</tr>
<tr>
<td>g5 (DLS frames)</td>
<td>Handle DLS frame arrival and remove acknowledged frames</td>
<td>g1 (Idle/Ready)</td>
</tr>
<tr>
<td>g6 (MAC frames)</td>
<td>Process downlink reservations, acknowledgments, and data frames</td>
<td>g1 (Idle/Ready)</td>
</tr>
<tr>
<td>g7 (MAC Reset)</td>
<td>Reinitialize all aircraft /ground links, process LME recovery</td>
<td>g1 (Idle/Ready)</td>
</tr>
</tbody>
</table>

13.5 Aircraft MAC Sublayer State Transitions

The MAC sublayer state diagram for the aircraft is illustrated in Figure 13-4. The state transitions are tabulated in Table 13-4.

MAC (Aircraft)

READY/IDLE (a1 wait)
Mac_Ack_Arrival (Data Interrupt)
Mac_Frm_Arrival (M_up And Data Interrupts)
M_RA_BURST (a2 interrupt)
M_DOWN_BURST (a3 interrupt)
DATA_BURST (a4 interrupt)
T1_TIME_OUT (a5 interrupt)
DLS_ARRIVAL (a6 interrupt and queuing)
PHY_ARRIVALS (a7 interrupt)
Figure 13.4. A State Diagram for VDL Mode 3 Aircraft MAC Sublayer

Table 13.4. VDL Mode 3 Aircraft MAC Sublayer State Transitions

<table>
<thead>
<tr>
<th>State</th>
<th>Actions</th>
<th>Next State</th>
</tr>
</thead>
<tbody>
<tr>
<td>a1 (Idle)</td>
<td>Process frame arrivals and handle external and internal interrupts</td>
<td>a2, a3, a4, a5, a6, or a7</td>
</tr>
<tr>
<td>a2 (M_RA)</td>
<td>Send reservation request or acknowledgment frame</td>
<td>a1 (Idle or ready)</td>
</tr>
<tr>
<td>a3 (M_down)</td>
<td>Send poll response (reservation request or null response)</td>
<td>a1 (Idle or ready)</td>
</tr>
<tr>
<td>a4 (Data)</td>
<td>Transmit downlink frame (if assigned)</td>
<td>a1 (Idle or ready)</td>
</tr>
<tr>
<td>a5 (T1_Time_Out)</td>
<td>Schedule uplink frame retransmission</td>
<td>a1 (Idle or ready)</td>
</tr>
<tr>
<td>a6 (DLS Frames)</td>
<td>Handle DLS frame arrivals (prepare reservation request)</td>
<td>a1 (Idle or ready)</td>
</tr>
<tr>
<td>a7 (MAC Frames)</td>
<td>Process M_up burst, uplink data frames, and acknowledgment frames</td>
<td>a1 (Idle or ready)</td>
</tr>
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LIST OF REFERENCES


<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
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<tbody>
<tr>
<td>A-CLDL</td>
<td>Acknowledged-Connectionless Data Link</td>
</tr>
<tr>
<td>ACK</td>
<td>Acknowledgment</td>
</tr>
<tr>
<td>ATN</td>
<td>Aeronautical Telecommunication Network</td>
</tr>
<tr>
<td>AGC</td>
<td>Automatic Gain Control</td>
</tr>
<tr>
<td>AM</td>
<td>Amplitude Modulation</td>
</tr>
<tr>
<td>ATC</td>
<td>Air Traffic Control</td>
</tr>
<tr>
<td>ATS</td>
<td>Alternate Timing Signal</td>
</tr>
<tr>
<td>BER</td>
<td>Bit Error Rate</td>
</tr>
<tr>
<td>bps</td>
<td>Bits per Second</td>
</tr>
<tr>
<td>CAASD</td>
<td>Center for Advanced Aviation System Development</td>
</tr>
<tr>
<td>CLNP</td>
<td>Connection-less Network Protocol</td>
</tr>
<tr>
<td>COTP</td>
<td>Connection Oriented Transport Protocol</td>
</tr>
<tr>
<td>CRC</td>
<td>Cyclic Redundancy Code</td>
</tr>
<tr>
<td>CTC1</td>
<td>Coast Time Counter 1</td>
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<td>CTC2</td>
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<tr>
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<td>Coast Time Counter 1</td>
</tr>
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<td>dB</td>
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<td>D8PSK</td>
<td>Differential 8-ary Phase Shift Key</td>
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<tr>
<td>DLM</td>
<td>Data Link Management</td>
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<td>DLS</td>
<td>Data Link Service</td>
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<tr>
<td>EOM</td>
<td>End of Message</td>
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<tr>
<td>GPS</td>
<td>Global Positioning System</td>
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<td>GSC</td>
<td>Ground Station Code</td>
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<td>ICAO</td>
<td>International Civil Aviation Organization</td>
</tr>
<tr>
<td>ID</td>
<td>identification</td>
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<tr>
<td>IDRП</td>
<td>Interdomain Routing Protocol</td>
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<tr>
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<td>Definition</td>
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<tr>
<td>kbps</td>
<td>Kilobits per second</td>
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<td>kHz</td>
<td>KiloHertz</td>
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<tr>
<td>LBAC</td>
<td>Logical Burst Access Channel</td>
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<tr>
<td>LME</td>
<td>Link Management Entity</td>
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<td>MAC</td>
<td>Media Access Control</td>
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<td>MID</td>
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<tr>
<td>ms</td>
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<td>nautical miles</td>
</tr>
<tr>
<td>ppm</td>
<td>parts per million</td>
</tr>
<tr>
<td>PTT</td>
<td>Push-to-Talk</td>
</tr>
<tr>
<td>QOS</td>
<td>Quality of Service</td>
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<td>RA</td>
<td>Random Access</td>
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<td>Reservation Request Acknowledgment</td>
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<td>RCE</td>
<td>Radio Control Equipment</td>
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<td>RS</td>
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<td>Standards and Recommended Practices</td>
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<td>SN-SME</td>
<td>Subnetwork-System Management Entity</td>
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<tr>
<td>SP</td>
<td>Segmentation Permitted</td>
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<tr>
<td>SQP</td>
<td>Signal Quality Parameter</td>
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<tr>
<td>TAI</td>
<td>International Atomic Time</td>
</tr>
<tr>
<td>TDMA</td>
<td>Time Division Multiple Access</td>
</tr>
<tr>
<td>UTC</td>
<td>Universal Coordinated Time</td>
</tr>
<tr>
<td>Acronym</td>
<td>Description</td>
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<td>----------------------------------</td>
</tr>
<tr>
<td>V/D</td>
<td>Voice or Data</td>
</tr>
<tr>
<td>VDL</td>
<td>VHF Digital Link</td>
</tr>
<tr>
<td>VDL MODE 3</td>
<td>VHF Digital Link TDMA</td>
</tr>
<tr>
<td>VHF</td>
<td>Very High Frequency</td>
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