NOT MEASUREMENT
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DEPARTMENT OF DEFENSE
INTERFACE STANDARD

DIGITAL MESSAGE TRANSFER DEVICE
SUBSYSTEMS

AMSC N/A

AREA TCSS

DISTRIBUTION STATEMENT A. Approved for public release; distribution is unlimited.

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FOREWORD

This military standard is approved for use by all Departments and Agencies of the Department of Defense (DoD). It applies to all inter- and intra-Department of Defense (DoD) digital message transfer devices (DMTDs) and command, control, communications, computers and intelligence (C^4I) systems that exchange information with DMTDs.

This standard contains technical parameters for the data communications protocols that support DMTD interoperability. It provides mandatory system standards for planning, engineering, procuring, and using DMTDs in tactical digital communications systems. This standard specifies the lower layer (Physical through Intranet) protocol for interoperability of C^4I systems over combat net radio (CNR) on the battlefield. This standard provides the information required to pass digital data via CNR on the battlefield.

The Preparing Activity (PA) for this standard is USACECOM, ATTN: AMSEL-SE-CD (Mr. E. Robinson), Fort Monmouth, NJ 07703. The custodians for the document are identified in the Defense Standardization Program, "Standardization Directory (SD-1)" under Standardization Area Data Communication Protocol Standards (DCPS).

Beneficial comments (recommendations, additions, deletions) and any pertinent data that may be of use in improving this military standard should be addressed to the PA at the above address by using the Standardization Document Improvement Proposal (DD Form 1426) appearing at the end of this document or by letter.

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1.   SCOPE

1.1 Purpose. This document promulgates the minimum essential technical parameters in the form of mandatory system standards and optional design objectives for interoperability and compatibility among DMTDs, and between DMTDs and applicable C^{4}I systems. These technical parameters are based on the data communications protocol standards specified herein to ensure interoperability.

1.2 Scope. This document identifies the procedures, protocols, and parameters to be applied in specifications for DMTDs and C^{4}I systems that exchange information with DMTDs. This document addresses the communications protocols and procedures for the exchange of information among DMTDs, among C^{4}I systems, and between DMTDs and C^{4}I systems participating in inter- and intra-Service tactical networks.

1.3 Application guidance. This document applies to the design and development of new equipment and systems, and to the retrofit of existing equipment and systems.

1.4 System standards and design. The parameters and other requirements specified in this document are mandatory system standards if the word shall is used in connection with the parameter value or requirement under consideration. Non-mandatory design objectives are indicated in parentheses after a standardized parameter value or by the word should in connection with the parameter value or requirement under consideration. Unless stated otherwise, the following convention is used in the figures of MIL-STD-188-220: Least Significant Bit (LSB) is always shown to the LEFT, and Most Significant Octet is always shown to the RIGHT.

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2. APPLICABLE DOCUMENTS

2.1 <u>General</u>. The documents listed in this section are specified in sections 3, 4, and 5 of this standard. This section does not include documents cited in other sections of this standard or recommended for additional information as examples. While every effort has been made to ensure the completeness of this list, document users are cautioned that they must meet all specified requirements documents cited in sections 3, 4, and 5 of this standard, whether or not they are listed.

2.2 <u>Government documents</u>.

2.2.1 <u>Specifications, standards, and handbooks</u>. The following specifications, standards, and handbooks form a part of this document to the extent specified herein. Unless otherwise specified, the issues of these documents are those listed in the current issue of the DoD Index of Specifications and Standards (DoDISS) and supplement thereto, cited in the solicitation (see 6.2).

STANDARDS

FEDERAL

FED-STD-1037   Glossary of Telecommunication Terms

MILITARY

MIL-STD-188-100 (Series)   Common Long Haul and Tactical
                                              Communications System Technical
                                              Standards

MIL-STD-188-110   Equipment Technical Design Standards for
                                              Common Long Haul/Tactical Data Modems

MIL-STD-188-114   Electrical Characteristics of Digital Interface
                                              Circuits

MIL-STD-188-200   System Design and Engineering Standards
                                              for Tactical Communications

MIL-STD-2045-14502-1   Information Technology DoD Standardized
                                              Profile -- Internet Transport Profile for DoD
                                              Communications – Part 1: Transport and
                                              Internet Services

MIL-STD-2045-47001   Interoperability Standard for Connectionless
                                              Data Transfer -- Application Layer Standard

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[Unless otherwise indicated, copies of federal and military standards are available from the Standardization Document Order Desk, 700 Robbins Avenue, Building 4D, Philadelphia, PA 19111-5094.]

2.2.2 Other Government documents, drawings, and publications. None.

2.3 Non-Government publications. The following documents form a part of this document to the extent specified herein. Unless otherwise specified, the issues of the documents that are DoD- adopted are those listed in the issue of the DoDISS cited in the solicitation. Unless otherwise specified, the issues of documents not listed in the DoDISS are the issues of the documents cited in the solicitation (see 6.2).

2.3.1 International Organization for Standardization (ISO).

ISO 3309	Information Processing Systems -- Data Communication -- High-level Data Link Control Procedures -- Frame Structure
ISO 7498-1	Information Processing Systems -- Open Systems Interconnection -- Basic Reference Model
ISO 8802-2	Information Processing Systems -- Local Area Networks -- Part 2: Logical Link Control

[ISO standards are available from the American National Standards Institute, Inc., 1430 Broadway, New York, NY 10018.]

2.3.2 International Telecommunications Union (ITU).

Formerly known as International Telephone and Telegraph Consultative Committee (CCITT)

CCITT V.10	Electrical Characteristics for Unbalanced Double-Current Interchange Circuits for General Use with Integrated Circuit Equipment in the Field of Data Communications.
CCITT V.33	14,400 Bits Per Second Modem Standardized for Use on Point-to-Point 4-wire Leased Telephone-Type Circuits.
CCITT V.36	Modems for Synchronous Data Transmission Using 60-108 kHz Group Band Circuits.
CCITT X.21	Interface Between Data Terminal Equipment (DTE) and Data Circuit-Terminating Equipment (DCE) for Synchronous Operation on Public Data Networks.

[CCITT standards are available from Omnicom, 115 Park Street, South East, Vienna, VA 22180]

2.3.3 Internet Architecture Board (IAB)Standards.

RFC 826	An Ethernet Address Resolution Protocol -- or -- Converting Network Protocol Addresses to 48-bit Ethernet Addresses for Transmission on Ethernet Hardware
RFC 903	A Reverse Address Resolution Protocol
RFC 1770	IPv4 Option for Sender Directed Multi-Destination Delivery

[RFCs are available from Network Information Center, 14200 Park Meadow Drive, Suite 200, Chantilly, VA 22021. The Network Information Center (NIC) can be reached, by phone, Monday through Friday, 7 AM through 7 PM, Eastern Standard time: 1-800-365-3642 and 1-703-802-4535. RFCs may also be obtained from the DS.INTERNIC.NET via FTP, WAIS, and electronic mail. Through FTP, RFCs are stored as rfc/rfcnnnn.txt or rfc/rfcnnnn.ps where 'nnnn' is the RFC number, 'txt' is a text file and 'ps' is a postscript file. Login as "anonymous" and provide your e-mail address as the password. Through WAIS, you may use either your local WAIS client or TELNET to DS.INTERNIC.NET and login as "wais" (no password required). Through electronic mail send a message to mailserv@ds.internic.net and include the following commands in the message body document -by-name RFC#### where #### is the RFC number without leading zeros or file /ftp/rfc/rfc####.yyy where 'yyy' is 'ps' or 'txt'. To obtain the complete RFC index, the subject line of your message should read "RFC index."]

2.3.4 Other. In parallel to the English specification found in this standard, several components of MIL-STD-188-220 also have been formally specified using Estelle. Estelle is a formal description technique based on communicating, extended finite state machines. Estelle is described in ISO 9074. The Estelle formal specifications are available via the CNR Implementation Working Group World Wide Web page: http://www-cnrwg.itsi.disa.mil.

2.4 Order of precedence. In the event of a conflict between the text of this document and the references cited herein, the text of this document takes precedence. Nothing in this document, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

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3. DEFINITIONS

3.1 <u>Definitions of terms</u>. Definitions of terms used in this document are specified in FED-STD-1037.

3.2 <u>Abbreviations and acronyms</u>. Abbreviations and acronyms used in this MIL-STD are defined in Appendix A. Those listed in the current edition of FED-STD-1037 have been included for the convenience of the reader.

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4. GENERAL REQUIREMENTS

4.1 <u>Digital message transfer device</u>. A DMTD is a portable data terminal device with limited message generation and processing capability. DMTDs are used for remote access to automated C^4I systems and to other DMTDs. The environment encompasses point-to-point, point-to-multipoint, relay and broadcast transfer of information over data communications links.

4.2 <u>Interoperability</u>. Interoperability of DMTDs and associated C^4I systems shall be achieved by implementing the standard interface for DMTD subsystems (see Figure 1) specified in this document. This standard defines the layered protocols for the transmission of single or multiple segment messages over broadcast radio subnetworks and point-to-point links. It provides the minimum essential data communications parameters and protocol stack required to communicate with other data terminal devices. These communications parameters and protocols will facilitate functional interoperability among DMTDs, and between DMTDs and applicable C^4I systems within the layered framework described below. Electrical and mechanical design parameters are design-dependent and are outside the scope of this document. Interoperability considerations for terminal designers and systems engineers are addressed in 6.3 and Appendix B.
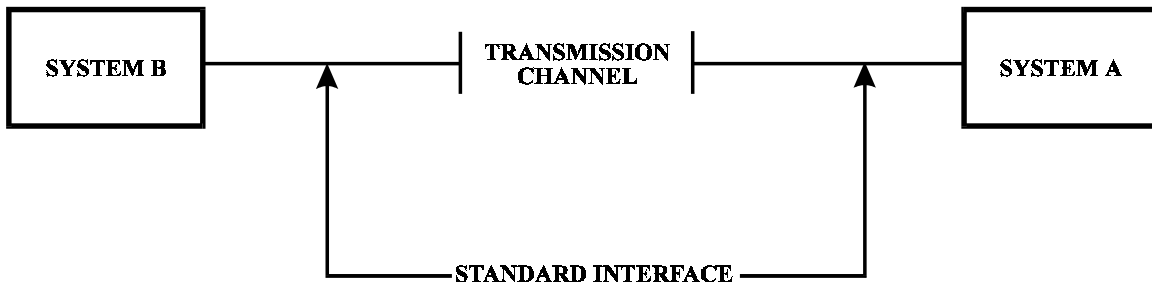
NOTES:

1. System A and System B (where either system, or both, can be a DMTD or a C^4I system) may include modems, line drivers, error control algorithms, encryption devices, control units, and other devices as required to comply with this standard.

2. The transmission channel may include single and multichannel transmission equipment.

FIGURE 1. <u>Standard interface for DMTD subsystems</u>.

4.3 <u>Framework</u>. The communications and procedural protocols used in DMTD equipment shall support the layers of the functional reference model depicted in Figure 2. The DMTD functional reference model in Figure 2 is based on the ISO 7498 OSI seven-layer model and is for reference only. Figure 2 contains the framework that is used in this document for defining the protocols required to exchange information among DMTD subsystems, and between DMTD subsystems and applicable C^4I systems. Figure 3 illustrates a representative time epoch of the basic frame structure supported by the DMTD subsystem. This standard describes the protocols at the following OSI layers:

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a.   Physical Layer

b.   Data Link Layer
        1. Network Access Control
        2. Link Level Control

c.   Network Layer (Intranet Layer)

Application Layer *

Presentation Layer *

Session Layer *

Transport Layer *

Network Layer

Data Link Layer
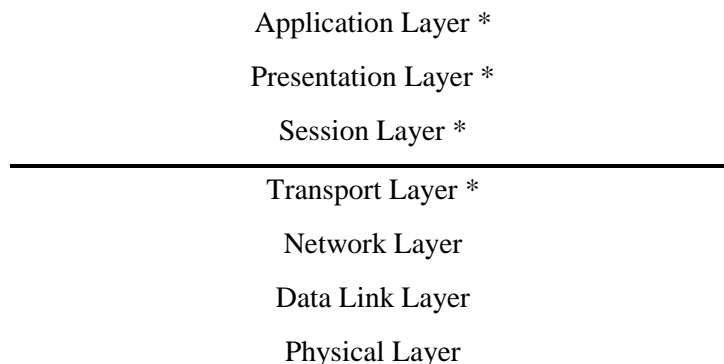
Physical Layer

* NOTE: These layers are not addressed in this standard.

FIGURE 2. DMTD functional reference model.
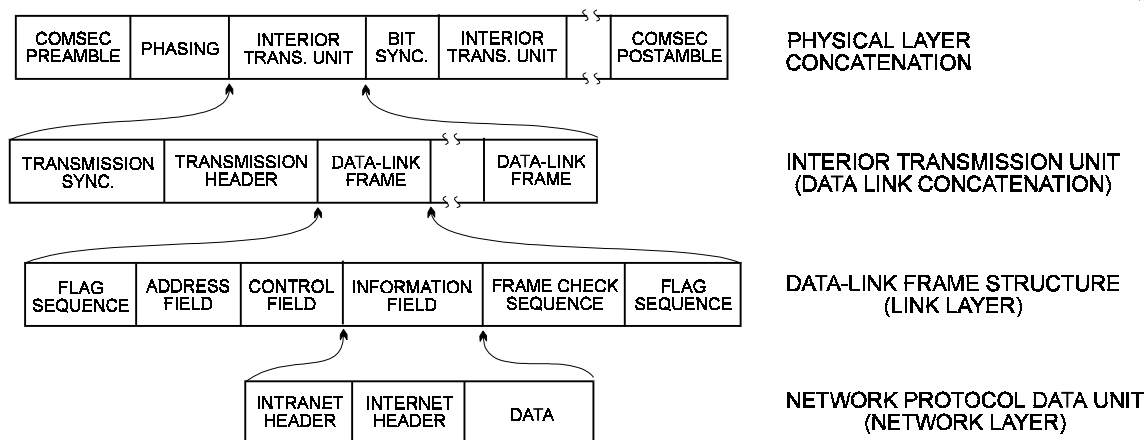
NOTES: Phasing if required, is applied before the first Interior Transmission Unit.

Bit Synchronization is applied between physically concatenated Interior Transmission Units.

The Network Protocol Data Unit may include an Internet header in addition to the required Intranet header.
This standard does not specify requirements for the Internet header.

FIGURE 3. Basic structure of DMTD protocol data units at the standard interface.

4.4 <u>DMTD capabilities</u>. The waveform and the protocols necessary to ensure end-to-end interoperability at the interface shall support the following capabilities:

    a.   Transmission in a half-duplex mode over radio, wireline, and satellite links;

    b.   Link encryption;

    c.   Point-to-point, multipoint, relay or broadcast connectivity between stations;

    d.   Asynchronous balanced mode of operation between two or more stations;

    e.   Network access control for network access management and collision avoidance;

    f.   Transport of bit-oriented or free-text (character-oriented) messages for information exchange in a variable message format over the link;

    g.   User data exchange using single or multiple frame packets;

    h.   Addressing conventions that support single, multiple, and global station broadcast addressing, as well as routing and relay;

    i.   Error control, for maintaining data integrity over the link, including frame check sequence (FCS), forward error correction (FEC), and time-dispersal coding (TDC);

    j.   Data-link frame acknowledgment, intranet frame acknowledgment and end-to-end, segment acknowledgment at the transport layer;

    k.   Intranet relay at the network layer; and

    l.   Topology update capability for the intranet.

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5. DETAILED REQUIREMENTS

5.1 <u>Physical layer</u>. The physical layer shall provide the control functions required to activate, maintain, and deactivate the connections between communications systems. This standard does not address the electrical or mechanical functions normally associated with physical layer protocols.

5.1.1 <u>Transmission channel interfaces</u>. The transmission channel interfaces specified below define the transmission envelope characteristics (signal waveform, transmission rates, and operating mode) authorized at the standard interface between a DMTD and the transmission channel. The transmission channel may consist of wireline, satellite, or radio links.

5.1.1.1 <u>Non-return-to-zero (NRZ) interface</u>. This interface shall be used primarily with digital transmission equipment. A non-return-to zero (NRZ) signal waveform shall be used for this interface.

5.1.1.1.1 <u>Waveform</u>. The NRZ unbalanced and balanced waveforms shall conform to paragraphs 5.1.1.7 and 5.2.1.7, respectively, of MIL-STD-188-114A.

5.1.1.1.2 <u>Transmission rates</u>. The output transmission rates of the NRZ interface shall be the following bit rates: 75, 150, 300, 600, 1200, 2400, 4800, 9600, and 16000 bits per second (bps).

5.1.1.1.3 <u>Operating mode</u>. The NRZ interface shall support half-duplex transmission.

5.1.1.2 <u>Frequency-shift keying (FSK) interface for voice frequency channels</u>. This interface may be used. It is primarily associated with analog single-channel [3-kilohertz (Khz)] radio equipment. The frequency-shift keying (FSK) data modem characteristics shall conform to paragraph 5.2.2 of MIL-STD-188-110.

5.1.1.2.1 <u>Waveform</u>. The FSK modulation waveform shall conform to paragraph 5.2.2.1 of MIL-STD-188-110. The characteristic frequencies, in hertz (Hz), for transmission rates of 600 bps or less, and 1200 bps, shall be as shown in Table I.

5.1.1.2.2 <u>Transmission rates</u>. Output transmission rates of the FSK interface shall be the following bit rates: 75, 150, 300, 600, and 1200 bps.

5.1.1.2.3 <u>Operating mode</u>. The FSK interface shall support half-duplex transmission.

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TABLE I. Characteristic frequencies of frequency-shift keying
interface for voice frequency channels.

PARAMETER	CHARACTERISTIC FREQUENCY (Hz)	
	600 bps or less	1200 bps
Mark Frequency	1300	1300
Space Frequency	1700	2100

5.1.1.3 Frequency-shift keying (FSK) interface for single-channel radio. This interface, used within DoD, may also be used for North Atlantic Treaty Organization (NATO) single-channel radio applications. The FSK interface data modem characteristics shall conform to paragraph 5.1 of MIL-STD-188-110.

5.1.1.3.1 Waveform. The FSK modulation waveform shall conform to paragraphs 5.1.1 and 5.1.2 of MIL-STD-188-110. The characteristic frequencies are specified in Table II.

TABLE II. Characteristic frequencies of frequency-shift keying
interface for single-channel radio.

PARAMETER	CHARACTERISTIC FREQUENCY (Hz)
Mark Frequency	1575
Space Frequency	2425

5.1.1.3.2 Transmission rates. Output transmission rates of the single-channel FSK interface shall be the following bit rates: 75, 150, 300, 600, and 1200 bps.

5.1.1.3.3 Operating mode. The single-channel FSK interface shall support half-duplex transmission.

5.1.1.4 Conditioned diphase (CDP) interface. This interface may be used. It is primarily associated with wideband wireline equipment.

5.1.1.4.1 Waveform. The CDP modulation waveform shall conform to paragraph 5.4.1.4 of MIL-STD-188-200. The unbalanced and balanced signal waveform shall conform to paragraphs 5.1.1.7 and 5.2.1.7, respectively, of MIL-STD-188-114.

5.1.1.4.2 Transmission rates. The output transmission rate of the CDP interface shall be 16 and 32 kilobits per second (kbps).

5.1.1.4.3 Operating mode. The CDP interface shall support half-duplex transmission.

5.1.1.5 Differential phase-shift keying (DPSK) interface for voice frequency channels. This interface may be used. It is primarily associated with analog (nominal 4-Khz voice frequency) wireline and radio equipment. Differential phase-shift keying (DPSK) modulation data modem (2400 bps) and phase-shift keying (PSK) modulation data modem (1200 bps) characteristics shall conform to the applicable requirements of MIL-STD-188-110.

5.1.1.5.1 Waveform. The DPSK modulation waveform shall conform to Appendix A of MIL-STD-188-110. The PSK modulation waveform shall conform to paragraph 5.3 of MIL-STD-188-110.

5.1.1.5.2 Transmission rates. The output transmission rate of the DPSK and PSK interfaces shall be 2400 and 1200 bps, respectively.

5.1.1.5.3 Operating mode. The DPSK and PSK interfaces shall support half-duplex transmission.

5.1.1.6 Packet mode interface. This interface shall use a modified CCITT X.21 half-duplex synchronous interface for transferring digital data across the interface between data terminal equipment (DTE) and data circuit-terminating equipment (DCE). The packet interface shall be a modified CCITT X.21 interface with a CCITT V.10 electrical circuit between a DTE (DMTD or C^4I system) and the DCE.

5.1.1.6.1 Waveform. The electrical characteristics of the packet mode interface shall be identical to CCITT V.10 for interfaces to voice band modems.

5.1.1.6.2 Transmission rates. The DTE device shall be required to accept signal timing from the DCE (radio) at 16 Kbps. The DTE shall be required to synchronize to the DCE signal timing and accept data at the supplied signaling timing rate. In the packet mode, the radio provides signal timing to support 16 Kbps data transfers between the radio and the DTE.

5.1.1.6.3 Operating mode. The packet mode interface shall support half-duplex transmission.

5.1.1.7 Amplitude shifting keying (ASK) interface. This interface is used primarily with analog voice grade radios to transmit digital data.

5.1.1.7.1 Waveform. The ASK waveform is a band limited NRZ waveform with average white Gaussian noise added to it. The ASK signal shall be a bipolar signal nominally centered around ground. However due to the radio automatic gain control performance, the ASK signal may have a direct current (DC) component. The ASK signal-to-noise ratio shall be in the range of 0 to 12 decibels (dB). The ASK signal shall be demodulated using an optimal bit synchronizer with a bit error rate performance of 1.5 dB from theoretical.

5.1.1.7.2 Transmission rates. The output transmission rates of the ASK interface shall be the following bit rates: 2400, 4800, 9600 and 16000 bits per second.

5.1.1.7.3 Operating mode. The ASK interfaces shall support half-duplex transmission.

5.2 Physical-layer protocol.

5.2.1 Physical-layer protocol data unit. The transmission frame shall be the basic protocol data unit (PDU) of the physical layer and shall be as shown in Figure 4. Figure 4a presents the transmission frame structure for traditional COMSEC (backward-compatible mode). Traditional COMSEC is used in this document to denote systems with the COMSEC equipment placed external to the C^{4}I system. Figure 4b presents the transmission frame structure with COMSEC embedded in the C^{4}I system (embedded mode). Figure 4c presents the transmission frame structure without COMSEC.

COMSEC PREAMBLE	PHASING	TRANSMISSION SYNCHRONIZATION	DATA FIELD	COMSEC POSTAMBLE

Figure 4a. Transmission frame structure with external COMSEC.

PHASING	TRANSMISSION SYNCHRONIZATION WITH COMSEC MESSAGE INDICATOR	DATA FIELD	COMSEC POSTAMBLE

Figure 4b. Transmission frame structure with embeddedl COMSEC.

PHASING	TRANSMISSION SYNCHRONIZATION	DATA FIELD

Figure 4c. Transmission frame structure with no COMSEC.

FIGURE 4. Transmission frame structure.

5.2.1.1 Communications security preamble and postamble. These fields are present when link encryption is used. The COMSEC preamble field shall be used to achieve cryptographic synchronization over the link. The COMSEC postamble field shall be used to provide an end-of-transmission flag to the COMSEC equipment at the receiving station. These fields and the COMSEC synchronization process are described in Appendix D (D5.1.1 and D5.1.4, respectively).

5.2.1.2 Phasing.   Phasing shall be a string of alternating ones and zeros, beginning with a one, sent by the DTE. For Packet Mode interfaces, the length of this field shall be 0. Phasing is described in C3.2b.

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5.2.1.3 <u>Transmission synchronization field</u>. The structure of the transmission synchronization field is dependent on the mode of operation. The three modes are Asynchronous for use with DCEs that present modulated data without a clock, Synchronous for use with DCEs that present a clock and data interface and Packet for use with DCEs that require no frame synchronization. The structures for Asynchronous and Synchronous modes are shown in Figure 5. The structure for the Packet Mode is described in 5.2.1.3.3.
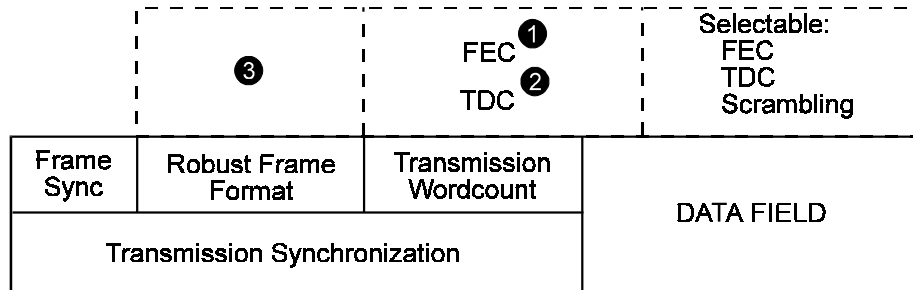
Figure 5a. With external COMSEC or No COMSEC.
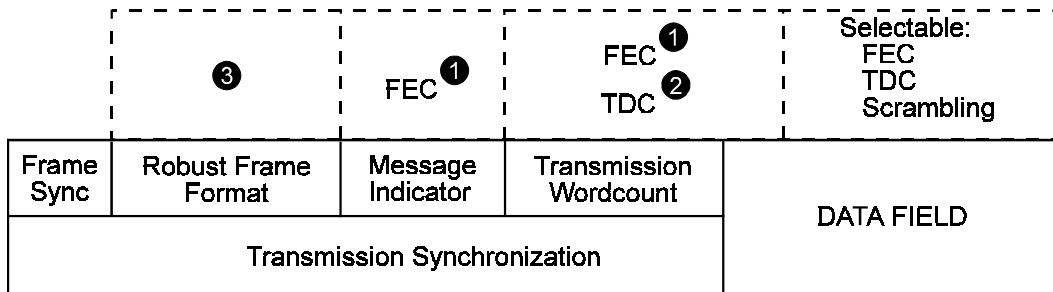
Figure 5b. With Embedded COMSEC.

Notes:
❶ Golay FEC is applied to the Transmission Wordcount, message Indicator and Transmission Header fields in Asynchronous and Synchronous Modes. (The Transmission Header is the leading portion of the Data Field as described in 5.3.1.)

❷ TDC is applied to the Transmission Wordcount and Transmission Header fields in Asynchronous and Synchronous Modes. (The Transmission header is the leading portion of the Data Field as described in 5.3.1.)

❸ The Robust Frame Format subfield is optional and is used only when implementing the Robust Communications Protocol described in Appendix J.

FIGURE 5. <u>Transmission synchronization field</u>.
(Synchronous and Asynchronous Mode)

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5.2.1.3.1 <u>Asynchronous mode transmission synchronization field</u>. The Asynchronous Transmission Synchronization field shall be composed of the following:

      a.   Frame Synchronization

      b.   Robust Frame Format (Optional)

      c.   Message Indicator (embedded COMSEC only)

      d.   Transmission Word Count

5.2.1.3.1.1 <u>Frame synchronization subfield</u>. This subfield shall consist of the fixed 64-bit synchronization pattern shown in Figure 6 or Figure 7. The receiver shall correlate for the frame synchronization pattern. A pattern shall be detected if 13 or fewer bits are in error with non-inverted or inverted data. If the correlation detects an inverted synchronization pattern, all received data shall be inverted before any other received processing is performed. If the frame synchronization subfield shown in Figure 6 is detected before the robust frame synchronization subfield shown in Figure 7, the receiver shall assume the optional robust processing is not requested for this transmission.

LSB	MSB
0110010011110010111100101001011010010000010111101010110111011001	
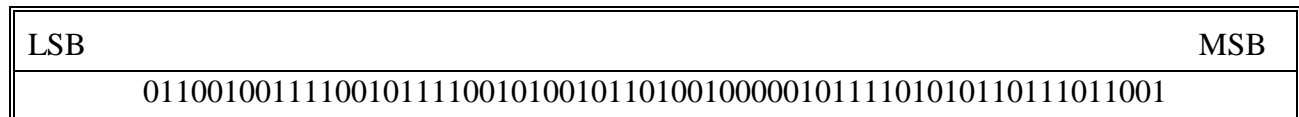
FIGURE 6. <u>Frame synchronization subfield</u>.

If the robust frame synchronization pattern shown in Figure 7 is detected, the robust frame format subfield shall be decoded to determine what physical level processing is required for data reception. If the robust frame synchronization pattern shown in Figure 7 is used, the frame synchronization pattern shown in Figure 6 shall not be used.

LSB	MSB
0100100111001100111011011011111110000001001101101010101111000111000	
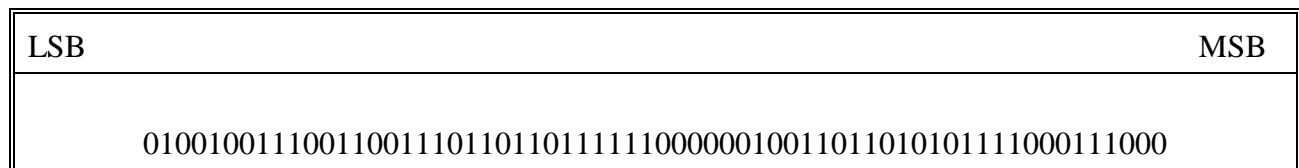
FIGURE 7. <u>Robust frame synchronization subfield</u>.

5.2.1.3.1.2 <u>Robust frame format subfield</u>. The robust frame subfield is an optional field that is used only with the robust frame synchronization subfield shown in Figure 7. The robust frame

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format subfield is a seven bit field which specifies the format of the transmitted frame. The robust frame format subfield shall be formatted with multi-dwell majority vote 3 out of 5 Bose-Chaudhuri-Hocquenghem (BCH) (15,7) coding and no scrambling or convolutional encoding. The bits are defined in Tables III, IV and V.

TABLE III. Robust frame format.

Bit(s)	Fields
0 (LSB)	Multi-Dwell Flag
1	Scrambling Flag
2, 3, 4	Multi-Dwell Transmission Format
5,6	Convolutional Coding Constraint Length

TABLE IV. Multi-dwell transmission format.
(The Least Significant Bit is shown on the Left)

000	Single BCH(15,7) word 32 BIT SOP, 11 64-bit segments per packet
100	Majority Vote 2 out of 3 BCH(15,7) word 64 BIT SOP, 13 64-bit segments per packet
010	Majority Vote 3 out of 5 BCH(15,7) word 64 BIT SOP, 13 64-bit segments per packet
110	Majority Vote 3 out of 5 BCH(15,7) word 64 BIT SOP, 6 64-bit segments per packet

TABLE V. Convolutional coding constraint length codes.
(The Least Significant Bit is shown on the Left)

00	Constraint Length 3
10	Constraint Length 5
01	Constraint Length 7
11	Convolutional Coding Disabled

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5.2.1.3.1.3 <u>Message indicator</u>. The message indicator field is contained within the transmission synchronization field only when COMSEC is embedded in the host. The message indicator field is defined in Appendix D (D5.1.1.3 and D5.2.3). Golay forward error correction (FEC) is applied to the TWC, Message Indicator (with embedded COMSEC) and Transmission Header in Asynchronous and Synchronous Modes.

5.2.1.3.1.4 <u>Transmission wordcount (TWC) subfield</u>. The TWC is a 12-bit value calculated by the transmitting station to inform the receiving station of the number of 16-bit words (after any appropriate FEC encoding, TDC fill or zero bit insertion) that form the data field(s) of the transmission frame. The maximum TWC is 4095 (2^{12}-1). The value provided by the 12 information bits is binary-encoded. The maximum number of words is dependent on the maximum number of bits allowed in the data field of a transmission frame. It is possible that the number of bits in the data field will not be evenly divisible by 16. In that case, the word count shall be rounded to the next higher integer. TDC is applied to the TWC and Transmission Header in Asynchronous and Synchronous Modes. Golay FEC is applied to the TWC, Message Indicator (with embedded COMSEC) and Transmission Header in Asynchronous and Synchronous Modes.

5.2.1.3.2 <u>Synchronous mode transmission synchronization field</u>. The Synchronous Transmission Synchronization field shall be composed of the following:

      a.   Frame Synchronization

      b.   Robust Frame Format (optional)

      c.   Message Indicator (embedded COMSEC only)

      d.   Transmission Word Count

5.2.1.3.2.1 <u>Frame synchronization subfield</u>. The Synchronous Mode Frame Synchronization subfield is the same as the Asynchronous Mode Frame Synchronization subfield defined in 5.2.1.3.1.1 and shown in Figures 6 and 7.

5.2.1.3.2.2 <u>Robust frame format subfield</u>. The Synchronous Mode Robust Frame Format subfield is the same as the Asynchronous Mode Robust Frame Format subfield defined in 5.2.1.3.1.2.

5.2.1.3.2.3 <u>Message indicator</u>. The format of the Synchronous Mode Message Indicator field is the same as for the Asynchronous Mode Message Indicator field defined in 5.2.1.3.1.3.

5.2.1.3.2.4 <u>Transmission wordcount</u>. The Synchronous Mode TWC format is the same as the Asynchronous Mode TWC defined in 5.2.1.3.1.4.

5.2.1.3.3 <u>Packet mode transmission synchronization field</u>. This field consists of at least 4 HDLC flags corresponding to the following bit pattern shown in Figure 8.

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LSB	MSB
0111111001111110011111001111110	
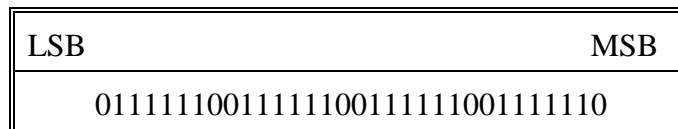
FIGURE 8. Packet mode transmission synchronization field.

5.2.1.3.4 Multi-dwell protocol. The multi-dwell protocol provides the capability to transmit data over frequency hopping radios without internal buffering. The multi-dwell protocol is described in Appendix J.

    a.   The multi-dwell start of packet (SOP) header size and segment count redundancy are configured depending upon the channel environment and are not changed on a per transmission basis.

    b.   The upper layer indicates the size of the transmission in the PL-Unitdata Request data length. The physical layer shall use the data length information to determine the most efficient multi-dwell parameters to use for data transmission. The optional multi-dwell segment count may be used by the upper layer to override the automatic determination of the multi-dwell transmission parameters made by the physical layer. For a multi-dwell reception, the upper layer will use the timing of the transition of the PL-Status Indication Network Activity from "busy with data" to "clear" to indicate the time of reception of the last bit of data.

5.2.1.4 Data field. The data field shall contain the string of bits created by the data-link layer following the procedures for framing, zero bit insertion, concatenation, FEC, TDC, and scrambling. FEC, TDC and Scrambling are not applied when Packet Mode is used.

5.2.1.5 Bit synchronization field. This field shall be used to provide the receiver a signal for re-establishing bit synchronization. Bit synchronization is used only between physically concatenated frames in Asynchronous Mode. The bit synchronization field shall be a 64-bit pattern that consists of alternating ones and zeros, beginning with a one.

5.2.2 Net access control related indications.

    a.   The net busy information is conveyed to the upper layer protocol (data link) through a status indication. Upon detection of a net busy, the net busy indicator shall be set. The net busy sensing indicator shall be reset when neither digital data nor voice is detected by the net busy sensing function. Appendix C (C4.1) describes the net busy sensing function.

    b.   The net access control algorithm described in Appendix C needs the transmitter to know when the last bit of data is transmitted, and the receiver to know when the last bit of data is received.

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5.2.3 <u>Physical-layer to upper-layer interactions</u>. At least three primitives are used to pass information for the sending and receiving of data across the upper layer boundary.

a. Requests for transmission of data are sent by the upper layer, using the physical layer (PL) Unitdata Request primitive with the following parameter:

  PL-Unitdata Request
   Data/Data length
   FEC/TDC/Scrambling
    No FEC, No TDC, No Scrambling
    No FEC, No TDC, Scrambling
    FEC, No TDC, No Scrambling
    FEC, No TDC, Scrambling
    FEC, TDC, No Scrambling
    FEC, TDC, Scrambling
   Multi-dwell transmission format segment count
    6 segments per packet
    11 segments per packet
    13 segments per packet

b. Indication of data received is provided to the upper layer through the Unitdata Indication primitive with the following parameter:

  PL-Unitdata Indication
   Data/Data length
   FEC/TDC/Scrambling
    No FEC, No TDC, No Scrambling
    No FEC, No TDC, Scrambling
    FEC, No TDC, No Scrambling
    FEC, No TDC, Scrambling
    FEC, TDC, No Scrambling
    FEC, TDC, Scrambling
   Multi-dwell transmission format segment count
    6 segments per packet
    11 segments per packet
    13 segments per packet

c. Net activity status information is provided to the upper layer through a Status Indication with the following parameters:

  PL-Status Indication
   Net activity
    net clear
    net busy

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busy with/data
busy with/voice
Transmission Status
transmit complete/idle
in-process
transmit aborted

5.3 Data-link layer. The data-link layer shall provide the control functions to ensure the transfer of information over established physical paths, to provide framing requirements for data, and to provide for error control. Zero bit insertion is applied to the Transmission Header and Data Link Frame.

5.3.1 Transmission header. The Transmission Header is sent before each data field transmission. The Transmission Header consists of a two-octet Transmission Information field, a 32-bit FCS, in accordance with paragraph 5.3.4.2.5, and is bounded by Flags in accordance with paragraph 5.3.4.2.1. The Transmission Information field contains Selection bits and a Transmission Queue subfield which indicates the transmitting station queue length. The Transmission Header format is shown in Figure 9. Golay FEC and TDC are applied to the entire Transmission Header (except when the Packet Mode Interface described in paragraph 5.1.1.6 is used at the Physical Layer), including leading and trailing flags, Message Indicator (with embedded COMSEC) and TWC. The TWC, Message Indicator and transmission header shall have Golay FEC applied when operating in the Asynchronous and Synchronous modes. TDC (7x24) bit interleaving shall be applied in unison with the FEC on the TWC and transmission header. The data shall be formatted into a TDC block composed of seven (7) 24-bit Golay (24,12) codewords in a manner analogous to 5.3.14.3. There are 168 FEC-encoded bits with this TDC.
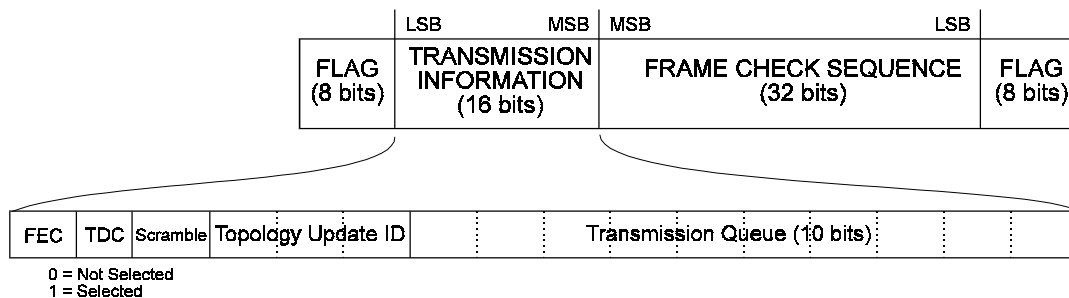
FIGURE 9. Transmission header.

5.3.1.1 Selection bits. The first three bits of the Transmission Information field selects FEC, TDC and Scrambling, respectively, on or off for the remainder of the physical layer data field. A zero indicates "off" and a one indicates "on" in these bit positions. Regardless of the setting of these three bits, Golay FEC/TDC is applied and Scrambling is not applied to the entire Transmission Header. Scrambling, if used, shall be applied before any FEC and TDC is applied.

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FEC, TDC and scrambling are not applied when the Packet Mode Interface described in paragraph 5.1.1.6 is used at the Physical Layer.

5.3.1.2 <u>Topology update identifier</u>. This subfield shall contain the least significant three bits of the Topology Update ID used in the most recent Topology Update message (see 5.4.1.2). If no Topology Update messages have been sent, this subfield shall be all zeros.

5.3.1.3 <u>Transmission queue subfield</u>. This subfield is used to support the radio embedded net access delay (RE-NAD) process and the deterministic adaptable priority net access delay (DAP-NAD) process. The entire field is 10-bits long with the first two bits ('T'-bits) indicating how the rest of the subfield is interpreted. The format of the transmission queue subfield is shown in Figure 10.

5.3.1.3.1 <u>T-bits</u>. The two left-most bits in the transmission queue subfield are the T-bits. The bit sequence interpretations are indicated in Figure 10. The transmission queue subfield has a variable format depending on which of the following uses are intended:

   a.   T-bits = 00   The transmission queue subfield does not contain information and is ignored.

   b.   T-bits = 01   The transmission queue subfield is used in conjunction with RE-NAD. This subfield contains queue precedence (in bit positions 2-3) and queue length (bit positions 4-7). Bit positions 8 and 9 are spare and ignored.

   c.   T-bits = 10   The transmission queue subfield is used in conjunction with DAP-NAD. This subfield contains Data Link Precedence (in bit positions 2 and 3) and First Subscriber Number (in bit positions 4-9).

   d.   T-bits =11   This bit sequence is INVALID and shall be ignored. Data link frame(s) after this header shall be processed normally.

T-Bits

0	1	2	3	4	5	6	7	8	9
0	0	Transmission Queue Subfield Ignored							
0	1	Queue Prec.		Queue Length				spare	
1	0	Data Link Prec.		First Subscriber Number					
1	1	Invalid/Ignored							

FIGURE 10. <u>Transmission queue subfield formats.</u>

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5.3.1.3.2 <u>Queue precedence</u>. The queue precedence component indicates the highest precedence level of information type frames in the queue.

The precedence levels and bit sequences are:

Precedence	Bit 2	Bit 3	Value
Urgent	0	0	0
Priority	1	0	1
Routine	0	1	2
Reserved	1	1	3

5.3.1.3.3 <u>Queue length</u>. The queue length component indicates the number of concatenated frame sequences required to transmit all of the highest precedence messages in the transmission queue at the time the transmission was created. This number may be used by receiving station to calculate the average network member's queue length. This average is used in calculation of the continuous scheduler for the Radio Embedded channel access procedure (C4.4.4).

5.3.1.3.4 <u>Data link precedence</u>. This subfield consists of two bits and contains a value that indicates the highest precedence of any message that is contained in the physical frame. It shall contain the value 0 if an urgent message is in the frame, 1 if a priority but no urgent message is in the frame and 2 if neither an urgent nor priority message is in the frame. The variable NP in the equations defined in C4.4.5.2 is set equal to the contents of the highest precedence Data Link precedence field in any (possibly concatenated) physical frame contained in the most recent reception.

The precedence levels and bit sequences for the Data Link precedence field are:

Precedence	Bit 2	Bit 3	Value
Urgent	0	0	0
Priority	1	0	1
Routine	0	1	2
Undefined	1	1	3

Undefined precedence values shall be handled as routine.

5.3.1.3.5 <u>First subscriber number</u>. This subfield consists of 6 bits and designates the number of the subscriber that is to have the first net access opportunity at the next net access period (the one immediately following this transmission). The number of the subscriber that has the first net access opportunity is the variable FSN in the equations defined in Appendix C (C4.4.5.2).

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Bit coding for First Subscriber Number is:

1st Subscriber #	Bit: 4--->9
Illegal	000000
1	100000
2	010000
.	..
.	..
.	..
63	111111

5.3.2 <u>Net access control</u>. The presence of multiple subscribers on a single communications net requires a method of controlling the transmission opportunities for each subscriber. To minimize conflicts, the net busy sensing function and net access control (NAC) procedures regulate transmission opportunities for all participants on the net. Random - Net Access Delay (R-NAD), Hybrid - Net Access Delay (H-NAD), Prioritized - Net Access Delay (P-NAD), Radio Embedded Net Access Delay (RE-NAD) and Deterministic Adaptable Priority - Net Access Delay (DAP-NAD) are the authorized NAC procedures at this interface. Appendix C defines the NAC parameters for R-NAD, H-NAD, P-NAD, DAP-NAD, and RE-NAD.

5.3.2.1 <u>Scheduler</u>. When the net access is embedded in the radio, a scheduler may be implemented in the DTE or communications processor to organize radio access throughout the network. The scheduler is used to provide a random distribution of timing for channel requests. When a station has data to transmit, it shall calculate the scheduler timer as indicated in Appendix C (C4.4.4.1). When this timer expires, the link layer shall first determine that the previous frame concatenation was transmitted by the physical layer. If the frame concatenation was not transmitted, the link layer shall request its transmission. If a higher precedence individual frame becomes available for transmission, the concatenated frames shall be re-built to include the higher precedence frame. If the previous frame concatenation was transmitted, the link layer shall build a new frame concatenation. This frame concatenation shall then be passed to the physical layer for transmission. Both randomized and immediate scheduler modes are specified in Appendix C (C4.4.4.1.1 and C4.4.4.1.5, respectively).

5.3.3 <u>Types of procedures</u>. Four types of operation for data communication between systems are defined to provide basic connectionless and connection mode operations:

> Type 1 - Unacknowledged Connectionless Operation
> Type 2 - Connection-mode Operation
> Type 3 - Acknowledged Connectionless Operation
> Type 4 - Decoupled Acknowledged Connectionless Operation

Types and services 1 through 3 are based on ISO 8802-2. The Type 1 and Type 3 connectionless operations are mandatory for implementation in all systems. The Type 2 connection mode is optional for this interface. The Type 4 connectionless mode (decoupled ACK) is optional.

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Estelle language formal specifications of these four types of data link operation are available via the CNR Implementation Working Group World Wide Web page: http://www-cnrwg.itsi.disa.mil.

5.3.3.1 <u>Type 1 operation</u>. For the purpose of this protocol, Type 1 operation will designate both of the ISO 8802-2 connectionless operations: Type 3 (acknowledged) and Type 1 (unacknowledged).

5.3.3.2 <u>Type 2 operation</u>. With Type 2 operation, a data-link connection shall be established between two systems prior to any exchange of information bearing PDUs. For efficiency at system startup, connections may be assumed to exist with all other stations in the network; and the system may depend on information transfer phase procedures to resolve error conditions. To guarantee a reliable (i.e., no loss) service, connections should be explicitly established, not assumed to exist. The connection normally shall remain open until a station leaves the net. The normal communications cycle between Type 2 systems shall consist of transferring PDUs from the source to the destination, and acknowledging receipt of these PDUs in the opposite direction.

5.3.3.3 <u>Type 3 operation</u>. For the purpose of this protocol, Type 3 operation is included in Type 1 operation.

5.3.3.4 <u>Type 4 operation</u>. With Type 4 operation, acknowledgments are decoupled from the original Decoupled Information Acknowledgment (DIA) PDU, and DIA PDUs contain a non-modulus identification number assigned by the originator.

5.3.3.5 <u>Station class</u>. Four station classes define the data link procedures supported by a system:

    Station Class A - Supports Types 1 and 3; not Types 2 and 4
    Station Class B - Supports Types 1, 2 and 3; not Type 4
    Station Class C - Supports Types 1, 3 and 4; not Type 2
    Station Class D - Supports Types 1, 2, 3 and 4.

5.3.4 <u>Data-link frame</u>. The data-link frame shall be the basic protocol data unit (PDU) of the link layer. The transmission header is not a PDU.

5.3.4.1 <u>Types of frames</u>. Three types of frames convey data over the data-link: an unnumbered frame (U PDUs), an information frame (I PDUs) and a supervisory frame (S PDUs).

5.3.4.1.1 <u>Unnumbered frame</u>. The U PDUs shall be used for Type 1, Type 2 and Type 4 operations. They provide connectionless information transfer for Types 1 and 4 operations. PDUs provide acknowledgment, and station identification/status information for Type 1 operations. They also provide data-link control functions for Type 1 through 4 operations.

5.3.4.1.2 <u>Information frame</u>. The I PDUs are used for information transfer in Type 2 operations only. They convey user data or message traffic across a link. The I PDUs are not used in Type 1 or Type 4 operations.

5.3.4.1.3 <u>Supervisory frame</u>. The S PDUs are optional and are used for data-link supervisory control functions and to acknowledge received I PDUs in Type 2 operations. Additionally, the Type 4 Decoupled Receive Ready (DRR) response S PDU is used to acknowledge Type 4 DIA PDUs. The S PDUs are not used in Type 1 operations.

5.3.4.2 <u>Data-link frame structure</u>. The basic elements of the data-link frame shall be the opening flag sequence, the address field, the control field, the information field, the FCS, and the closing flag sequence. Each Type 1, Type 2 and Type 4 data-link frame shall be structured as shown in the data link frame portion of Figure 11.
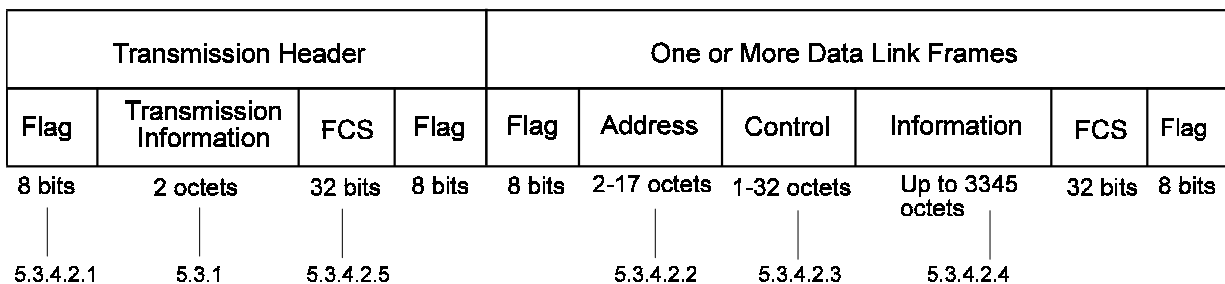
FIGURE 11. <u>Data link frame structure and placement</u>.

5.3.4.2.1 <u>Flag sequence</u>. All frames shall start and end with the 8-bit flag sequence of one 0 bit, six 1 bits, and one 0 bit (01111110). The flag shall be used for data-link frame synchronization.

5.3.4.2.2 <u>Address fields</u>. These fields shall identify the link addresses of the source and destinations.

5.3.4.2.2.1 <u>Address format</u>. Each address in the address fields shall consist of a single octet. The source address octet shall consist of a command/response (C/R) designation bit [the least significant bit (LSB)] followed by a 7-bit address representing the source. Each destination octet shall consist of an extension bit (the LSB) followed by the 7-bit destination address. The destination address uses a modification of the High-Level Data-link Control (HDLC) extended addressing format. The destination address shall be extended by setting the extension bit of a destination address octet to 0, indicating that the following octet is another destination address. The destination address field shall be terminated by an octet that has the extension bit set to 1. The destination address field shall be extendible from 1 address octet to 16 address octets. The format of the address fields shall be as shown in Figure 12.

5.3.4.2.2.2 <u>Addressing convention</u>. The following addressing conventions shall be implemented in the 7 address bits of each address octet. Address allocations, as shown in Figure 13, are divided among five address types: individual, group, global, special, and reserved.

NOTE: Source and destination addresses are assigned by an administrative authority.

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5.3.4.2.2.2.1 Source and destination.

5.3.4.2.2.2.1.1 Source address. The source address is either an individual or special (Net Control or Net Entry) address and is always the first address. Its legal values range from 1 to 95. The source address has two parts: the C/R designation bit (bit 1, LSB) and the actual 7-bit address value. The C/R designation bit shall be set to 0 for commands and 1 for responses.

LSB							MSB	
1	2	3	4	5	6	7	8	
0/1	X	X	X	X	X	X	X	SOURCE Octet (1 = response; 0 = command)
0	X	X	X	X	X	X	X	DESTINATION 1 Octet

. ..

. ..

. ..

1	X	X	X	X	X	X	X	DESTINATION M Octet where M ≤ 16
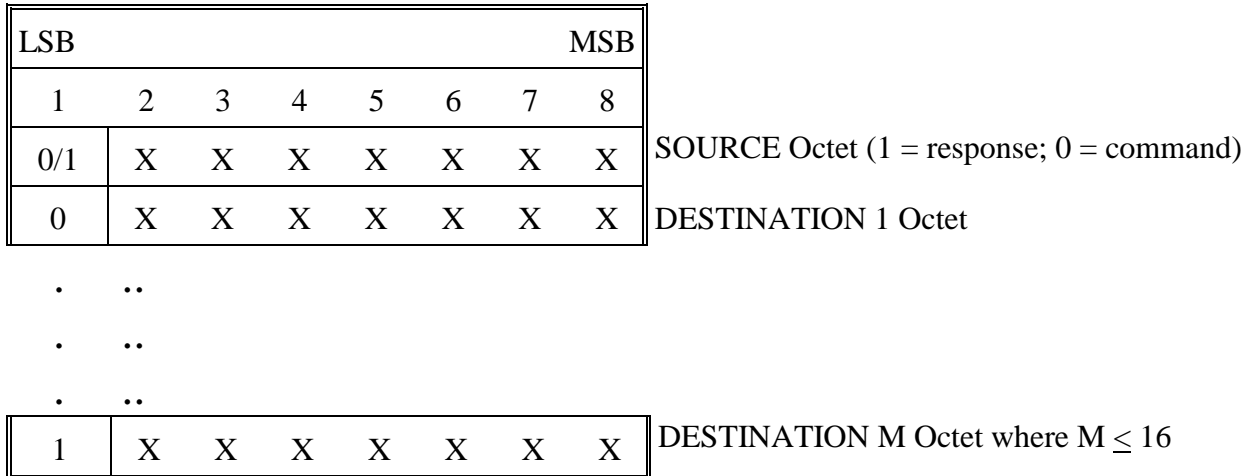
FIGURE 12. Extended address field format.

LSB							MSB		
1	1	1	1	1	1	1	1	127	Global Multicast Address
X	X	X	X	X	X	1	1	96-126	Group Multicast Addresses
X	X	X	X	X	X	X	X	4-95	Individual Addresses
X	1	1	0	0	0	0	0	3	Special (Immediate Retransmission)
X	0	1	0	0	0	0	0	2	Special (Net Control) Address
X	1	0	0	0	0	0	0	1	Special (Net Entry) Address
X	0	0	0	0	0	0	0	0	Reserved Address

FIGURE 13. Address allocation.

5.3.4.2.2.2.1.2 <u>Destination address(es)</u>. The second through seventeenth address bytes are labeled destination addresses, which may be global, group, individual, or special addresses. Each destination address is contained in an 8-bit field, which has two parts: the extension bit (bit 1, LSB) and the actual 7-bit address value. An extension bit set to 0 indicates that 1 or more addresses follow. An extension bit set to 1 indicates the last address of the address string has been reached.

5.3.4.2.2.2.2 <u>Types of addresses</u>. The following paragraphs describe the five types of addresses and how they shall be used.

5.3.4.2.2.2.2.1 <u>Reserved address</u>. Address 0 is labeled a reserved address. A station receiving a value of 0 in the destination address field shall ignore the address and continue processing any remaining addresses.

5.3.4.2.2.2.2.2 <u>Special addresses</u>. Addresses 1, 2 and 3 are labeled special addresses. Addresses 1 and 2 are provided as network control and unit entry addresses for units entering a new network without knowledge of actual addresses being used. These special addresses are used as described in Appendix E (E5.1). The special address 3 is used for Type 1 acknowledged transmissions which require an immediate retransmission capability.

5.3.4.2.2.2.2.3 <u>Individual addresses</u>. Individual addresses uniquely identify a single station on a broadcast subnetwork. Individual addresses shall be assigned within the address range 4 to 95. Stations shall be capable of sending and receiving 1 to 16 individual destination addresses in a single data-link frame. Sending stations shall not use any individual address more than once in a data link frame. When individual address(es) are present, a receiving station shall receive all addresses, search for its unique individual address, and follow the media access procedures described in Appendix C.

5.3.4.2.2.2.2.4 <u>Group multicast addresses</u>. Group multicast addressing, used when broadcasting messages to multiple (but not all) stations on a broadcast subnetwork, may be implemented. The valid address range shall be 96 to 126. Assignment of membership to (or deletion from) a group is outside the scope of this protocol. While the use of link group multicast addresses is optional, all stations shall be capable of recognizing received group addresses. If a receiving station does not implement group addressing procedures, it shall still process all received addresses, but ignore the group addresses (that is, recognize range 96 to 126 as group addresses). When group addressing is implemented, a station shall be capable of sending and receiving 1 to 16 destination group addresses. Coupled data link acknowledgment of group multicast addresses using the F-bit shall not be allowed. An uncoupled TEST response PDU with its F-bit set to zero shall be sent in response to a TEST command PDU addressed to a group multicast address when the receiving station is a member of the specified group.

5.3.4.2.2.2.2.5 <u>Individual, special and multicast addresses mixed</u>. A station that optionally implements multicast (group and global) addressing shall also be capable of sending and receiving multicast, special and individual addresses "mixed" in a destination address subfield. All stations shall be capable of receiving mixed addresses. The reception and acknowledgment

procedures stated in this paragraph shall be valid even for stations that do not implement multicast addressing procedures.

  a. The total number of destination addresses shall not exceed 16.

  b. Individual and special addresses may be mixed in any order.

  c. All individual and special addresses shall precede multicast addresses.

  d. The special address 3, if used, shall follow all individual, reserved, and other special addresses. It may precede group or global addresses, but shall not precede individual, reserved or other special addresses.

  e. Only one type of multicast (group or global) shall be mixed in a destination address subfield.

  f. If multicast, special and individual addresses are mixed, only the individual and special addresses are acknowledged when indicated.

  g. Multicast addresses shall not be acknowledged but a data link response (using a TEST Response PDU) is allowed in the case where a TEST message is received with a multicast address in the destination field and the poll bit is set to 0.

  h. A station that optionally implements multicast (group and global) addressing shall also be capable of sending and receiving multicast, special and individual addresses "mixed" in a destination subfield.

5.3.4.2.2.2.2.6 <u>Global multicast addressing</u>. Global multicast addressing, used when broadcasting messages to all systems on a broadcast subnetwork, shall be implemented through the unique bit pattern 1111111 (127). If the global address is used, it shall be the only multicast destination address, but individual addresses are allowed with the global address. All broadcast stations shall be capable of receiving and sending this address, and all stations will process the information contained within the frame. Data-link acknowledgment of the global address shall not be allowed, although the TEST response PDU is allowed in the case where a TEST message is received with the global address in the destination field and the poll bit is set to 0. Coupled data link acknowledgment of the global address using the F-bit shall not be allowed. An uncoupled TEST response PDU with its F-bit set to zero shall be sent in response to a TEST command PDU addressed to the global address.

5.3.4.2.2.3 <u>Mapping</u>. A link address is a point of attachment to a broadcast network. The upper-layer protocol is responsible for mapping one or more upper-layer addresses to a data-link address. Multiple upper-layer addresses may map to one or more group or individual addresses.

5.3.4.2.3 <u>Control field</u>. The control field indicates the type of PDU and the response requirements and connection information about the PDU being transmitted over the data link. A summary of

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the formats and bit patterns (showing LSB as the left most bit) for Types 1, 2 and 4 is shown in Tables VI, VII and VIII, respectively. Figure 14 illustrates the data-link PDU control field formats.

TABLE VI. Type 1 PDU formats.

COMMANDS/ RESPONSES	ADDRESS FIELD	CONTROL FIELD The left-most bit is the least significant bit.	INFORMATION FIELD
UI COMMAND PDU ACKNOWLEDGMENT REQUIRED	Contains the source address and up to 16 individual, special, group or global link addresses of agencies for which the message is intended.	Bit pattern = 11001000 identifies this frame as a UI PDU requiring acknowledgment.	Contains data from the upper protocol layer.
ACKNOWLEDGMENT NOT REQUIRED	Contains the source address and up to 16 destination (individual, special, group and/or global mixed) addresses of agencies for which the message is intended.	Bit pattern = 11000000 identifies this frame as a UI PDU not requiring acknowledgment.	Contains data from the upper protocol layer.
Status PDU UNNUMBERED RECEIVE READY (URR) COMMAND	Contains source address, and individual, group, or global addresses.	Bit pattern = 11000100 indicating receive ready command.	No information field allowed.
UNNUMBERED RECEIVE READY (URR) RESPONSE	Contains source address and the address contained in the source subfield of a received UI PDU, which this frame acknowledges.	Bit pattern = 11001100 indicating last UI PDU is acknowledged.	No information field allowed.
UNNUMBERED RECEIVE NOT READY (URNR) COMMAND	Contains source address and individual, group, or global addresses of agencies that are to stop transmitting I and UI PDUs to the agency generating this frame.	Bit pattern = 11010000 indicating receive not ready command.	No information field allowed.
UNNUMBERED RECEIVE NOT READY (URNR) RESPONSE	Contains source address and destination to which this response is being sent.	Bit pattern = 11011000 indicating receive not ready response.	No information field allowed.
TEST COMMAND	Contains source address and the individual, group, or global address of agencies that are to respond.	Bit pattern = 1100X111	Information field optional.
TEST RESPONSE	Contains source address and destination to which this response is being sent.	Bit pattern = 1100X111	Information field optional.

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TABLE VII. Type 2 PDU formats.

COMMANDS/ RESPONSES	ADDRESS FIELD	CONTROL FIELD The left-most bit is the least significant bit.	INFORMATION FIELD
U PDUs			
UNNUMBERED ACKNOWLEDGMENT (UA) RESPONSE	Contains source address and up to 16 individual link addresses of stations to receive this PDU.	Bit pattern = 1100X110	No information field allowed.
SET ASYNCHRONOUS BALANCED MODE EXTENDED (SABME) COMMAND	Contains source address and up to 16 individual link addresses of stations to receive this PDU.	Bit pattern = 1111X100	No information field allowed.
RESET (RSET) COMMAND	Contains source address and up to 16 individual link addresses of stations to receive this PDU.	Bit pattern = 1111X001	No information field allowed.
FRAME REJECT (FRMR) RESPONSE	Contains source address and up to 16 individual link addresses of stations to receive this PDU.	Bit pattern = 1110X001	See Figure 19.
DISCONNECT MODE (DM) RESPONSE	Contains source address and up to 16 individual link addresses of stations to receive this PDU.	Bit pattern = 1111X000	No information field allowed.
DISCONNECT (DISC) COMMAND	Contains source address and up to 16 individual destination addresses.	Bit pattern = 1100X010	No information field allowed.
I PDU			
ACKNOWLEDGMENT OR OTHER APPROPRIATE RESPONSE REQUIRED	Contains source address and up to 16 individual and/or group or global addresses of agencies for which the message is intended.	Bit pattern = 0SSSSSSSXRRRRRRR. Identifies this frame as an I PDU.	Contains data from the upper layer protocol.

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TABLE VII. Type 2 PDU formats (Continued).

COMMANDS/ RESPONSES	ADDRESS FIELD	CONTROL FIELD The left-most bit is the least significant bit.	INFORMATION FIELD
S PDUs RECEIVE READY (RR) COMMAND	Contains source address and up to 16 individual addresses.	Bit pattern = 10000000XRRRRRRR, indicating receive ready command.	No information field allowed.
RECEIVE READY (RR) RESPONSE	Contains source address and up to 16 individual link addresses of stations to receive this PDU.	Bit pattern = 10000000XRRRRRRR, indicating last I PDU is acknowledged.	No information field allowed.
RECEIVE NOT READY (RNR) COMMAND	Contains source address and up to 16 individual link addresses of stations to receive this PDU.	Bit pattern = 10100000XRRRRRRR, indicating receive not ready command.	No information field allowed.
RECEIVE NOT READY (RNR) RESPONSE	Contains source address and up to 16 individual link addresses of stations to receive this PDU.	Bit pattern = 10100000XRRRRRRR, indicating receive not ready.	No information field allowed.
SELECTIVE REJECT (SREJ) COMMAND AND RESPONSE	Contains source address and up to 16 individual link addresses of stations to receive this PDU.	Bit pattern = 10110000XRRRRRRR.	No information field allowed.
REJECT (REJ) COMMAND AND RESPONSE	Contains source address and up to 16 individual link addresses of stations to receive this PDU.	Bit pattern = 10010000XRRRRRRR.	No information field allowed.

(X represents the P/F bit setting, S represents send sequence number, and R represents receive sequence number.)

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TABLE VIII. Type 4 PDU formats.

COMMANDS/ RESPONSES	ADDRESS FIELD	CONTROL FIELD The left-most bit is the least significant bit.	INFORMATION FIELD
U PDUs		Bit pattern -	
DIA ACK Req'd	Contains source address and up to 16 individual and/or group or global link addresses for which the message is intended.	110101LL<-ID #-> L-bits are used to indicate PDU precedence	Contains data from the upper layer protocol.
S PDU			
DRR resp	Contains source address and individual address for the originator of the DIA PDU which this PDU ACKs.	100010LL<-ID #-> L-bits are used to indicate precedence of PDU being ACK'd. The ID no. is that of the DIA PDU being ACK'd.	No information field allowed
DRR cmd	Contains source address and individual, group or global address	1000100000000000 indicates a station is ready to receive DIA PDUs.	No information field allowed
DRNR resp	Contains source address and individual address for the originator of the DIA PDU, which this PDU acknowledges	101010LL<-ID #-> indicates a station is not ready to receive DIA PDUs due to a busy condition. L-bits are used to indicate precedence of PDU being ACK'd. The ID no. is that of the DIA PDU being ACK'd.	No information field allowed
DRNR cmd	Contains source address and individual, group or global address	1010100000000000 indicates a station is not ready to receive DIA PDUs due to a busy condition.	No information field allowed

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		LSB 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15 MSB 16
INFORMATION TRANSFER	Type 2	0			N(S)					P/F				N(R)		
SUPERVISORY COMMANDS/RESPONSES (S PDUs)	Type 2	1	0	S	S	Z	Z	Z	Z	P/F				N(R)		
	Type 4	1	1	S	S	1	0	L	L				ID Number			
UNNUMBERED COMMANDS/RESPONSES (U PDUs)	Types 1 & 2	1	1	M	M	P/F	M	M	M							
	Type 4	1	1	0	1	0	1	L	L				ID Number			

Notes:

The left-most bit is the first bit delivered to and received from the physical layer.

N(S) = Transmitter send sequence number (Bit 2 = LSB)
N(R) = Transmitter receive sequence number (Bit 10 = LSB)
S   = Supervisory Function bit
M   = Modifier function bit
Z   = Reserved and set to zero
P/F   = Poll bit - command PDU transmissions
         Final bit - response PDU transmissions
              (1 = Poll/Final)
L   = Level of precedence (LSB on left)
         1 1 = reserved (value = 3)
         0 1 = routine (value = 2)
         1 0 = priority (value = 1)
         0 0 = urgent   (value = 0)

FIGURE 14. Data-link PDU control field formats.

5.3.4.2.3.1 Type 1 operations. For Type 1 operations, the control field is an 8-bit pattern designating 1 of 5 types of U PDUs. The URR and URNR PDUs are used to indicate overall station status.

5.3.4.2.3.2 Type 2 operations. The Type 2 control field is a 16-bit pattern for I PDUs and S PDUs and includes sequence numbers. The Type 2 U PDUs have an 8-bit pattern. The Type 2 control field shall be repeated if more than one destination address is present. Each destination address field shall have a corresponding control field. Each of the corresponding control fields (when repeated) shall be identical except for the P/F bit and sequence numbers. The Type 1

Unnumbered Receive Ready (URR) and Unnumbered Receive Not Ready (URNR) PDUs are used to indicate overall station status. The RR and RNR are used to indicate station status for Type 2 operations only.

5.3.4.2.3.3 <u>Type 4 operations</u>. The Type 4 control field is a 16-bit pattern for U PDUs and S PDUs, and includes identification numbers. The control field distinguishes between a DIA PDU with a frame identification number and four S PDUs used in a connectionless environment with decoupled acknowledgments. The Type 1 URR and URNR are used to indicate overall station status. The DRR and Decoupled Receive Not Ready (DRNR) PDUs are used to indicate station status for Type 4 operations only.

5.3.4.2.3.4 <u>Poll/final bit</u>. The Poll/final (P/F) bit serves a function in both command and response PDUs. In command PDUs, the P/F bit is referred to as the P-bit. In response PDUs, it is referred to as the F-bit. The P-bit set to 1 shall be used to solicit a response PDU, with the F-bit set to 1. On a data link, at most one Type 1 PDU and one Type 2 PDU with P-bit set to 1 shall be outstanding in a given direction at a given time. Before a station issues another PDU with the P-bit set to 1 to a particular destination, it shall have received a response PDU from that remote station with the F-bit set to 1 or have timed out waiting for that response PDU. The P/F bit is not implemented in Type 4 operations.

5.3.4.2.3.5 <u>Sequence numbers</u>. Sequence numbers are used only with Type 2 I and S PDUs. The Type 2 I and S PDUs shall contain sequence numbers. The sequence numbers shall be in the range of 0-127.

5.3.4.2.3.6 <u>Identification numbers</u>. Identification numbers are used only with Type 4 DIA PDUs and DRR/DRNR S PDUs. The Type 4 DIA and DRR/DRNR response S PDUs shall contain an identification number. The identification number is used to identify each DIA PDU and permit decoupled acknowledgments in a connectionless environment. The identification numbers shall be in the range of 1-255.

5.3.4.2.3.7 <u>Precedence</u>. The two level-of-precedence bits (L-bits) are used only in the control field of Type 4 PDUs. In the DIA PDU, the L-bits indicate the precedence of the data in the information field. In the DRR response S PDU, the L-bits are used to indicate the precedence of the DIA PDU information being acknowledged. The data link precedence values and their appropriate mappings to network layer precedence levels are indicated in 5.3.16.

5.3.4.2.4 <u>Information field</u>. The information field may be present in either the I, UI, DIA, FRMR or TEST PDU. The length of the information field shall be a multiple of 8 bits, not to exceed 3345 octets. If the data is not a multiple of 8 bits, 1 to 7 fill bits (0) shall be added to meet this requirement. The maximum information field size defaults to 3345 octets. A smaller size may be established at initialization through local system information or using the XNP messages (see Appendix E). Contents of the information fields of the FRMR and TEST PDUs are described in 5.3.6.2.3.6 and 5.3.6.1.5, respectively.

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5.3.4.2.5 <u>Frame check sequence</u>. For error detection, all frames shall include a 32-bit FCS prior to the closing flag sequence. The contents of the address, control, and information fields are included in the FCS calculation. Excluded from the FCS calculation are the 0's inserted by the 0-bit insertion algorithm. The formula for calculating the FCS, which is the 1's complement (inversion) of the remainder of a modulo-2 division process, employs the generator polynomial, P(X), having the form

$$P(x) = x32 +x26 +x23 +x22 +x16 +x12 +x11 +x10 +x8 +x7 +x5 +x4 +x2 +x +1$$

FCS generation shall be in accordance with the paragraph entitled "32-bit Frame Checking Sequence" in ISO 3309, and implemented in a manner that provides a unique remainder when a frame is received without bit errors incurred during transmission. If the FCS of a received frame proves the frame to be invalid, the frame shall be discarded.

5.3.4.3 <u>Data-link PDU construction</u>. The data-link procedures that affect data-link PDU construction include (a) order-of-bit transmission and 0-bit insertion, discussed below; and (b) FEC and TDC, discussed in 5.3.14.

5.3.4.3.1 <u>Order-of-bit transmission</u>. The order-of-bit transmission function specifies the sequence in which bits are ordered by the data-link layer for transmission by the physical layer. The Information Field and control field(s) shall be transmitted LSB of each octet first. The flag shall be transmitted LSB first. For the FCS, the most significant bit (MSB) shall be transmitted first. For the address field, the source address octet is transmitted first and the destination address octet(s) are transmitted in order. The LSB of each address octet is transmitted first. The information field octets shall be transmitted in the same order as received from the upper layers, LSB of each octet first.

5.3.4.3.2 <u>Zero-bit insertion algorithm</u>. The occurrence of a spurious flag sequence within a frame or Transmission Header shall be prevented by employing a 0-bit insertion algorithm. After the entire frame has been constructed, the transmitter shall always insert a 0 bit after the appearance of five 1's in the frame (with the exception of the flag fields). After detection of an opening flag sequence, the receiver shall search for a pattern of five 1's. When the pattern of five 1's appears, the sixth bit shall be examined. If the sixth bit is a 0, the 5 bits shall be passed as data, and the 0 shall be deleted. If the sixth bit is a 1, the receiver shall inspect the seventh bit. If the seventh bit is a 0, a flag sequence has been received. If the seventh bit is a 1, an invalid message has been received and should be discarded.

5.3.5 <u>Operational parameters</u>. The various parameters associated with the control field formats are described in the following sections.

5.3.5.1 <u>Type 1 operational parameters</u>. The only parameter that exists in Type 1 operation is the P/F bit. The Poll (P) bit set to 1 shall be used to solicit (poll) an immediate correspondent response PDU with the Final (F) bit set to 1 from the addressed station. The response with F-bit set to 1 shall be transmitted in accordance with the response hold delay (RHD) procedures defined in Appendix C (C4.2).

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5.3.5.2 <u>Type 2 operational parameters</u>. The various parameters associated with the control field formats in Type 2 operation are described in 5.3.5.2.1 to 5.3.5.2.3.2.

5.3.5.2.1 <u>Modulus</u>. Each I PDU shall be sequentially numbered with a numeric value between 0 and MODULUS minus ONE (where MODULUS is the modulus of the sequence numbers). MODULUS shall equal 128 for the Type 2 control field format. The sequence numbers shall cycle through the entire range. The maximum number of sequentially numbered I PDUs that may be outstanding (that is, unacknowledged) in a given direction of a data-link connection at any given time shall never exceed one less than the modulus of the sequence numbers. This restriction shall prevent any ambiguity in the association of sent I PDUs with sequence numbers during normal operation and error recovery action.

5.3.5.2.2 <u>PDU-state variables and sequence numbers</u>. A station shall maintain a send-state variable, V(S), for the I PDUs it sends and a receive-state variable, V(R), for the I PDUs it receives on each data-link connection. The operation of V(S) shall be independent of the operation of V(R).

5.3.5.2.2.1 <u>Send-state variable V(S)</u>. The V(S) shall denote the sequence number of the next in-sequence I PDU to be sent on a specific data-link connection. The V(S) shall take on a value between 0 and MODULUS minus ONE. The value of V(S) shall be incremented by one with each successive I PDU transmission on the associated data-link connection, but shall not exceed receive sequence number N(R) of the last received PDU by more than MODULUS minus ONE.

5.3.5.2.2.2 <u>Send-sequence number N(S)</u>. Only I PDUs shall contain N(S), the send sequence number of the sent PDU. Prior to sending an I PDU, the value of N(S) shall be set equal to the value of the V(S) for that data-link connection.

5.3.5.2.2.3 <u>Receive-state variable V(R)</u>. The V(R) shall denote the sequence number of the next in-sequence I PDU to be received on a specific data-link connection. The V(R) shall take on a value between 0 and MODULUS minus ONE. The value of the V(R) associated with a specific data-link connection shall be incremented by one whenever an error-free I PDU is received whose N(S) equals the value of the V(R) for the data-link connection.

5.3.5.2.2.4 <u>Receive sequence number N(R)</u>. All I and S PDUs shall contain N(R), the expected sequence number of the next received I PDU on the specified data-link connection. Prior to sending an I or S PDU, the value of N(R) shall be set equal to the current value of the associated V(R) for that data-link connection. N(R) shall indicate that the station sending the N(R) has received correctly all I PDUs numbered up through N(R)-1 on the specified data-link connection.

5.3.5.2.3 <u>Poll/final (P/F) bit</u>. The P/F bit shall serve a function in Type 2 operation in both command and response PDUs. In command PDUs the P/F bit shall be referred to as the P-bit. In response PDUs it shall be referred to as the F-bit. P/F bit exchange provides a distinct C/R linkage that is useful during both normal operation and recovery situations.

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5.3.5.2.3.1 <u>Poll-bit functions</u>. A command PDU with the P-bit set to 1 shall be used to solicit (poll) a response PDU with the F-bit set to 1 from the addressed station on a data-link connection. Only one Type 2 PDU with a P-bit set to 1 shall be outstanding in a given direction at a given time on the data-link connection between any specified pair of stations. Before a station issues another PDU on the same data-link connection with the P-bit set to 1, the station shall have received a response PDU with the F-bit set to 1 from the addressed station. If no valid response PDU is received within a system-defined P-bit timer time-out period, the resending of a command PDU with the P-bit set to 1 shall be permitted for error recovery purposes.

5.3.5.2.3.2 <u>Final-bit functions</u>. The F-bit set to 1 shall be used to respond to a command PDU with the P-bit set to 1. Following the receipt of a command PDU with the P-bit set to 1, the station shall send a response PDU with the F-bit set to 1 on the appropriate data-link connection at the first possible opportunity. First possible opportunity is defined as transmitting the frame ahead of other frames at the next network access opportunity. The response PDU shall be assigned an URGENT precedence. The station shall be permitted to send appropriate response PDUs with the F-bit set to 0 at any net access opportunity without the need for a command PDU.

5.3.5.3 <u>Type 4 operational parameters</u>. The two parameters associated with the control field formats in Type 4 operation are precedence described in 5.3.4.2.3.7 and Identification number.

5.3.5.3.1 <u>Identification number</u>. The Identification number field is used in conjunction with the originator's station address to identify the PDU. The station's identification number is assigned just prior to the initial transmission of the PDU. This number is not changed on link layer retransmission of the PDU. Each station shall keep a number for originating PDUs. Duplicate frame identification numbers from the same originator shall not be used for more than one outstanding (unacknowledged) DIA PDU.

5.3.6 <u>Commands and responses</u>. This section defines the commands and associated responses. Definitions of the set of commands and responses for each of the control field formats for Type 1, Type 2 and Type 4 operations, respectively, are contained in 5.3.6.1, 5.3.6.2 and 5.3.6.3. The C/R bit, the LSB of the source address field, is used to distinguish between commands and responses. The following discussion of commands and responses assumes that the C/R bit has been properly decoded. A single multi-addressed frame shall not contain different PDU types nor contain the same individual address more than once. The control field for all addresses in a single multi-addressed frame shall be the same except for the P/F bit and sequence number. Some of the commands described in the following paragraphs require a response at the earliest opportunity. Response PDUs requiring "earliest opportunity" transmission shall be queued ahead of all other PDUs, except those queued for "first possible opportunity" for transmission during the next network access opportunity. The response PDU shall assume the precedence level of the highest PDU queued or the mid (PRIORITY) level, whichever is greater. The Type 4 DRR response PDU shall assume the precedence of the DIA frame it is acknowledging.

5.3.6.1 <u>Type 1 operation commands and responses</u>. Type 1 commands and responses are all U PDUs. The U PDU encodings for Type 1 operations are listed in Figure 15.

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1	2	3	4	5	6	7	8	Bit Position
FIRST CONTROL FIELD BIT DELIVERED TO/RECEIVED FROM THE PHYSICAL LAYER ↓								
1	2	3	4	5	6	7	8	Bit Position
1	1	0	0	P	0	0	0	UI Command
1	1	0	0	0	1	0	0	URR Command
1	1	0	0	1	1	0	0	URR Response
1	1	0	1	0	0	0	0	URNR Command
1	1	0	1	1	0	0	0	URNR Response
1	1	0	0	P/F	1	1	1	Test Command/Response

FIGURE 15. Type 1 operation control-field bit assignments.

5.3.6.1.1 Unnumbered information command. The unnumbered information PDU (UI PDU) shall be used to send information to one or more stations. The P-bit of the control field of the UI PDU is used by the transmitter to request that individually addressed receiver(s) acknowledge receipt of the transmitted UI PDU or to specify that an acknowledgment is not required. The UI PDU shall be addressed to individual, special, group, or global addresses. The source address shall be the individual address of the transmitting station.

5.3.6.1.2 Unnumbered receive-ready command. The unnumbered receive-ready (URR) command PDU shall be transmitted to one or more stations to indicate that the sending station is ready to receive I, DIA and UI PDUs. The URR PDU shall be addressed to individual, group, or global addresses. The source address shall be the individual address of the transmitting station.

5.3.6.1.3 Unnumbered receive-not-ready command. The unnumbered receive-not-ready (URNR) command PDU shall be transmitted to one or more stations to indicate that the sending station is busy and cannot receive I, DIA or UI PDUs. The URNR PDU shall be addressed to individual, group, or global addresses. The source address shall be the individual address of the transmitting station.

5.3.6.1.4 Test command. The test command (TEST) shall be used to cause the destination station to respond with the TEST response at the earliest opportunity, thus performing a basic test of the transmission path. An information field is optional with the TEST command PDU. It may contain any bit pattern, but is limited to a maximum length of 128 octets. If present, however, the received information field shall be returned, if possible, by the addressed station in the TEST response PDU. The TEST command, with the P-bit set to 1, shall cause the individually addressed destination station(s) to respond with a TEST response PDU (with no information field), with the F-bit set to 1, after the appropriate RHD period (see C4.2). The TEST command, with the P-bit set to 0 shall cause each destination station (including members of group and global addresses) to respond with a TEST response (with information field) with the F-bit set to 0 at the earliest opportunity. Group and global addressees do not reply to a TEST command with the P-bit set to 1. The TEST

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command PDU shall be addressed to an individual and/or group or global destination addresses. The source address shall be an individual address.

5.3.6.1.6 <u>Unnumbered receive-ready response</u>. The URR response shall be used to acknowledge a UI command that requested an acknowledgment (P-bit set to 1). The URR response shall be the first PDU sent by the receiving station upon receiving a UI command after the appropriate RHD period (see C4.2). The source and destination shall be individual addresses.

5.3.6.1.7 <u>Test response</u>. The TEST response, with F-bit set to 1, without an information field shall be used by individual addressees to reply to the TEST command with the P-bit set to 1. The TEST response shall be the first PDU sent by the receiving station upon receiving a TEST command PDU, after the appropriate RHD period (see C4.2). Group and global addressees do not reply to TEST command with P-bit set to 1. The TEST response, with F-bit set to 0, shall be used by all addressees (individual, group and global) to reply to the TEST command with the P-bit set to 0 at the earliest opportunity. If an information field was present in the TEST command PDU that had the P-bit set to 0, the TEST response PDU shall contain the same information field contents. If the station cannot accept the information field of the TEST command, a TEST response without an information field may be returned. The source and destination addresses shall be an individual address.

5.3.6.1.9 <u>Unnumbered receive-not-ready response</u>. The URNR response PDU shall be used to reply to a UI command with the P-bit set to 1, if the UI command cannot be processed due to a busy condition. The URNR response PDU does not contain any acknowledgment information. If used, the URNR response shall be the first PDU transmitted by the receiving station, upon receiving a UI command, after the appropriate RHD period (see C4.2). The URNR response shall have the F-bit set to 1 and shall be addressed to the source of the UI command.

5.3.6.2 <u>Type 2 operation commands and responses</u>. Type 2 commands and responses consist of I, S, and U PDUs.

5.3.6.2.1 <u>Information-transfer-format command and response</u>. The function of the information (I) command and response shall be to transfer sequentially numbered PDUs that contain an information field across a data-link connection. Send and receive sequence numbers associated with group and global addresses shall be set to zero by the transmitter and ignored by the receiver and are not acknowledged. The encoding of the I PDU control field for Type 2 operation shall be as listed in Figure 16.

The I PDU control field shall contain two sequence number subfields: N(S), which shall indicate the sequence number associated with the I PDU; and N(R), which shall indicate the sequence number (as of the time the PDU is sent) of the next expected I PDU to be received, and, consequently, shall indicate that the I PDUs numbered up through N(R)-1 have been received correctly.

FIRST CONTROL FIELD BIT DELIVERED TO/RECEIVED FROM THE PHYSICAL LAYER ↓			
1	2 3 4 5 6 7 8	9	10 11 12 13 14 15 16
0	N(S)	P/F	N(R)
INFORMATION TRANSFER FORMAT	SEND SEQUENCE NUMBER (0-127)	COMMAND (POLL) RESPONSE (FINAL)	RECEIVE SEQUENCE NUMBER (0-127)

FIGURE 16. <u>Information-transfer-format control field bits</u>.

5.3.6.2.2 <u>Supervisory-format commands and responses</u>. Supervisory (S) PDUs shall be used to perform numbered supervisory functions such as acknowledgments, temporary suspension of information transfer, or error recovery. S PDUs shall not contain an information field and, therefore, shall not increment the send-state variable at the sender or the receive-state variable at the receiver. Encoding of the S PDU control field for Type 2 operation shall be as shown in Figure 17. An S PDU shall contain an N(R), which shall indicate, at the time of sending, the sequence number of the next expected I PDU to be received. This shall acknowledge that all I PDUs numbered up through N(R)-1 have been received correctly, except in the case of the selective reject (SREJ) PDU. The use of N(R) in the SREJ PDU is explained in 5.3.6.2.2.4.

FIRST CONTROL FIELD BIT DELIVERED TO/RECEIVED FROM THE PHYSICAL LAYER ↓					
1 2	3 4	5 6 7 8		9	10 11 12 13 14 15 16
1 0	S S	X X X X		P/F	N(R)
		\-----------------------/			\-----------------------/
↓	↓		↓	↓	↓
SUPER-VISORY FORMAT		RESERVED SET TO 0		COMMAND (POLL) RESPONSE (FINAL)	RECEIVE SEQUENCE NUMBER (0-127)

COMMANDS	SS	RESPONSES
RECEIVE READY (RR)	00	RECEIVE READY (RR)
REJECT (REJ)	01	REJECT (REJ)
RECEIVE NOT READY (RNR)	10	RECEIVE NOT READY (RNR)
SELECTIVE REJECT (SREJ)	11	SELECTIVE REJECT (SREJ)

FIGURE 17. <u>Supervisory-format control field bits</u>.

5.3.6.2.2.1 <u>Receive-ready (RR) command and response</u>. The RR PDU shall be used by a station to indicate it is ready to receive I PDUs. I PDUs numbered up through N(R)-1 shall be considered as acknowledged.

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5.3.6.2.2.2 <u>Reject (REJ) command and response</u>. The REJ PDU shall be used by a station to request the resending of I PDUs, starting with the PDU numbered N(R). I PDUs numbered up through N(R)-1 shall be considered as acknowledged. It shall be possible to send additional I PDUs awaiting initial sending after the resent I PDUs. With respect to each direction of sending on a data-link connection, only one "sent REJ" condition shall be established at any given time. The "sent REJ" condition shall be cleared upon receipt of an I PDU with an N(S) equal to the N(R) of the REJ PDU. The "sent REJ" condition may be reset in accordance with procedures described in 5.3.7.2.5.4. Receipt of a REJ PDU shall indicate the clearance of a busy condition except as noted in 5.3.7.2.5.8.

5.3.6.2.2.3 <u>Receive-not-ready (RNR) command and response</u>. The RNR PDU shall be used by a station to indicate a busy condition (a temporary inability to accept subsequent I PDUs). I PDUs numbered up through N(R)-1 shall be considered as acknowledged. I PDUs numbered N(R) and any subsequent I PDUs received shall not be considered as acknowledged; the acceptance status of these PDUs shall be indicated in subsequent exchanges.

5.3.6.2.2.4 <u>Selective-reject (SREJ) command and response</u>. The selective reject PDU is used by a station to request retransmission of the single I PDU numbered N(R). If the P-bit in the SREJ PDU is set to 1, then I PDUs numbered up to N(R)-1 shall be considered acknowledged. If the P-bit is set to 0, then the N(R) of the SREJ PDU does not indicate acknowledgment of any I PDUs. Each SREJ exception condition shall be cleared (reset) upon receipt of an I PDU with an N(S) equal to the N(R) of the SREJ PDU. A data station may transmit one or more SREJ PDUs, each containing a different N(R) with the P-bit set to 0, before one or more earlier SREJ exception conditions have been cleared. I PDUs that have been transmitted following the I PDU designated by the SREJ PDU shall not be retransmitted as the result of receiving the SREJ PDU. Additional I PDUs awaiting initial transmission may be transmitted following the retransmission of the specific I PDU requested by the SREJ PDU. The SREJ is used to recover from receipt of frames with various types of errors, including sequence number errors due to lost frames and FCS errors.

5.3.6.2.3 <u>Unnumbered-format commands and responses</u>. Unnumbered (U) commands and responses shall be used in Type 2 operations to extend the number of data-link connection control functions. The U PDUs shall not increment the state variables on the data-link connection at either the sending or the receiving station. Encoding of the U PDU control field shall be as in Figure 18.

5.3.6.2.3.1 <u>Set asynchronous balanced mode extended (SABME) command</u>. The SABME command PDU shall be used to establish a data-link connection to the destination station in the asynchronous balanced mode (ABM). No information shall be permitted with the SABME command PDU. The destination station shall confirm receipt of the SABME command PDU by sending a UA response PDU on that data-link connection at the earliest opportunity. Upon acceptance of the SABME command PDU, the destination station send- and receive-state variables shall be set to 0. If the UA response PDU is received correctly, then the initiating station shall also assume the asynchronous balanced mode with its corresponding send- and receive-state variables set to 0. Previously sent I PDUs that are unacknowledged when this command is executed shall remain unacknowledged. A station may resend the contents of the information field of unacknowledged outstanding I PDUs

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FIRST CONTROL FIELD BIT DELIVERED TO/RECEIVED FROM THE PHYSICAL LAYER ↓								
1	2	3	4	5	6	7	8	
1	1	1	1	P	1	0	0	SABME Command
1	1	0	0	P	0	1	0	DISC Command
1	1	1	1	P	0	0	1	RSET Command
1	1	0	0	F	1	1	0	UA Response
1	1	1	1	F	0	0	0	DM Response
1	1	1	0	F	0	0	1	FRMR Response

FIGURE 18. Unnumbered-format control field bits.

5.3.6.2.3.2 Disconnect (DISC) command. The DISC command PDU shall be used to terminate an asynchronous balanced mode previously set by a SABME command PDU. It shall be used to inform the destination station that the source station is suspending operation of the data-link connection and the destination station should assume the logically disconnected mode. No information field shall be permitted with the DISC command PDU. Prior to executing the command, the destination station shall confirm the acceptance of the DISC command PDU by sending a UA response PDU on that data-link connection. Previously sent I PDUs that are unacknowledged when this command is executed shall remain unacknowledged.

5.3.6.2.3.3 Reset (RSET) command. The RSET command PDU shall be used by a station in an operational mode to reset the V(R) in the addressed station. No information field is permitted with the RSET command PDU. The addressed station shall confirm acceptance of the RSET command by transmitting a UA response PDU at the earliest opportunity. Upon acceptance of this command, the V(R) of the addressed station shall be set to 0. If the UA response PDU is received correctly, the initializing station shall reset its V(S) to 0.

5.3.6.2.3.4 Unnumbered acknowledgment (UA) response. The UA response PDU shall be used by a station on a data-link connection to acknowledge receipt and acceptance of the SABME, DISC, and RSET command PDUs. These received command PDUs shall not be executed until the UA response PDU is sent. No information field shall be permitted with the UA response PDU.

5.3.6.2.3.5 Disconnect mode (DM) response. The DM response PDU shall be used to report status indicating that the station is logically disconnected from the data-link connection and is in asynchronous disconnected mode (ADM). No information field shall be permitted with the DM response PDU.

5.3.6.2.3.6 Frame reject (FRMR) response. The FRMR response PDU shall be used by the station in the ABM to report that one of the following conditions, which is not correctable by resending the identical PDU, resulted from the receipt of a PDU from the remote station:

a.　The receipt of a command PDU or a response PDU that is invalid or not implemented. Below are three examples of invalid PDUs:

　　(1)　the receipt of an S or U PDU with an information field that is not permitted,
　　(2)　the receipt of an unsolicited F-bit set to 1, and
　　(3)　the receipt of an unexpected UA response PDU.

b.　The receipt of an I PDU with an information field that exceeded the established maximum information field length that can be accommodated by the receiving station for that data-link connection.

c.　The receipt of an invalid N(R) from the remote station. An invalid N(R) shall be defined as one that signifies an I PDU that has previously been sent and acknowledged, or one that signifies an I PDU that has not been sent and is not the next sequential I PDU waiting to be sent.

d.　The receipt of an invalid N(S) from the remote station. An invalid N(S) shall be defined as an N(S) that is greater than or equal to the last sent $N(R)+ k$, where k is the maximum number of outstanding I PDUs. The parameter k is the window size indicated in the XNP message (see Appendix E).

The responding station shall send the FRMR response PDU at the earliest opportunity. An information field shall be returned with the FRMR response PDU to provide the reason for the PDU rejection. The information field shall contain the fields shown in Figure 19. The station receiving the FRMR response PDU shall be responsible for initiating the appropriate mode setting or resetting corrective action by initializing one or both directions of transmission on the data-link connection, using the SABME, RSET or DISC command PDUs, as applicable.

5.3.6.3 Type 4 operation commands and responses. The Type 4 commands and responses consist of U and S PDUs.

5.3.6.3.1 Unnumbered information transfer format commands. The function of the Type 4 unnumbered information with decoupled acknowledgment (DIA) commands shall be to transfer PDUs that contain an identification number and an information field across a connectionless link. The encoding of the PDU control field for Type 4 operation shall be as listed in Figure 20.

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FIRST CONTROL BIT DELIVERED TO/RECEIVED FROM THE PHYSICAL LAYER ↓						
1----------16	17	18--24	25	26--32	33--36	37--40
REJECTED PDU CONTROL FIELD	0	V(S)	C/R	V(R)	WXYZ	V000

FIGURE 19. <u>FRMR information field format</u>.

Notes to Figure 19:

a)   Rejected PDU control field shall be the control field of the received PDU that caused the FRMR exception condition on the data-link connection. When the rejected PDU is a U PDU, the control field of the rejected PDU shall be positioned in bit positions 1-8, with 9-16 set to 0.

b)   V(S) shall be the current send-state variable value for this data-link connection at the rejecting station (bit 18 = low-order bit).

c)   C/R set to 1 shall indicate that the PDU causing the FRMR was a response PDU, and C/R set to 0 shall indicate that the PDU causing the FRMR was a command PDU.

d)   V(R) shall be the current receive-state variable value for this data-link connection at the rejecting station (bit 26 = low-order bit).

e)   W set to 1 shall indicate that the control field received and returned in bits 1 through 16 was invalid or not implemented. Examples of invalid PDU are defined as:

(1)   the receipt of an S or U PDU with an information field that is not permitted,
(2)   the receipt of an unsolicited F-bit set to 1, and
(3)   the receipt of an unexpected UA response PDU.

f)   X set to 1 shall indicate that the control field received and returned in bits 1 through 16 was considered invalid because the PDU contained an information field that is not permitted with this command or response. Bit W shall be set to 1 in conjunction with this bit.

g)   Y set to 1 shall indicate that the information field received exceeded the established maximum information field length which can be accommodated by the rejecting station on that data-link connection.

h)   Z set to 1 shall indicate that the control field received and returned in bits 1 through 16 contained an invalid N(R).

i)   V set to 1 shall indicate that the control field received and returned in bits 1 through 16 contained an invalid N(S). Bit W shall be set to 1 in conjunction with this bit.

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FIRST CONTROL BIT DELIVERED TO/RECEIVED FROM THE PHYSICAL LAYER ↓		
PDU Identifier	L-bits	PDU Identification No.
1 2 3 4 5 6	7 8	9 10 11 12 13 14 15 16
1 1 0 1 0 1	L L	<---ID Number--->

FIGURE 20. Type 4 DIA PDU control field bit assignments.

5.3.6.3.1.1 DIA PDU acknowledgment. Transmitted DIA PDUs are acknowledged by a Type 4 DRR response S PDU with the same precedence from the receiving stations, except for the following cases:

      a.   The receiving station is a global or group multicast addressee only.

      b.   The receiving station's link address is not in the destination address field.

      c.   The response mode parameter is set to no.

5.3.6.3.2 Supervisory format commands and responses. The S PDUs shall be used to convey link acknowledgment of a DIA PDU and whether or not a station is ready to receive Type 4 PDUs. The S PDU has a single destination address. For the command DRR and DRNR S PDUs the destination address is the global address and does not acknowledge DIA PDUs. These S PDUs are used to indicate Type 4 receive status. The response DRR S PDU contains a single destination address, that of the originator of the DIA PDU being acknowledged. The command S PDU level of precedence shall be set to the highest precedence while response S PDUs shall use the precedence of the DIA PDU which they are acknowledging. The encoding of the S PDU control field for Type 4 operation shall be as listed in Figure 21.

5.3.7 Description of procedures by type. The procedures for each operation type are described in 5.3.7.1, 5.3.7.2 and 5.3.7.3 (and their subparagraphs). The three types of procedures can coexist on the same network.

5.3.7.1 Description of type 1 procedures. The procedures associated with Type 1 operation are described in 5.3.7.1 through 5.3.7.1.5.11.

5.3.7.1.1 Modes of operation. In Type 1 operation, no modes of operation are defined. A station using Type 1 procedures shall support the entire procedure set whenever it is operational on the network.

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FIRST CONTROL BIT DELIVERED TO/RECEIVED FROM THE PHYSICAL LAYER ↓		
PDU Identifier	L-bits	PDU Identification No.
1 2 3 4 5 6	7 8	9 10 11 12 13 14 15 16
1 0 0 0 1 0	0 0	0 0 0 0 0 0 0 0 DRR Command
1 0 0 0 1 0	L L	<---ID Number---> DRR Response
1 0 1 0 1 0	0 0	0 0 0 0 0 0 0 0 DRNR Command
1 0 1 0 1 0	L L	<---ID Number---> DRNR Response

FIGURE 21. Type 4 S PDU control field bit assignments.

5.3.7.1.2 Procedure for addressing. The address fields shall be used to indicate the source and destinations of the transmitted PDU. The first bit in the source address field shall be used to identify whether a command or a response is contained in the PDU. Individual, group, special, and global addressing shall be supported for destination addresses in command PDUs. The source address field shall contain an individual or special address.

5.3.7.1.3 Procedure for using the P/F bit. The station receiving a UI or TEST command PDU with the P-bit set to 1 shall send an appropriate response PDU with the F-bit set to 1.

5.3.7.1.4 Procedures for logical data-link set-up and disconnection. Type 1 operation does not require any prior data-link connection establishment (set-up), and hence no data-link disconnection. Once the service access point has been enabled within the station, information may be sent to, or received from, a remote station also participating in Type 1 operation.

5.3.7.1.5 Procedures for information transfer.

5.3.7.1.5.1 Sending UI command PDUs. Information transfer from an initiating station to a responding station shall be accomplished by sending the UI command PDU. When a sending station sends a UI command PDU with the P-bit set to 1, it shall start an acknowledgment timer for that transmission and initialize the internal transmission count variable to zero. If all expected URR or URNR response PDUs are not received before the timer runs out, the sending station shall resend the UI command PDU, increment the internal transmission count variable, and restart the acknowledgment timer. Prior to resending the UI command PDU, the group and global

addresses shall be removed as well as individual and special addresses from which a response (URR or URNR) was received. The special address 3 shall not be removed prior to retransmission unless it is the only address remaining. No retransmission shall be attempted unless an individual or special address other than 3 remains. If a URR response PDU is still not received, this resending procedure shall be repeated until the value of the internal transmission count variable is equal to the value of the logical link parameter N4, as described in 5.3.8.1.1c, at which time a DL-Status-Indication shall be reported to the upper layer indicating an acknowledgment failure. An internal transmission count shall be maintained for each UI information exchange (where P-bit = 1) between a pair of sending and receiving stations. Both the acknowledgment timer and the internal transmission count, for that exchange, shall not affect the information exchange with other receiving stations. If a URNR response PDU is received in response to a UI command with the P-bit set to 1, the receiving station shall designate the sending station as busy. The retransmission of the UI command shall follow the rules for the busy condition. Transmission of UI commands to that station shall be discontinued until the busy state is cleared. UI PDUs that have the P-bit set to 0 are not acknowledged nor retransmitted.

5.3.7.1.5.2 <u>Receiving UI command PDUs</u>. Reception of the UI command PDU with P-bit set to 0 shall not be acknowledged. A station shall acknowledge the receipt of a valid UI command PDU, which has the P-bit set to 1 and contains the station individual address, by sending a URR response PDU to the originator of the command UI PDU. If the receiving station is unable to accept UI PDUs due to a busy condition, it shall respond with a URNR response PDU.

5.3.7.1.5.3 <u>Sending URR response PDUs</u>. A URR response PDU, with the F-bit set to 1, shall be sent only upon receipt of a UI command PDU, with the P-bit set to 1. The URR response PDU shall be sent to the originator of the associated UI command PDU.

5.3.7.1.5.4 <u>Sending URNR response PDUs</u>. A URNR response PDU, with the F-bit set to 1, may be sent by the remote station to advise the originator of the associated UI command PDU that it is experiencing a busy condition and is unable to accept UI PDUs.

5.3.7.1.5.5 <u>Receiving UI acknowledgment</u>. After sending a UI command PDU with the P-bit set to 1, the sending station shall expect to receive an acknowledgment in the form of a URR response PDU from the station to which the command PDU was sent. No acknowledgment shall be expected from group or global addresses or from the special address 3. Upon receiving such a response PDU, the station shall stop the acknowledgment timer associated with the transmission for which the acknowledgment was received and reset the associated internal transmission count to zero. If the response was a URNR response PDU, the sending station will stop sending UI, I, and DIA PDUs to that remote station until a URR command PDU is received or the busy-state timer expires, indicating termination of the busy condition. If High Reliability was requested for the command PDU, a DL-Status.Indication should be sent to the upper layer indicating acknowledgment success.

5.3.7.1.5.6 <u>Sending URNR command PDUs</u>. A URNR command PDU, with the P-bit set to 0, may be sent at any time to indicate a busy condition.

5.3.7.1.5.7 <u>Receiving URNR command PDUs</u>. Receipt of the URNR indicates that the sending station is busy and, with one exception described below, no additional I, UI or DIA PDUs should be sent until the sending station regains its ability to receive messages. The URNR command PDU does not contain any acknowledgment information.

Exception: A Station may include a busy destination in a PDU that is addressed to multiple destination addresses if at least one of the multiple destinations is not busy.

5.3.7.1.5.8 <u>Sending URR command PDUs</u>. A URR command PDU, with the P-bit set to 0, may be sent by a station at any time to indicate the regaining of its ability to receive messages.

5.3.7.1.5.9 <u>Receiving URR command PDUs</u>. The receipt of the URR command PDU cancels the prior receipt of a URNR and indicates that the sending station is now operational.

5.3.7.1.5.10 <u>Using TEST command and response PDUs</u>. The TEST function provides a facility to conduct loop-back tests of the station-to-station transmission path. The TEST function may be initiated within the data-link layer by any authorized station within the data-link layer. Successful completion of a test started by sending a TEST command PDU with the P-bit set consists of receiving a TEST response PDU with the F-bit set and containing no data from each individual addressee. Successful completion of a test started by sending a TEST command PDU without the P-bit set consists of receiving a TEST response PDU without the F-bit set and containing the identical data from each individual, group or global addressee. The length of the information field is variable from 0 to 128 octets. Any TEST command PDU received in error shall be discarded and no response PDU sent. In the event of a test failure, it shall be the responsibility of the TEST function initiator to determine any future actions.

5.3.7.2 <u>Description of type 2 procedures</u>. The procedures associated with Type 2 operation are described in 5.3.7.2.1 through 5.3.7.2.8.

5.3.7.2.1 <u>Modes</u>. Two modes of operation are defined for Type 2 operation: an operational mode and a non-operational mode.

5.3.7.2.1.1 <u>Operational mode</u>. The operational mode shall be the ABM. ABM is a balanced operational mode in which a data-link connection has been established between two stations. Either station shall be able to send commands at any time and initiate response transmissions without receiving explicit permission from the other station. Such an asynchronous transmission shall contain one or more PDUs that shall be used for information transfer and to indicate status changes in the station (for example, the number of the next expected I PDU; transition from a ready to a busy condition, or vice versa; occurrence of an exception condition). A station in ABM receiving a DISC command PDU shall respond with the UA response PDU if it is capable of executing the command. ABM consists of a data-link connection phase, an information transfer phase, a data-link resetting phase, and a data-link disconnection phase.

5.3.7.2.1.2 <u>Non-operational mode</u>. The non-operational mode shall be the ADM. ADM differs from ABM in that the data-link connection is logically disconnected from the physical medium

such that no information (user data) shall be sent or accepted. ADM is defined to prevent a data-link connection from appearing on the physical medium in a fully operational mode during unusual situations or exception conditions. Such operation could cause a sequence number mismatch between stations or a station's uncertainty of the status of the other station. A data-link connection shall be system-predefined as to the conditions that cause it to assume ADM. Below are three examples of possible conditions, in addition to receiving a DISC command PDU, that may cause a data-link connection to enter ADM:

      a.   the power is turned on,

      b.   the data-link layer logic is manually reset, or

      c.   the data-link connection is manually switched from a local (home) condition to the connected-on-the-data-link (on-line) condition.

A station on a data-link connection in ADM shall be required to monitor transmissions received from its physical layer to accept and respond to one of the mode-setting command PDUs (SABME, DISC), or to send a DM response PDU at a medium access opportunity, when required. In addition, since the station has the ability to send command PDUs at any time, the station may send an appropriate mode-setting command PDU. A station in ADM receiving a DISC command PDU or any I or S PDU shall respond with the DM response PDU. A station in ADM shall not establish a FRMR exception condition. ADM consists of a data-link disconnected phase.

5.3.7.2.2 <u>Procedure for addressing</u>. The address fields for a PDU shall be used to indicate the individual source and up to 16 destinations. The first bit in the source address field shall be used to identify whether a command or response is contained in the PDU. A single data-link connection can be established between any two stations on the network.

5.3.7.2.3 <u>Procedures for using the P/F bit</u>. An individually addressed station receiving a command PDU (SABME, DISC, RR, RNR, REJ, or I) with the P-bit set to 1 shall send a response PDU with the F-bit set to 1. The response PDU returned by a station to a RSET, SABME or DISC command PDU with the P-bit set to 1 shall be a UA or DM response PDU with the F-bit set to 1. The response PDU returned by a station to an I, RR, or REJ command PDU with the P-bit set to 1 shall be an I, RR, REJ, RNR, DM, or FRMR response PDU with the F-bit set to 1. The response PDU returned by a station to an RNR command PDU with the P-bit set to 1 shall be an RR, REJ, RNR, DM, or FRMR response PDU with the F-bit set to 1. The response PDU returned by a station to a SREJ with the P-bit set to one shall be the requested I-Frame (response) with the F-bit set to one.

NOTE: The P-bit is usable by the station in conjunction with the timer recovery condition. (See 5.3.7.2.5.11)

5.3.7.2.4 Procedures for data-link set-up and disconnection.

5.3.7.2.4.1 Data-link connection phase. Either station shall be able to take the initiative to initialize the data-link connection.

5.3.7.2.4.1.1 Initiator action. When the station wishes to initialize the link, it shall send the SABME command PDU to one or more individual addresses and start the acknowledgment timer(s). Upon receipt of the UA response PDU, the station shall reset both the V(S) and V(R) to 0 for the corresponding data-link connection, shall stop the acknowledgment timer and shall enter the information transfer phase. When receiving the DM response PDU, the station that originated the SABME command PDU shall stop the acknowledgment timers for that link, shall not enter the information transfer phase for that station, and shall report to the higher layer for appropriate action. Should any acknowledgment timer run out before receiving all UA or DM response PDUs, the station shall resend the SABME command PDU, after deleting the address and control fields corresponding to the received UAs or DMs, and restart the acknowledgment timers. After resending the SABME command PDU N2 times, the station shall stop sending the SABME command PDU, may report to the higher layer protocol and may initiate other error recovery action. The value of N2 is defined in 5.3.8.1.2.d. Other Type 2 PDUs received (commands and responses) while attempting to connect shall be ignored by the station.

5.3.7.2.4.1.2 Respondent action. When a SABME command PDU is received, and the connection is desired, the station shall return a UA response PDU to the remote station, set both the V(S) and V(R) to 0 for the corresponding data-link connection, and enter the information transfer phase. The return of the UA response PDU shall take precedence over any other response PDU that may be pending at the station for that data-link connection. It shall be possible to follow the UA response PDU with additional PDUs, if pending. If the connection is not desired, the station shall return a DM response PDU to the remote station and remain in the link disconnected mode. For a description of the actions to be followed upon receipt of a SABME or DISC command PDU, see 5.3.7.2.4.4.

5.3.7.2.4.2 Information transfer phase. After having sent the UA response PDU to an SABME command PDU or having received the UA response PDU to a sent SABME command PDU, the station shall accept and send I and S PDUs according to the procedures described in 5.3.7.2.5. Any time a station has established a connection and enters the information transfer phase, it should also send a DL-Status Indication to its local upper layer indicating a Type 2 connection has been established. When receiving an SABME command PDU while in the information transfer phase, the station shall conform to the resetting procedure described in 5.3.7.2.6. When receiving an RSET command PDU while in the information transfer phase, the station shall conform to the resetting procedure described in 5.3.7.2.7.

5.3.7.2.4.3 Data-link disconnection phase. During the information transfer phase, either station shall be able to initiate disconnecting of the data-link connection by sending a DISC command PDU and starting the acknowledgment timer (see 5.3.8.1.2.a). When receiving a DISC command PDU, the station shall return a UA response PDU and enter the data-link disconnected phase. The return of the UA response PDU shall take precedence over any other response PDU that may be

pending at the station for that data-link connection. Upon receipt of the UA or DM response PDU from a remote station, the station shall stop its acknowledgment timer for that link, and enter the link disconnected mode. Should the acknowledgment timer run out before receiving the UA or DM response PDU for a particular link, the station shall send another DISC command PDU and restart the acknowledgment timer. After sending the DISC command PDU N2 times, the sending station shall stop sending the DISC command PDU, shall enter the data-link disconnected phase, and shall report to the higher layer for the appropriate error recovery action. The value of N2 is defined in 5.3.8.1.2.d.

5.3.7.2.4.4 <u>Data-link disconnected phase</u>. After having received a DISC command PDU from the remote station and returned a UA response PDU, or having received the UA response PDU to a sent DISC command PDU, the station shall enter the data-link disconnected phase. In the disconnected phase, the station shall react to the receipt of an SABME command PDU, as described in 5.3.7.2.4.1, and shall send a DM response PDU in answer to a received DISC command PDU. When receiving any other Type 2 command, I or S PDU, the station in the disconnected phase shall send a DM response PDU. In the disconnected phase, the station shall be able to initiate a data-link connection. Any time a station enters the disconnected phase, it should send a DL-Status Indication to its local upper layer indicating a Type 2 connection has been disconnected.

5.3.7.2.4.5 <u>Contention of unnumbered mode-setting command PDUs</u>. A contention situation on a data-link connection shall be resolved in the following way: If the sent and received mode-setting command PDUs are the same, each station shall send the UA response PDU at the earliest opportunity. Each station shall enter the indicated phase either after receiving the UA response PDU, or after its acknowledgment timer expires. If the sent and received mode-setting command PDUs are different, each station shall enter the data-link disconnected phase and shall issue a DM response PDU at the earliest opportunity.

5.3.7.2.5 <u>Procedures for information transfer</u>. The procedures that apply to the transfer of I PDUs in each direction on a data-link connection during the information transfer phase are described in 5.3 7.2.5.1 through 5.3.7.2.5.11. When used, the term number one higher is in reference to a continuously repeated sequence series, that is, 127 is 1 higher than 126, and 0 is 1 higher than 127 for the modulo-128 series.

5.3.7.2.5.1 <u>Sending I PDUs</u>. When the station has an I PDU to send (that is, an I PDU not already sent), it shall send the I PDU with an N(S) equal to its current V(S) and an N(R) equal to its current V(R) for that data-link connection. At the end of sending the I PDU, the station shall increment its V(S) by 1. If the acknowledgment timer is not running at the time that an I PDU is sent, the acknowledgment timer shall be started. If the data-link connection V(S) is equal to the last value of N(R) received plus k (where k is the maximum number of outstanding I PDUs; see 5.3.8.1.2.e), the station shall not send any new I PDUs on that data-link connection, but shall be able to resend an I PDU as described in 5.3.7.2.5.6 or 5.3.7.2.5.9. Upon sending an I PDU that causes the number of outstanding I PDUs to be equal to the k2 value for that connection, the station shall send an RR (or RNR) command to the destination station. The destination station shall respond with a RR Response with the N(R) indicating the last received I PDU. When a local

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station on a data-link connection is in the busy condition, the station shall still be able to send I PDUs, provided that the remote station on this data-link connection is not also busy. When the station is in the FRMR exception condition for a particular data-link connection, it shall stop transmitting I PDUs on that data-link connection. When a station is in the timer recovery condition, it shall not send any new I PDUs on that data-link connection as per 5.3.7.2.5.11.

5.3.7.2.5.2 <u>Receiving an I PDU</u>. When the station is not in a busy condition and receives an I PDU whose N(S) is equal to its V(R), the station shall accept the information field of this PDU, increment by 1 its V(R), and act as follows:

a)   If an I PDU is available to be sent, the station shall be able to act as in 5.3.7.2.5.1 and acknowledge the received I PDU by setting N(R) in the control field of the next sent I PDU to the value of its V(R). The station shall also be able to acknowledge the received I PDU by sending an RR PDU with the N(R) equal to the value of its V(R).

b)   If no I PDU is available to be sent by the station, then the station shall either:

      (1)   If the received I PDU is a command PDU with the P-bit set to 1, then send an S PDU with its F-bit set to 1 and its N (R) equal to the current value of V (R) at the first possible opportunity (this transmission is time critical to maintaining the connection), and stop the Response Delay Timer; or

      (2)   If the received I PDU is not a command PDU with the P-bit set to 1, then the station shall:

            (a)   if the number of outstanding I PDUs received since the last I PDU for which an acknowledgment was sent is equal to or greater than *k3*, then send an S PDU with its N(R) equal to the current value of V(R) at the earliest opportunity, and stop the Response Delay Timer; else

            (b)   if the number of outstanding I PDUs received since the last I PDU for which an acknowledgment was sent is less than *k3*, and if the Response Delay Timer is not already running, then start the Response Delay Timer. When the Response Delay Timer is running then the station shall:

                  (i)   if an I PDU is sent back to the originator of the recently received I PDU before the Response Delay Timer expires, then stop the Response Delay Timer. The N(R) in the outgoing I frame will acknowledge any recently received correct in sequence I PDU frames as described in 5.3.7.2.5.1 (No S PDU needs to be sent); else

(ii)   if another PDU of any type that can be concatenated is transmitted to any destination and adequate space exists to concatenate additional frames, then concatenate onto this PDU an S PDU with its N(R) equal to the current value of V(R) addressed to the originator of the recently received I PDU, and stop the Response Delay Timer; else

(iii)   if the Response Delay Timer expires, then at the earliest opportunity, send an S PDU with its N(R) equal to the current value of V(R). (Note that S PDUs to other destinations may be concatenated with this frame as described in the preceding paragraph.)

c)   If receipt of the I PDU caused the station to go into the busy condition with regard to any subsequent I PDUs, the station shall send an RNR PDU with the N(R) equal to the value of its V(R). If I PDUs are available to send, the station shall be able to send them (as in 5.3.7.2.5.1) prior to or following the sending of the RNR PDU.

When the station is in a busy condition, the station shall be able to ignore the information field contained in any received I PDU on that data-link connection. (See 5.3.7.2.5.10.)

5.3.7.2.5.3 Receiving incorrect PDUs. When the station receives an invalid PDU or a PDU with an incorrect source address, the entire PDU shall be discarded. If an incorrect destination address is received, disregard that address field and continue processing the PDU.

5.3.7.2.5.4 Receiving out-of-sequence PDUs. When the station receives one or more I PDUs whose N(S)s are not in the expected sequence, that is, not equal to the current V(R) but is within the receive window, the station shall respond by sending a REJ or a SREJ PDU as described in either 5.3.7.2.5.4.1 or 5.3.7.2.5.4.2. Use of the SREJ is the preferred method of indicating missing frames since it allows the receiving station to request the retransmission of only those frames that are actually missing. Use of REJ to indicate missing frames results in the unnecessary retransmission of frames that were received correctly since the procedure requires that frames received out of sequence be discarded until the missing frame is received. Use of REJ to indicate missing frames is intended for use by an implementation in the case that it is providing ordered delivery of I PDUs to the next layer and adequate storage is not available (on a static or dynamic basis) within the implementation to retain out-of-sequence frames until the missing frames are received.

5.3.7.2.5.4.1 Reject response. When an I PDU has been received out-of-sequence and more than one frame is missing, the station may discard the information field of the I PDU and send a REJ PDU with the N(R) set to the value of V(R). The station shall then discard the information field of all I PDUs until the expected I PDU is correctly received. When receiving the expected I PDU, the station shall acknowledge the PDU, as described in 5.3.7.2.5.2. The station shall use the N(R) and P-bit indications in the discarded I PDU. On a given data-link connection, only one "sent REJ" exception condition from a given station to another given station shall be established at a

time. A REJ and SREJ exception condition cannot be active at the same time. A "sent REJ" condition shall be cleared when the requested I PDU is received. The "sent REJ" condition shall be able to be reset when a reject timer time-out function runs out. When the station perceives by reject timer time-out that the requested I PDU will not be received, because either the requested I PDU or the REJ PDU was in error or lost, the station shall be able to resend the REJ PDU up to N2 times to reestablish the "sent REJ" condition. The value of N2 is defined in 5.3.8.1.2.d.

5.3.7.2.5.4.2 <u>Selective reject response</u>. When an I PDU has been received and at least one frame is missing, the station may retain the information field of the out-of-sequence I PDUs and send SREJ PDUs for the missing I PDUs. A station may transmit one or more SREJ PDUs, each containing a different N(R) with the P-bit set to 0. However, a SREJ PDU shall not be transmitted if an earlier REJ condition has not been cleared. When the station perceives by the reject timer time-out that the requested I PDU will not be received, because either the requested I PDU or the SREJ PDU was in error or lost, the station shall be able to resend all outstanding SREJ PDUs in order to reestablish the "sent SREJ" condition up to N2 times.

5.3.7.2.5.5 <u>Receiving acknowledgment</u>. When correctly receiving an I or S PDU, even in the busy condition (see 5.3.7.2.5.10), the receiving station shall consider the N(R) contained in this PDU as an acknowledgment for all the I PDUs it has sent on this data-link connection with an N(S) up to and including the received N(R) minus one. The station shall reset the acknowledgment timer when it correctly receives an I or Type 2 S PDU with the N(R) higher than the last received N(R) (actually acknowledging some I PDUs). If High Reliability was requested for any of the acknowledged PDU(s), a DL-Status.Indication should be sent to the upper layer indicating acknowledgment success for those PDUs. If the timer has been reset and there are outstanding I PDUs still unacknowledged on this data-link connection, the station shall restart the acknowledgment timer. If the timer then runs out, the station shall follow the procedures in 5.3.7.2.5.11 with respect to the unacknowledged I PDUs.

5.3.7.2.5.6 <u>Receiving an SREJ PDU</u>. If the received transmission is an SREJ command or response PDU, the I PDU corresponding to the N(R) being rejected shall be retransmitted.

5.3.7.2.5.7 <u>Receiving an RSET PDU</u>. Upon receipt of the RSET command PDU, the receiving station shall reply with a UA response PDU and shall then set its V(R) to 0 for the initiating station.

5.3.7.2.5.8 <u>Receiving an REJ PDU</u>. When receiving an REJ PDU, the station shall set its V(S) to the N(R) received in the REJ PDU control field. The station shall resend the corresponding I PDU as soon as it is available. If other unacknowledged I PDUs had already been sent on that data-link connection following the one indicated in the REJ PDU, then those I PDUs shall be resent by the station following the resending of the requested I PDU. If retransmission beginning with a particular PDU occurs while waiting acknowledgment (see 5.3.7.2.5.11) and an REJ PDU is received, which would also start retransmission with the same I PDU [as identified by the N(R) in the REJ PDU], the retransmission resulting from the REJ PDU shall be inhibited.

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5.3.7.2.5.9 <u>Receiving an RNR PDU</u>. A station receiving an RNR PDU shall, with one exception described below, stop sending I PDUs on the indicated data-link connection at the earliest possible time and shall start the busy-state timer, if not already running. When the busy-state timer runs out, the station shall follow the procedure described in 5.3.7.2.5.11. In any case, the station shall not send any other I PDUs on that data-link connection before receiving an RR or REJ PDU, or before receiving an I response PDU with the F-bit set to 1, or before the completion of a resetting procedure on that data-link connection.

Exception: A Station may include a busy destination in a PDU that is addressed to multiple destination addresses if at least one of the multiple destinations is not busy.

5.3.7.2.5.10 <u>Station-busy condition</u>. A station shall enter the busy condition on a data-link connection when it is temporarily unable to receive or continue to receive I PDUs due to internal constraints; for example, receive buffering limitations. When the station enters the busy condition, it shall send an RNR PDU at the first possible opportunity. It shall be possible to send I PDUs waiting to be sent on that data-link connection prior to or following the sending of the RNR PDU. The station may send a URNR command PDU to the global address after the RNR PDU. While in the busy condition, the station shall accept and process supervisory PDUs and return an RNR response PDU with the F-bit set to 1 if it receives an S or I command PDU with the P-bit set to 1 on the affected data-link connection. To indicate the clearance of a busy condition on a data-link connection, the station shall send an I response PDU with the F-bit set to 1 if a P-bit set to 1 is outstanding, an REJ response PDU, or an RR response PDU on the data-link connection with N(R) set to the current V(R), depending on whether or not the station discarded information fields of correctly received I PDUs. The station may then send a URR command PDU to the global address. Additionally, the sending of a SABME command PDU or a UA response PDU shall indicate the clearance of a busy condition at the sending station on a data-link connection.

5.3.7.2.5.11 <u>Waiting acknowledgment</u>. The station maintains an internal retransmission count variable for each data-link connection, which shall be set to 0 when the station receives or sends a UA response PDU to a SABME command PDU, when the station receives an RNR PDU, or when the station correctly receives an I or S PDU with the N(R) higher than the last received N(R) (actually acknowledging some outstanding I PDUs). If the acknowledgment timer, busy-state timer, or the P-bit timer runs out, the station on this data-link connection shall enter the timer recovery condition and add 1 to its retransmission count variable. When a station is in the timer recovery condition, the station shall not send any new I PDUs to the destination station. The station shall then start the P-bit timer and send an S command PDU with the P-bit set to 1. The timer recovery condition shall be cleared on the data-link connection when the station receives a valid I or S PDU from the remote station with the F-bit set to 1. If, while in the timer recovery condition, the station correctly receives a valid I or S PDU with:

      a.   the F-bit set to 1 and the N(R) within the range from the last value of N(R) received to the current V(S) inclusive, the station shall clear the timer recovery condition, set its V(S) to the received N(R), stop the P-bit timer, and resend any unacknowledged PDUs; or

b.   the P/F bit set to 0 and the N(R) within the range from the last value of N(R) received to the current V(S) inclusive, the station shall not clear the timer recovery condition but shall treat the N(R) value received as an acknowledgment for the indicated previously transmitted I PDUs. (See 5.3.7.2.5.5.)

If the P-bit timer runs out in the timer recovery condition, the station shall add 1 to its retransmission count variable. If the retransmission count variable is less than N2, the station shall resend an S PDU with the P-bit set to 1 and restart its P-bit timer. If the retransmission count variable is equal to N2, the station shall initiate a resetting procedure, by sending a SABME command PDU, as described in 5.3.7.2.6. N2 is a system parameter defined in 5.3.8.1.2.d.

5.3.7.2.6 Procedures for mode resetting. The resetting phase is used to initialize both directions of information transfer according to the procedure described in 5.3.7.2.6.1 through 5.3.7.2.6.3. The resetting phase shall apply only during ABM. Either station shall be able to initiate a resetting of both directions by sending a SABME command PDU and starting its acknowledgment timer. Any time a station resets its connection with a remote station, it should also send a DL-Status Indication to its local upper layer indicating a Type 2 connection has been reset.

5.3.7.2.6.1 Receiver action. After receiving a SABME command PDU, the station shall return one of two types of responses, at the earliest opportunity:

a.   a UA response PDU and reset its V(S) and V(R) to 0 to reset the data-link connection, or

b.   a DM response PDU if the data-link connection is to be terminated.

The return of the UA or DM response PDU shall take precedence over any other response PDU for that data-link connection that may be pending at the station. It shall be possible to follow the UA PDU with additional PDUs, if pending.

5.3.7.2.6.2 Initiator action. If the UA PDU is received correctly by the initiating station, it shall reset its V(S) and V(R) to 0 and stop its acknowledgment timer. This shall also clear all exception conditions that might be present at either of the stations involved in the reset. The exchange shall also indicate clearance of any busy condition that may have been present at either station involved in the reset. If a DM response PDU is received, the station shall enter the data-link disconnected phase, shall stop its acknowledgment timer, and shall report to the higher layer for appropriate action. If the acknowledgment timer runs out before a UA or DM response PDU is received, the SABME command PDU shall be resent and the acknowledgment timer shall be started. After the timer runs out N2 times, the sending station shall stop sending the SABME command PDU, and shall enter the ADM, may report to the higher layer protocol and may initiate other error recovery actions. The value of N2 is defined in 5.3.8.1.2.d. Other Type 2 PDUs, with the exception of the SABME and DISC command PDUs, received by the station before completion of the reset procedure shall be discarded.

5.3.7.2.6.3 Resetting with the FRMR PDU. Under certain FRMR exception conditions (listed in 5.3.7.2.8), it shall be possible for the initiating station, by sending an FRMR response PDU, to ask the remote station to reset the data-link connection. Upon receiving the FRMR response PDU (even during a FRMR exception condition), the remote station shall either initiate a resetting procedure, by sending a SABME or RSET command PDU, or initiate a disconnect procedure, by sending a DISC command PDU. After sending an FRMR response PDU, the initiating station shall enter the FRMR exception condition. The FRMR exception condition shall be cleared when the station receives or sends a SABME or DISC command PDU, DM response PDU or RSET command PDU. Any other Type 2 command PDU received while in the FRMR exception condition shall cause the station to resend the FRMR response PDU with the same information field as originally sent. In the FRMR exception condition, additional I PDUs shall not be sent, and received I and S PDUs shall be discarded by the station. It shall be possible for the station to start its acknowledgment timer on the sending of the FRMR response PDU. If the timer runs out before the reception of a SABME or DISC command PDU from the remote station, it shall be possible for the station to resend the FRMR response PDU and restart its acknowledgment timer. After the acknowledgment timer has run out N2 times, the station shall reset the data-link connection by sending a SABME command PDU. The value of N2 is defined in 5.3.8.1.2.d. When an additional FRMR response PDU is sent while the acknowledgment timer is running, the timer shall not be reset or restarted.

5.3.7.2.7 Procedures for sequence number resetting. This resetting procedure, employing the RSET command, is used to reinitialize the receive-state variable V(R) in the addressed station and the send-state variable V(S) in the local station. The addressed station shall confirm acceptance of the RSET command by transmission of a UA response at the earliest opportunity. Upon acceptance of this command, the addressed station V(R) shall be set to 0. If the UA response is received correctly, the initializing station shall reset its V(S) to 0. The RSET command shall reset all PDU rejection conditions in the addressed station, except for an invalid N(R) sequence number condition which the addressed station has reported by a FRMR. The RSET command may be sent by the station that detects an invalid N(R) to clear such a frame rejection condition in place of sending a FRMR frame. To clear an invalid N(R) frame rejection condition with an RSET command, the RSET command shall be transmitted by the station that detects the invalid N(R). A station may resend the contents of the information field of unacknowledged outstanding I PDUs. Any time a station resets its connection with a remote station, it should also send a DL-Status Indication to its local upper layer indicating a Type 2 connection has been reset.

5.3.7.2.8 FRMR exception conditions. The station shall request a resetting procedure by sending an FRMR response PDU, as described in 5.3.7.2.6.3, after receiving, during the information transfer phase, a PDU with one of the conditions identified in 5.3.6.2.3.6. The coding of the information field of the FRMR response PDU that is sent is given in 5.3.6.2.3.6. The other station shall initiate a resetting procedure by sending a SABME or RSET command PDU, as described in 5.3.7.2.6, after receiving the FRMR response PDU.

5.3.7.3 Description of type 4 procedures. The procedures associated with Type 4 operation are described in 5.3.7.3.1 through 5.3.7.3.5.3.

5.3.7.3.1 <u>Modes of operation</u>. In Type 4 operation, no modes of operation are defined. A station using Type 4 procedures shall support the entire set whenever it is operational on the network.

5.3.7.3.2 <u>Procedures for addressing</u>. The address field shall be used to indicate the source and destinations of the transmitted PDU. The first bit in the source address shall be used to identify whether a command or a response is contained in the PDU. Individual, group, and global addressing shall be supported for the destination addresses in command PDUs. The source address shall contain an individual address.

5.3.7.3.3 <u>Procedure for using the P/F bit</u>. The P/F bit is not implemented in Type 4 operation.

5.3.7.3.4 <u>Procedures for logical data-link set-up and disconnection</u>. Type 4 operation does not require any prior data-link set-up and disconnection. Data-link set-up and disconnection procedures are not required for Type 4 operation. All stations shall advance to the information transfer state.

5.3.7.3.5 <u>Procedures for information transfer</u>.

5.3.7.3.5.1 <u>Sending DIA command frames</u>. The DIA PDU may either be a new PDU from the local user, or a retransmission of a DIA PDU which was not acknowledged within the period determined by the T1 parameter. DIA PDUs are retransmitted up to N2 times, where N2 is as specified by the station parameters. If a DIA PDU is not acknowledged after N2 retransmissions, a DL-Status-Indication should be sent to the upper layer indicating an acknowledgment failure.

5.3.7.3.5.2 <u>Receive not ready procedure</u>.

5.3.7.3.5.2.1 <u>Sending a DRNR command PDU</u>. A station may generate and transmit a DRNR command PDU if its Quiet Mode is disabled and it receives a DIA PDU which it cannot accept because its receive buffers are full. A station may generate a DRNR command PDU when directed by the management function (e.g., operator). The DRNR command S PDU does not acknowledge a DIA PDU. The station may send a URNR command PDU to the global address after the DRNR PDU.

5.3.7.3.5.2.2 <u>Receiving a DRNR command PDU</u>. Upon receipt of a DRNR PDU a station shall, with one exception described below, inhibit transmission of DIA PDUs to the station which originated the DRNR command by updating the station status table to reflect this busy condition. The DRNR PDU shall not change the Quiet Mode status of a station. Any PDUs in the Retransmission queue addressed to the busy station shall be modified to delete (null) the busy station from the destination address list. Normal transmissions of DIA PDUs to that station shall resume upon receipt of a DRR command from the station.

Exception: A Station may include a busy destination in a PDU that is addressed to multiple destination addresses if at least one of the multiple destinations is not busy.

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5.3.7.3.5.2.3 Sending a DRNR response PDU. A station shall generate and transmit a DRNR response PDU after it has sent a DRNR command PDU (if its Quiet Mode is disabled) while it is processing frames in its receive queues in the busy condition. A DRNR response acknowledges the DIA PDU indicated in the PDU identification number field while reinforcing the station's busy condition.

5.3.7.3.5.2.4 Receiving a DRNR response PDU. Upon receipt of a DRNR response PDU, a station shall search the destination addresses associated with the identification number in the DRNR response PDU. The response PDU originator's address shall be deleted from the destination address field (if it is still there) of the DIA being acknowledged.

5.3.7.3.5.3 Receive ready procedures.

5.3.7.3.5.3.1 Sending a DRR PDU. A station shall generate and transmit a DRR PDU if its Quiet Mode is disabled and one of the following conditions exist.

      a.   The station is no longer busy and had previously sent a DRNR command PDU.

      b.   The station is not busy and the station received a DIA PDU from a transmitting station which requires acknowledgment.

      c.   If directed by the user interface.

5.3.7.3.5.3.1.1 Sending a DRR command PDU. The DRR command PDU is generated and transmitted by a station to indicate the end of a Type 4 busy/buffer full condition. The DRR command S PDU does not acknowledge DIA PDUs. The DRR command PDU only changes the busy status to DRR. This frame does not change the Quiet Mode status. The station may send a URR command PDU to the global address after the DRR PDU.

5.3.7.3.5.3.1.2 Sending a DRR response PDU. The DRR response PDU is generated and transmitted by a station whose Quiet Mode is disabled to acknowledge the acceptance of a DIA PDU, and is addressed to the originator of the DIA PDU. The DIA PDU which is being acknowledged is indicated by the PDU identification number.

5.3.7.3.5.3.2 Receiving a DRR response PDU. Upon receipt of a DRR response PDU a station shall search the destination addresses associated with the identification number in the DRR response PDU. The DRR response PDU originator's address shall be deleted from the destination address field of the DIA being acknowledged. If High Reliability was requested for the DIA, a DL-Status Indication should be sent to the upper layer indicating acknowledgment success.

5.3.8 Data-link initialization. The XNP messages, described in Appendix E, are used to establish and control link parameters. The Join Request message contains the link operating parameters such as net busy detect time, subscriber rank, and net access method. Initialization is caused by an operator or system request. The Join Request is sent to the default network control (NETCON) destination address, which shall be the station assigned to perform NETCON station

responsibilities. The NETCON station verifies link parameters and provides values for missing or incorrect parameters to ensure that the new station will not disrupt the net. The NETCON station will reply with either a Join Reject or Join Accept PDU. If the initializing station receives a Join Reject PDU, it should not attempt any link activity until the correct parameters have been obtained.

NOTE: Link initialization may also occur without an XNP message exchange. Prearrangement by timing, voice, written plans, or orders provides the operator with the necessary frequency, link address, data rate, and other parameters to enter a net and establish a link. With the prearranged information, an operator may begin link activity on the net and initialization is assumed when the new station senses the net and transmits its first message.

5.3.8.1 List of data-link parameters. This document defines a number of data-link parameters for which the system-by-system range of values are determined at network establishment. The maximum number of octets in the information field of a UI, I or DIA PDU is an adjustable data-link parameter in the range of 708 - 3345. The definitions of additional parameters for the three types of operation are summarized in 5.3.8.1.1 through 5.3.8.1.3.

5.3.8.1.1 Type 1 logical data-link parameters. The logical data-link parameters for Type 1 operation shall be as follows:

a. Acknowledgment timer. The acknowledgment timer is a data-link parameter that shall define the timeout period (TP) during which the sending station shall expect an acknowledgment from a specific destination station. The acknowledgment timer should not be activated until the corresponding PDU has been transmitted. TP shall take into account any delay introduced by the physical sublayer. The value of TP is described in Appendix C (C4.3).

b. Busy-state timer. The busy-state timer is a data-link parameter that defines the time interval following receipt of the URNR command PDU during which the station shall wait for the other station to clear the busy condition. Default value is 120 seconds.

c. Maximum number of retransmissions, N4. N4 is a data-link parameter that indicates the maximum number of times that an UI or TEST command PDU is retransmitted by a station trying to accomplish a successful information exchange. Normally, N4 is set large enough to overcome the loss of a PDU due to link error conditions. The maximum number of times that a PDU is retransmitted following the expiration of the acknowledgment timer is established at protocol initialization. This value is in the range of 0 through 5 and defaults to 2. The retransmission of PDUs may be overridden by the Quiet Mode parameter, which is described in 5.3.11.2.

d. <u>Minimum number of octets in a PDU</u>. The minimum-length valid data-link PDU shall contain 2 flags, 2 addresses, one 8-bit control field, and the FCS. The minimum number of octets in a valid data-link PDU shall be 9.

5.3.8.1.2 <u>Type 2 data-link parameters</u>. The data-link connection parameters for Type 2 operation shall be as follows:

a. <u>Acknowledgment timer</u>. The acknowledgment timer is a data-link connection parameter that shall define the time interval during which the station shall expect to receive acknowledgment to one or more outstanding I PDUs or an expected response to a sent U command PDU. The acknowledgment timer should not be activated until the corresponding PDU has been transmitted. Time values are established at protocol initialization and are in the range of 10 to 1800 seconds in one-second increments. Default is 120 seconds.

b. <u>P-bit timer</u>. The P-bit timer is a data-link connection parameter that defines the time interval during which the station shall expect to receive a frame with the F-bit set to 1 in response to a sent Type 2 command with the P-bit set to 1. The P-bit timer should not be activated until the corresponding PDU has been transmitted. Time values are established at protocol initialization and are in the range of 10 to 60 seconds in increments of 1 second. Default is 10 seconds.

c. <u>Reject timer</u>. The reject (REJ) timer is a data-link connection parameter that defines the time interval during which the station shall expect to receive a reply to a sent REJ or SREJ PDU. The reject timer value shall be equal to or less than twice the acknowledgment timer. The reject timer should not be activated until the corresponding PDU has been transmitted.

d. <u>Maximum number of retransmissions, N2</u>. N2 is a data-link connection parameter that indicates the maximum number of times that a PDU (including the S command PDU that is sent as a result of the acknowledgment P-bit or reject timer expiring) is sent, following the running out of the acknowledgment timer, the P-bit timer, or the reject timer. The maximum number of times that a PDU is retransmitted following the expiration of the timers is established at protocol initialization. This value is in the range of 0 through 5 and defaults to 2. The retransmission of PDUs may be overridden by the Quiet Mode parameter, which is described in 5.3.11.2.

e. <u>Maximum number of outstanding I PDUs, k</u>. The maximum number (k) of sequentially numbered I PDUs that the sending station may have outstanding (i.e. unacknowledged) on a single data-link connection simultaneously. The value of this parameter is in the range 1 through 127. (This value of this parameter may be established through the use of the Type 2 k Window field of an XNP message as described in Appendix E, "Type 2 Parameters".)

f.　　Maximum number of outstanding I PDUs at which an acknowledgment is requested, *k2*. The maximum number (*k2*) of outstanding (i.e. unacknowledged) I PDUs that can be sent by a source station on a data-link connection before the station requests acknowledgment. When this threshold is reached the sending station sends an S PDU that both acknowledges received I frames and causes an S PDU to be sent in return to acknowledge outstanding I PDUs. The value of this parameter is in the range 1 through 127, but would normally be less than or equal to the value of parameter *k*.

g.　　Maximum number of outstanding received I PDUs threshold, *k3*. The maximum number (*k3*) of correct in sequence I PDUs received on a data-link connection since the last I PDU received on the data-link connection was acknowledged. When this threshold is reached the receiving station generates a S PDU to acknowledge received frames. The value of this parameter is in the range 1 through 127, but would normally be less than or equal to the value of parameter *k*.

h.　　Response delay timer. The amount of time that a station waits after an I PDU Response or an I PDU Command with its P-bit set to 0 is received until it is acknowledged by transmission of a S PDU in the case that no other frames are available for transmission. The value of this parameter is in the range of 1 to 1800 seconds in one-second increments, but will normally be less that the value of the Acknowledgment Timer parameter. (The value of this parameter may be established by the Type 2 Acknowledgment Timer and Response Timer fields of an XNP Parameter Update message as described in Appendix E, "Type 2 Parameters".)

i.　　Minimum number of octets in a PDU. A minimal-length valid data-link connection PDU shall contain exactly 2 flags, 2 address fields, 1 control field, and the FCS. Thus, the minimum number of octets in a valid data-link connection PDU shall be 9 or 10, depending on whether the PDU is a U PDU, or an I or S PDU, respectively.

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5.3.8.1.3 Type 4 data-link parameters. The logical data-link parameters for Type 4 operation shall be as follows:

    a.   Acknowledgment (T1) timer. The T1 timer is the maximum time a station shall wait for an acknowledgment of a transmitted DIA PDU before that PDU is retransmitted. The value of T1 shall be in the range of 5-120 seconds in increments of 0.2 seconds. Each DIA PDU transmitted shall be assigned a T1 timer. When the T1 timer expires for DIA PDU, that DIA PDU shall be retransmitted in the next transmission opportunity for that precedence, assuming the N2 count has not been reached. DIA PDUs with only one destination will be discarded if the destination replied with a DRNR or DRR response PDU. If the DIA PDU is multi-addressed, the receive station is removed (nulled) from the destination address field. This timer shall be paused whenever the net is busy with voice. This timer is resumed when voice transmission has completed.

    b.   Maximum number of retransmission attempts, N2. The N2 parameter shall indicate the maximum number of retransmission attempts to complete the successful transmission of a DIA PDU. The value of N2 shall be the maximum retransmit value (range = 0-5).

    c.   k maximum number of outstanding DIA frames. The value of k indicates the maximum number of DIA PDUs that a station may have outstanding (awaiting acknowledgment) to all stations at any given time. The value of k ranges from 5 - 20 DIA PDUs.

5.3.9 Frame transfer. After the station has joined the net, it can begin to send frames. The data-link layer shall request the transmission of a frame by issuing a Unitdata request to the physical layer.

5.3.9.1 PDU transmission. The data-link layer initiates transmission by building a transmission unit and passing it to the physical layer. The elements of a transmission unit include one transmission header (see 5.3.1), one or more PDUs (see data-link concatenation, below), the additional bits resulting from the operations of zero-bit-insertion, optional FEC encoding, optional TDC and optional scrambling. To request transmission, a PL-Unitdata-Request is issued by the data-link layer protocol after a transmission unit has been constructed. PDUs shall be queued for transmission in such a manner that the highest precedence PDUs are transmitted before lower precedence PDUs. If a prioritized net access scheme is active, the precedence access level used shall be the precedence of the PDU that is to be transmitted next. Transmission units of the same precedence shall be in first-in first-out order. Type 2 I PDUs for a particular connection shall be transmitted in the order of their sequence numbers. Any PDUs may be concatenated at the data-link layer or physical layer except Type 1 PDUs with the P bit set to 1.

5.3.9.2 <u>Data-link concatenation</u>. The sending station may concatenate any PDUs, except Type 1 PDUs that require the TP timer (P bit set to 1), by using one or two flags to separate each PDU. All receiving stations shall be able to de-concatenate the reception into separate PDUs. The combined length of the concatenated PDUs, before 0-bit insertion, may not exceed the established maximum PDU size for a single PDU (see 5.3.8.1). The PDUs are concatenated after the 0-bit insertion algorithm is applied. FEC, with or without TDC, and scrambling are optionally applied before the transmission unit is passed to the physical layer in a PL-Unitdata-Request. Data-link concatenation to add another interior data frame shall not be performed if the resulting frame would take longer to transmit than the maximum transmit time allowed for the network. Data-link concatenation is shown in Figure 22.
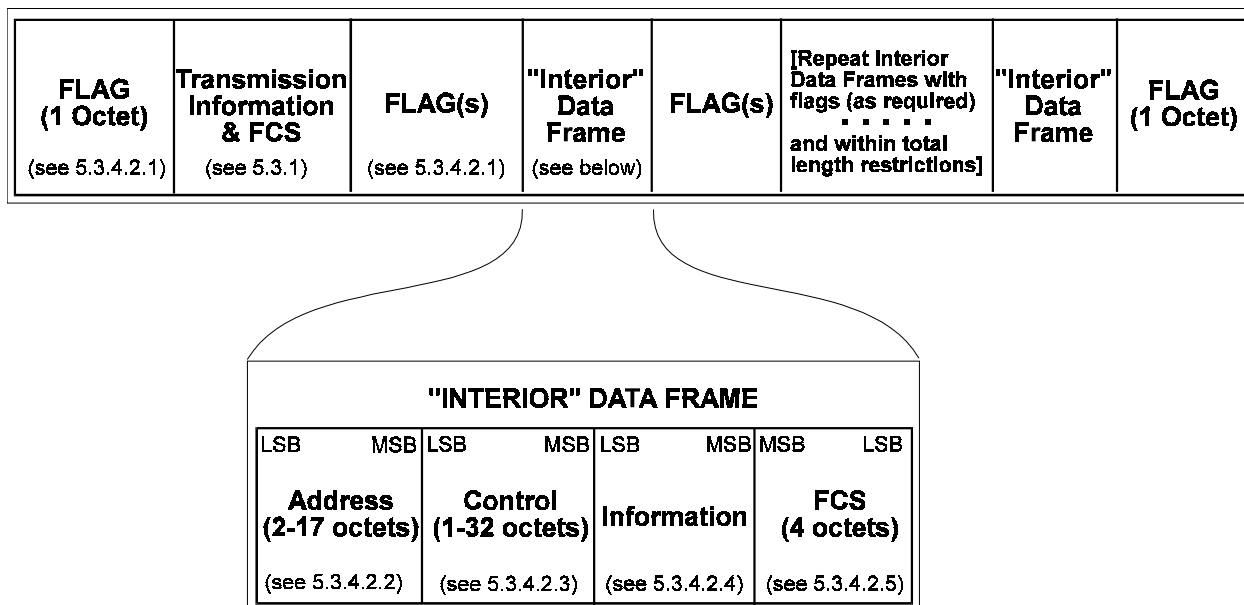
FIGURE 22. <u>Data-link concatenation</u>.

5.3.9.3 <u>Physical-layer concatenation</u>. Physical layer concatenation does not apply when Packet Mode is used. More than one PDU may be passed to the physical layer without waiting for an intervening net access delay period. The time to transmit the combined length of the transmission frame, shall not exceed the maximum transmit time allowed for the network. The physical layer shall transmit each transmission unit following the complete physical layer procedures with no additional bits between Interior Transmission Units (except for bit synchronization when used in Asynchronous Mode). Physical layer concatenation is shown in Figure 23. Note that the Phasing field described in 5.2.1.2 shall precede the first Interior Transmission Unit only.

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TRANSMISSION FRAME

Phasing	"Interior" Transmission Unit	Bit Sync	"Interior" Transmission Unit	[Repeat Bit Sync and Interior Transmission Units • • • • • as needed, within total length restrictions]	Bit Sync	"Interior" Transmission Unit

NOTE: Bit Synchronization is used only in Asynchronous Mode.

"INTERIOR" TRANSMISSION UNIT

Transmission Synchronization	Transmission Header				Data Link Frame					
	Flag	Transmission Information	FCS	Flag	Flag	Address	Control	Information	FCS	Flag
(variable length)	(8 bits)	(2 octets)	(32 bits)	(8 bits)	(8 bits)	(2-17 octets)	(1-27 octets)	(up to 3345 octets)	(32 bits)	(8 bits)
5.2.1.3	5.3.4.2.1	5.3.1	5.3.4.2.5			5.3.4.2.2	5.3.4.2.3	5.3.4.2.4		

FIGURE 23. Physical-layer concatenation.

5.3.9.4 PDU transmissions. Both data link layer and physical layer concatenation may be used to build a single transmission frame. All types of operation PDUs, except Type 1 PDUs with the P-bit set may be concatenated within the same single transmission frame. PDUs are placed in the appropriate precedence-level queue, with each level queue using a single first-in first-out order. If the first PDU in the highest precedence level queue (or only queue) may be concatenated, then other PDUs may be concatenated with that PDU even if a PDU that does not allow concatenation is queued ahead of them. The PDU that did not allow concatenation shall be at the head of its appropriate queue for the next net access period. If the first PDU in the highest precedence level queue (or only queue) does not allow concatenation, it shall be the only PDU transmitted in that net access period.

5.3.10 Flow control. Flow control provides the capability of reducing the allowed input rate of information to prevent congestion to the point where normal operation may become impossible. The control-field sequence numbers are available for this service.

5.3.10.1 Type 1 flow control. Type 1 transmissions can be acknowledged or unacknowledged. Acknowledged and unacknowledged operations can perform flow control using URR and URNR messages. These messages announce the station's ability to accept incoming frames.

5.3.10.2 Type 2 flow control. The send and receive sequence numbers, $N(S)$ and $N(R)$, are used in conjunction with the send- and receive-state variables, $V(S)$ and $V(R)$, to control data flow. Flow control is implemented by the window method. The window defines the maximum number of undelivered frames a given user may have outstanding. The maximum number (k) of sequentially numbered I PDUs that may be outstanding (that is, unacknowledged) at any given

time is a data-link connection parameter, which shall never exceed 127. The incremental updating of N(R) acts as the positive acknowledgment of transmitted frames up to, but not including, that frame number. The window flow-control mechanism requires that the highest sequence number transmitted by the user be less than the sum of the last received N(R) plus k mod MODULUS (see 5.3.5.2.1). Window size (k) is a feature that is agreed upon by the users at initialization. The larger the window, the greater the traffic loading a given user places on a single channel.

5.3.10.3 Type 4 flow control. Type 4 flow control is performed using DRR and DRNR messages. These messages indicate a station's ability to accept incoming DIA frames. In addition, a window method is used to define the maximum number of frames a given station may have outstanding. The maximum number of DIA PDUs that may be outstanding (unacknowledged) at any given time is the Type 4 k parameter.

5.3.11 Acknowledgment and response. All UI, DIA or I PDUs that require an acknowledgment shall be acknowledged except for the following cases:

     a.   the control field of the received PDU specifies that no acknowledgment is required,

     b.   the Quiet Mode (described in 5.3.11.2), has been set to ON,

     c.   the receiving station is a group (including global) addressee only,

     d.   the receiving station's individual address is not in the address field, or

     e.   the PDU is invalid.

5.3.11.1 Acknowledgment. Acknowledgments are applicable for Type 1, Type 2 and Type 4 operations.

5.3.11.1.1 Type 1 acknowledgment. Each PDU, with the P-bit set to 1, shall be responded to before another PDU is transmitted. This is defined as a coupled acknowledgment. All UI and TEST command PDUs that have the P-bit set to 1 shall be acknowledged. The RHD procedures (see C4.2) shall be followed by all stations on the network to allow each responding station an interval in which they can transmit their response.

5.3.11.1.2 Type 2 acknowledgment. Type 2 PDUs that require acknowledgment shall activate the acknowledgment timer. Type 2 also uses P and F-bit procedures for acknowledgments, but these P and F-bit procedures do not involve coupled acknowledgments. The Type 2 operation does not use the RHD timer, which allows receiving stations to send their acknowledgments during the current net access period. All acknowledgments are transmitted in another net access period. An I PDU acknowledgment does not necessarily correspond on a one-to-one basis with the I PDU and does not necessarily apply to the immediately preceding I PDU.

5.3.11.1.3 Type 4 acknowledgment. The DIA PDU shall activate the acknowledgment timer. The Type 4 operation does not use the RHD timer. All acknowledgments are sent in another channel access period. All DIA PDUs are independently acknowledged.

5.3.11.2 Quiet mode. The protocol shall allow an operator to initiate Quiet Mode as an override feature that, when invoked, prevents any transmission (including retransmission) without explicit permission from the operator. As a security feature, the operator shall be able to turn off automatic transmissions but still continue to receive. Normal protocol exchanges shall occur when the Quiet Mode is OFF. Only the operator can initiate a transmission when the Quiet Mode is ON. The Quiet Mode shall override the Maximum Number of Retransmissions data-link parameters. The default value of the Quiet Mode is OFF. If the Quiet Mode is ON during Type 2 operations, the flow control mechanism and retransmission timers in the remote system will eventually cause the connection to be lost. UI, I, or DIA PDUs received by a station with Quiet Mode ON shall be serviced in the normal way except nothing will be returned nor queued for later transmission.

5.3.11.3 Immediate retransmission. Certain time critical exchanges require immediate retransmission if the acknowledgment is not received in the allocated response interval. This is accomplished by using the special address of 3 in the destination field with the Type 1 operation with the P-bit set to 1. All receiving stations calculate their TP based upon the total number of individual and special addresses. The sending station shall not include the special address 3 in its TP calculation and shall schedule any necessary retransmissions during the longer TP experienced by other stations.

5.3.12 Invalid frame. A frame is invalid if it has one or more of the following characteristics:

      a.   not bounded by a beginning and ending flag,

      b.   too short,

      c.   too long,

      d.   has an invalid address or control field, and

      e.   has an FCS error.

A frame is too short if it contains less than 9 bytes. A frame is too long if it exceeds the maximum PDU length as described in 5.3.8.1. Any invalid frame shall be discarded.

5.3.13 Retransmission. The data-link layer will retransmit a command frame waiting for a response. The default number of retransmissions is 2, but the data-link layer protocol may be initialized to automatically retransmit 0 to 5 times. If the Quiet Mode is ON, no automatic retransmissions shall be made.

5.3.14 Error detection and correction. FEC coding alone, or FEC coding in unison with TDC, may be used to provide error detection and correction (EDC) capabilities to compensate for errors induced during transmission. If selected, the FEC process shall be used to encode the data-link frame of 5.3.4. If selected, the TDC process shall be applied to the FEC-encoded data-link frame and to the fill bits. Three modes of EDC shall be supported: FEC OFF, FEC ON with TDC, and FEC ON without TDC (NOTE: FEC ON without TDC may be used when the transmission channel provides the TDC capability). The EDC modes are selectable.

5.3.14.1 Forward-error-correction coding. When FEC is selected, the Golay (24,12) cyclic block code, described in detail in Appendix F, shall be used for FEC. The generator polynomial to obtain the 11 check bits shall be

$$g(x) = x^{11} + x^{10} + x^6 + x^5 + x^4 + x^2 + 1$$

where $g(x)$ is a factor of $x^{23} +1$.

5.3.14.2 Forward-error-correction preprocessing. When FEC is selected, data bits shall be divided into a sequence of 12-bit segments for Golay encoding. The total number of segments shall be an integral number. If the data bits do not divide into an integral number of segments, fill bits, consisting of 1 to 11 0's, shall be added at the end to form an integral number of segments. Coupled acknowledgment of Type I URR, URNR and TEST Response frames with their F-bit set shall be duplicated, including the beginning and ending flag, when FEC and TDC are selected. This provides a station with two opportunities to receive an error-free frame. The duplicated copy shall always start at the exact midpoint of the TDC Block.

5.3.14.3 Time-dispersive coding. TDC bit interleaving may be selected in unison with FEC. When TDC is selected, data shall be formatted into a sequence of TDC blocks composed of sixteen 24-bit Golay (24, 12) codewords (that is, there are 384 FEC-encoded bits per TDC block). Each TDC block shall contain a total of 16 FEC codewords. If the last TDC block of a message contains less than 16 FEC codewords, fill codewords shall be added to complete the TDC block. These 24-bit fill codewords shall be created by Golay-encoding an alternating sequence of 12-bit data words, with the first word composed of 12 ones followed by a word composed of 12 zeros. The fill codewords shall alternate until the TDC block is filled. The TDC block shall be structured into a 16 x 24 matrix (the Golay codewords appear as rows), as shown in Figure 24.

A_1 through A_{24} are the bits of the first Golay codeword. A_{25} is the first bit of the second Golay codeword. Each TDC block matrix shall be rotated to form a 24 x 16 matrix. The Golay codewords now appear as columns, as shown in Figure 25. The TDC block is transmitted row by row with the LSB (A_1) of the first row first. At the receiver, the TDC-encoded bit stream shall be structured into a 24 x 16 matrix. Each received TDC block matrix shall be rotated to form the original 16 x 24 matrix, as shown in Figure 24. The TDC decoder at the receiver shall perform the inverse of the TDC encoding process.

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A$_1$	A$_2$				A$_{23}$	A$_{24}$
A$_{25}$	A$_{26}$				A$_{47}$	A$_{48}$
A$_{49}$	A$_{50}$				A$_{71}$	A$_{72}$
A$_{361}$	A$_{362}$				A$_{383}$	A$_{384}$

Golay Codeword in each row
A$_1$, A$_2$, A$_3$, ... , A$_4$

FIGURE 24. 16 x 24 matrix before interleaving.

A$_1$	A$_{25}$				A$_{337}$	A$_{361}$
A$_2$	A$_{26}$				A$_{338}$	A$_{362}$
A$_3$	A$_{27}$				A$_{339}$	A$_{363}$
A$_{24}$	A$_{48}$				A$_{360}$	A$_{384}$

Golay Codeword in each row
A$_1$, A$_{25}$, ... A$_{337}$, A$_{361}$

FIGURE 25. Transmitter's 24 x 16 matrix after interleaving.

5.3.15 Data scrambling. Data scrambling must be performed if the transmission medium does not have a DC response and there is the possibility that "long" strings of NRZ ones or zeros are transmitted. Long is a relative term that is dependent on the data rate, the low frequency channel cutoff frequency, and the channel signal-to-noise ratio (S/N), since at low S/N there is less margin for DC drift.

    a.   At the Data Link layer, the Transmission Header selects a CCITT V.36 scrambler, which includes a randomizer function as well as a pseudo-noise (PN) generator. It is applied inside the FEC (that is, before FEC is applied).

    b.   CCITT V.36 scrambling shall not be applied outside the FEC because bit errors at the receiver will be extended. In addition, a CCITT V.33 scrambler, which uses a PN generator but not a randomizer, is specified for use at the physical layer. In a high bit error rate environment this extension will become catastrophic. For that reason a CCITT V.33 scrambler, which uses a PN generator but not a randomizer, is specified for use at the Physical layer (as part of the multi-dwell protocol; see

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J3.3). In both cases, there is a very small probability that the interleaving for the Data Link layer scrambler or the fixed PN sequence for the Physical layer scrambler may do more harm than good. Therefore, they are individually selectable. Both scramblers should not be used at the same time. If CCITT V.36 scrambling/descrambling is used, the contents of the adverse state detector (ASD) and the 20-state shift register shall be initialized to all ones prior to scrambling or descrambling data link frames in each interior transmission unit.

5.3.16 <u>Link layer interactions</u>. The data-link layer interacts with both the next higher and next lower layer to pass or receive information regarding services requested or performed. Three primitives are used to pass information for the sending and receiving of data across the upper layer boundary.

a. Requests for transmission of data are sent by the upper layer, using the data-link layer (DL) Unitdata Request primitive, with the following parameters:

DL-Unitdata Request
Message ID
Destination(s)
Source
Topology Update ID
Quality of Service
Precedence
Throughput Requested (Normal/High)
Delay Requested (Normal/Low)
Reliability Requested (Normal/High)
Data/Data Length

b. Indications are provided to the upper layer through the DL-Unitdata Indication and DL-Unitdata Status Indication primitives with the following parameters:

DL-Unitdata Indication
Destination(s)
Source
Topology Update ID
Data/Data Length

DL-Status Indication
Message ID
Destination(s)
Acknowledgment Success/Failure
Connection Status
Neighbor detection

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c.   Descriptions of the above parameters follow:

(1)   Message ID is an indicator established by the upper layer in the DL-Unitdata Request and used to associate a subsequent DL-Status Indication acknowledgment status with that request.

(2)   The destination(s) can be 1 to 16 individual, special or multicast (including global) addresses.

(3)   The source address is the individual address of the outgoing link.

(4)   Topology Update ID, in a DL-Unitdata Request, shall contain the most recent Topology Update ID sent from the upper layer. Topology Update ID, in a DL-Unitdata Indication, shall contain the Topology Update Identifier field from the Transmission Header.

(5)   Quality of Service parameters are used to determine the service provided by the data-link layer.

(a)   Precedence parameters are used by the prioritized transmission scheme and are used to order outgoing queues. The precedence levels available to the network will be mapped into three levels (urgent, priority, and routine) in the data-link layer. Precedence levels in the network layer shall be mapped as shown in Table IX.

(b)   Precedence and the other Quality of Service parameters are used to select a preferred data link type of procedure. The recommended mapping shown in Table X is provided for guidance.

(6)   Data/Data Length is the block of data exchanged between the data-link layer and its upper layer user, and an indication of the data's length.

(7)   Acknowledgment Success/Failure is an indicator to inform the upper layer whether a data-link acknowledgment was received from the remote station when high reliability was requested in a Unitdata Request.

(8)   Connection Status is an indicator to inform the upper layer if a Type 2 connection has been established, reset or disconnected.

(9)   Neighbor detection is an indicator to inform the upper layer when a data-link transmission is detected from a previously unknown station.

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TABLE IX. <u>Network layer to data link layer precedence mapping</u>.

Network Precedence	Data-Link Precedence
Critic/ECP Flash Override Flash Network Control (NETCON) Internet Control	URGENT
IMMEDIATE PRIORITY	PRIORITY
ROUTINE	ROUTINE

TABLE X. <u>Mapping intranet TOS field to data link type of service</u>.

TOS		STATION CLASS (see 5.3.3.5)			
DTR	Precedence	A	B	C	D
000 (& other)	Urgent Priority Routine	1 (ACK) 1 (ACK) 1 (No ACK)	1 (ACK) 2 2	1 (ACK) 1 (ACK) 4	1 (ACK) 2 4
100	Urgent Priority Routine	1 (ACK) 1 (ACK) 1 (No ACK)	1 (ACK) 2 1 (No ACK)	1 (ACK) 1 (ACK) 1 (No ACK)	1 (ACK) 2 1 (No ACK)
010	Urgent Priority Routine	1 (ACK) 1 (ACK) 1 (No ACK)	2 2 2	1 (ACK) 1 (ACK) 4	2 2 2
001	Urgent Priority Routine	1 (ACK) 1 (ACK) 1 (ACK)	2 2 2	1 (ACK) 1 (ACK) 4	2 2 2

NOTE: Type 3 Immediate Retransmission is invoked for Urgent precedence messages when DTR is 000 or 100.

5.4 <u>Network layer</u>.

5.4.1. <u>Intranet protocol</u>. The Intranet layer, layer 3a, has been dedicated to routing intranet packets between a source and possibly multiple destinations within the same radio network. The intranet layer also accommodates the exchange of topology and connectivity information. An Estelle language formal specification of the Intranet layer is available via the CNR Implementation Working Group World Wide Web page: http://www-cnrwg.itsi.disa.mil.

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5.4.1.1 Intranet header. Figure 26 defines the Intranet header. For Intranet relaying and message types 1, 2 and 3, the entire header shall be used. Otherwise, only the Version Number, Message Type, Intranet Header Length and Type of Service shall be used. The Intranet header shall only be used with UI, I and DIA PDUs.

LSB							*MSB*
0	*1*	*2*	*3*	*4*	*5*	*6*	*7*
VERSION NUMBER				MESSAGE TYPE			
INTRANET HEADER LENGTH							
TYPE OF SERVICE							
MESSAGE IDENTIFICATION NUMBER							
MAX. HOP COUNT				SPARE			
ORIGINATOR ADDRESS							
DESTINATION/RELAY STATUS BYTE 1							
DESTINATION/RELAY ADDRESS 1							
DESTINATION/RELAY STATUS BYTE 2							
DESTINATION/RELAY ADDRESS 2							
.							
.							
.							
DESTINATION/RELAY STATUS BYTE N							
DESTINATION/RELAY ADDRESS N							

FIGURE 26. Intranet header.

5.4.1.1.1. Version. The version number shall indicate which version of the intranet protocol is being used. The current value is 0.

5.4.1.1.2. Message type. The message type is a number 0 to 15 which indicates the type of data in the data field of the intranet layer packet. Table XI lists all the valid message types. Since the message type field in the intranet header is always present in information frames of any link layer type, it is used to determine what type of data is borne by the information frame.

TABLE XI. Intranet message types.

0	Reserved
1	Intranet Acknowledgment
2	Topology Update
3	Topology Update Request
4	IP Packets
5	ARP/RARP
6	XNP
7	MIL-STD-2045-47001 Header
8 to 15	Spare

5.4.1.1.2.1 ARP/RARP. The Address Resolution Protocol (ARP) is defined in Request For Comment (RFC) 826. The Reverse Address Resolution Protocol (RARP) is defined in RFC 903. For hardware type (ar&hrd) = 22 (CNR), the source hardware address (ar$sha) field shall contain the data link address (range 0-127). The hardware address length (ar$hln) field shall specify the number of octets in the hardware address field.

5.4.1.1.2.2 XNP. XNP messages are used for CNR management. See Appendix E.

5.4.1.1.2.3 MIL-STD-2045-47001 header. When set to 7, the Intranet message type field specifies a direct connection from the Intranet layer to the MIL-STD-2045-47001 Application header.

5.4.1.1.3. Intranet header length. The Header Length shall be the number of octets in the intranet header only. The minimum length is 3 octets.

5.4.1.1.4. Type of service. The Type of Service (TOS) field in the intranet header is modeled exactly upon the IP TOS field, including the Precedence subfield.

5.4.1.1.5. Message identification number. The message identification number shall be a number, 0-255, assigned by the originating hosts. Together with the originator address it uniquely identifies each packet being relayed.

5.4.1.1.6. Maximum hop count. The maximum hop count shall be the maximum number of times this intranet packet can be relayed on the radio net. A hop is defined as a single link between two adjacent nodes. This number is set by the source host and is decremented each time a device receives the intranet header. If the maximum hop count is decremented to 0, the intranet packet shall not be forwarded any further, however it shall be processed locally if applicable.

5.4.1.1.7. Destination/Relay status byte. The Destination/Relay Status Byte (see Figure 27) shall provide intranet routing information for each destination and/or relay address. In addition, this octet also selects end-to-end intranet acknowledgments.

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LSB							*MSB*
0	*1*	*2*	*3*	*4*	*5*	*6*	*7*
Distance			REL	Relay Type		DES	ACK

FIGURE 27. Destination/Relay status byte.

5.4.1.1.7.1. Distance. The distance subfield specifies how many hops a relay address is away from the originator node. For final destination addresses which are not relayers, the distance field gives the number hops from the originator node to the destination node.

5.4.1.1.7.2. REL. The REL bit when set indicates that the given node will participate in relaying.

5.4.1.1.7.3. Relay type. The Relay Type bits indicate the type of relaying to be performed. The relay types are defined in Table XII. The value of 0 indicates source directed relay defined in Appendix I.

TABLE XII. Relay types.

0	Source Directed Relay
1	Spare
2	Spare
3	Spare

5.4.1.1.7.4. DES. When the DES bit is set, the following address is at least one of the destinations for the packet. The following address may also be a next hop relay for another destination.

5.4.1.1.7.5. ACK. The ACK bit when set requests end-to-end (ETE) intranet acknowledgments for the associated node only. The procedure for end-to-end intranet acknowledgment follows.

5.4.1.1.7.5.1 Receiving ETE intranet ACK. When a node receives an Intranet Packet with the ACK bit set, it shall return an Intranet Acknowledgment packet at the first possible opportunity. The Intranet Acknowledgment packet shall have the same Message Identification Number as the received Intranet Packet. The path specified in the Intranet Acknowledgment packet shall be the reverse path specified in the received Intranet Packet. The Intranet Acknowledgment packet shall specify exactly one destination, namely the originator of the received Intranet Packet.

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5.4.1.1.7.5.2 <u>ETE intranet ACK timeout</u>. When a node sends an intranet packet with the ACK bit set, it shall start its ETE acknowledgment timer. The ETE acknowledgment timer is an intranet parameter that defines the period within which a sending station shall expect an acknowledgment from the destination(s). The value of the ETE acknowledgment timer shall be a fixed factor plus a factor proportional to the number of hops required for all destinations to receive the packet. The default value for the fixed factor shall be 20 seconds. The default value for the proportional factor shall be twice the value of the data link layer acknowledgment timer, multiplied by the number of hops to the furthest destination. The maximum value for the ETE Intranet Acknowledgment Timer shall be 10 minutes (600 seconds).

5.4.1.1.7.5.3 <u>Receiving an intranet acknowledgment packet</u>. When an Intranet Acknowledgment Packet is received, that destination shall be removed from the list of destinations from which an acknowledgment is required. When all destinations have acknowledged, no further action is taken at the Intranet Layer.

5.4.1.1.7.5.4 <u>Expiration of the ETE intranet ACK timer</u>. When the ETE acknowledgment timer expires, the sending station shall retry the transmission of the Intranet packet. The number of retries shall be a value between 1 and 4, with a default of 2. Each retransmission may use a new path to each unacknowledging destination. If only one path exists to a destination, that path shall be used until either the acknowledgment is received or the maximum number of Intranet retransmissions is exhausted. If no acknowledgment is received after the maximum number of Intranet retransmissions, an IL-Status-Indication would be sent to the upper layer indicating acknowledgment failure.

The retransmitted packet shall have a recreated Intranet Header with the same Type of Service field and Message Identification Number. The Intranet Header shall be recreated to specify the new path to the destination. This recreated Intranet Header shall not specify paths to nodes that have already acknowledged the message. This recreated Intranet Header shall not specify paths to nodes from which an acknowledgment is not required. This recreated Intranet Header shall include paths to all nodes from which an acknowledgment is required, but from which an acknowledgment has not yet been received.

5.4.1.1.8. <u>Originator address</u>. The originator address shall be the link layer address of the originating node.

5.4.1.1.9. <u>Destination/Relay address</u>. The intranet destination/relay address shall be the 7-bit link layer address. It is either the destination address for an intranet packet or the relay address. The extension bit (LSB) is available for use by relaying procedures.

5.4.1.2 <u>Topology update</u>. Connectivity and topology information of the intranet is essential for a node to initiate and/or perform intranet relay. Each node on the radio network needs to determine what nodes are on the network and whether they are 1 or more hops away. This information can be partially determined passively by listening to a node's traffic at layers 3a and 2 and/or actively by exchanging topology information. The topology update data structure, defined in Figure 28, has been provided for nodes in the intranetwork to exchange topology and connectivity

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information. Appendix H specifies the procedure for exchanging topology information between nodes.

LSB 0	1	2	3	4	5	6	MSB 7
Topology Update Length							
Topology Update ID							
Node 1 Address							
Node 1 Status Byte							
Node 1 Predecessor Address							
Node 2 Address							
Node 2 Status Byte							
Node 2 Predecessor Address							
...							
Node N Address							
Node N Status Byte							
Node N Predecessor Address							

FIGURE 28. Topology update data structure.

5.4.1.2.1. Topology update length. The Topology Update Length field is the length in octets of topology update data. Topology Update Length shall not exceed the MTU minus 8 octets.

5.4.1.2.2. Topology update ID. The Topology Update ID is a number from 0 to 255. Together with the originator's link layer address, the Topology Update ID uniquely identifies each topology update generated by the originating node. This number is incremented by 1 every time a topology update is generated. The Topology Update ID for the first topology update generated shall be 1.

5.4.1.2.3. Node address. The Node Address is the link layer address of node in the intranet.

5.4.1.2.4. Node status byte. The ith Node Status Byte characterizes the link between originator host (the host whose address appears in the originator address of the intranet header) and the ith node whose address immediately follows the Node Status Byte as defined in Figure 29.

LSB 0	1	2	3	4	5	6	MSB 7
LINK QUALITY			HOP LENGTH			NR	QUIET

FIGURE 29. Node status byte.

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5.4.1.2.4.1 <u>Link quality</u>. The Link Quality subfield for the *i*th node provides an assessment of the link quality between the *i*th node predecessor and the *i*th node. The Link Quality is set to 0 if the quality of a link is unknown. Increasing Link Quality value infers a poorer link. Link Quality is set to 7 to indicate that the node is static. Static nodes have pre-assigned data link addresses, and do not affect Intranet Topology as they enter and leave the network. Table XIII lists the Link Quality values.

TABLE XIII. <u>Topology link quality values</u>.

Link Quality	Description
0	Unknown
1	Best Link
2	
3	
4	
5	
6	Worst Link
7	Static Node

5.4.1.2.4.2. <u>Hop length</u>. The Hop Length subfield defined in Table XIV indicates the distance in hops from the source to the given node. Hop Length = 1 means the node can be reached directly by the source - no relays are required. A hop length of 0 indicates the source node itself or that the source may know that node should be on the network but does not know where it is.

5.4.1.2.4.3. <u>NR</u>. The NR bit when set to 1 indicates that the node is not participating as a relayer.

5.4.1.2.4.4. <u>Quiet</u>. The Quiet bit, when set, indicates the node is either in quiet mode or going into quiet mode and cannot transmit any traffic.

TABLE XIV. <u>Hop length values.</u>

Hops	Description
0	Unknown
1	0 Relays required
2	1 relays required
3	
4	
5	
6	
7	6 or more relays required

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5.4.1.2.5. Node predecessor address. Each node maintains intranet topology as routing tree rooted at itself. For the *i*th node in the routing tree, the Node Predecessor Address is the link layer address of the node one branch up from the *i*th node in the routing tree. The predecessor for all nodes within 1 hop of the originator node, which is the root of the routing tree is the originator node. The predecessor for all nodes n hops away is a node which is n-1 hops away from the originator and that can talk directly with the node n hops away. If the *i*th node has not been integrated into the source node's routing tree, the Node Predecessor Address for the *i*th node should be set to 0.

5.4.1.3 Topology update request message. The Topology Update Request message, Intranet Relay Message Type 3, consists of the Intranet Header with one originator and possibly multiple destination addresses. No Information field is permitted. The maximum hop count and distance field shall be set to 1. The Relay, Relay Type, and ACK bit shall be always zero. The DES bit shall be always 1. The destination address in the Intranet Header shall be the link layer address to which this request has been made. The addressing at the link layer may be either the broadcast address or the individual link layer addresses.

5.4.1.4 Intranet layer interactions. The Intranet Layer (Layer 3A) interacts with both the next higher layer and next lower layer to pass or receive information regarding services requested or performed. Three primitives are used to pass information for the sending and receiving of data across the upper layer boundary.

      a.   Requests for transmission of data are sent by the upper layer, using the Intranet layer (IL) Unitdata Request primitive, with the following parameters:

> IL-Unitdata Request
> > Destination(s)
> > Source
> > Quality of Service
> > Precedence
> > Throughput (Normal/High)
> > Delay (Normal/Low)
> > Reliability (Normal/High)
> > Data/Data Length
> > Intranet Message Type
> > IL-Unitdata-ID

      b.   Indications are provided to the upper layer when data is received through the IL-Unitdata Indication primitive, with the following parameters:

> IL-Unitdata Indication
> > Destination(s)
> > Source
> > Data/Data Length

IL-Status Indication
Acknowledgment failure
Intranet Path Status
IL-Unitdata-ID

c.   Descriptions of the above parameters follow:

1.   The destination can be 1 to 16 individual or data link layer multicast (including global) addresses.

2.   The source address is the data link layer individual address of the outgoing link.

3.   Quality-of-service parameters are used in determining the service provided by the Intranet layer. Quality of service parameters are identical to those at the data link layer, described in 5.3.16c(4).

(a)   Precedence shall be mapped from the TOS field (see 5.4.1.1.4) as follows:

PPP	Precedence
111	Network Control
110	Internet Control
101	CRITIC/ECP
100	Flash Override
011	Flash
010	Immediate
001	Priority
000	Routine

where the least significant bit is shown to the right under PPP.

(b)   The other Quality of Service parameters shall be mapped from the TOS field (see 5.4.1.1.4) as follows:

T=0	Normal Throughput
T=1	High Throughput
D=0	Normal Delay
D=1	Low Delay
R=0	Normal Reliability
R=1	High Reliability

(c)   The end-to-end intranet acknowledgment procedures described in 5.4.1.1.7.5 shall be used when R=1, and relaying is used to deliver the message to any destination of the packet.

4.   Data/Data Length is the block of data exchanged between the Intranet layer and its upper layer (i.e. IP) user, and an indication of the data's length.

5.   Acknowledgment Failure is an indicator to inform the upper layer if an Intranet acknowledgment was not received from the remote station when high reliability was requested in an IL-Unitdata Request.

6.   Whenever a node becomes reachable or unreachable, an Intranet Path Status indication is sent to the upper layer identifying the destination link address.

7.   Intranet Message Type is defined in 5.4.1.1.2.

8.   IL-Unitdata-ID is an indicator established by the upper layer in the IL-Unitdata Request and used to associate a subsequent IL-Status Indication acknowledgment status with that request.

5.4.2. Subnetwork Dependent Convergence Function (SNDCF). The International Organization for Standardization description of the network layer defines a subnetwork dependent convergence layer, between the intranet and internet layers. The layer performs the necessary functions to assure that IP expected services are provided within a particular subnetwork type. The functions required to converge IP services within a MIL-STD-188-220 subnetwork (layers 3a and below) services are: (1) determine the complete list of IP final destinations within the subnetwork; (2) determine the associated subnetwork address(es) for each IP address; and (3) determine the subnetwork type of service requirements (reliability, throughput, delay, immediate retransmission and precedence). The preceding information is contained in the IP header. If the IP protocol implementation does not provide the required information through an inter-layer interaction, the SNDCF must examine the IP header fields to "learn" the destinations and type of service. The SNDCF is only active for an IL-Unitdata request from the IP. The convergence functions for a MIL-STD-188-220 subnetwork using the Selective Directive Broadcast protocol described in RFC 1770 are described below.

5.4.2.1 Determine destination function. The Determine Destination function obtains final destination information from the IP header. The IP destination address field of the IP header is examined first. If the address in that field is an individual address, broadcast address (all 1's), or multicast address (Class D IP address), the Determine Destination function is complete and it passes the single IP address to the Address Mapping Function. If the IP destination address is a directed broadcast address, (all ones in the host portion of the IP address only) the network portion of the IP address (NET ID) is compared to the local NET ID. If the NET ID portion of the directed broadcast address is not the same as the local NET ID, the single IP directed broadcast address is passed to the Address Mapping function. If the NET ID portion of the directed broadcast IP address is the same as the local NET ID, the Determine Destination function examines the IP option field for the presence of the multi-address IP option (selective directed broadcast). If the option is present, the list of individual IP addresses contained in the option is passed to the Address

Mapping function. If the option is not present, the single IP directed broadcast address is passed to the Address Mapping function

5.4.2.2. <u>Address mapping function</u>. The SNDCF Address Mapping function is provided one or more addresses from the Determine Destinations function. The Address Mapping function determines the data link address(es) associated with an IP address. The Address Mapping function accesses an information base to determine the data link layer address associated with an IP address. IP broadcast (all 1's) addresses and directed broadcast addresses for the local subnetwork are mapped to the data link global address.

5.4.2.3 <u>Type of service function</u>. The SNDCF Type of Service function obtains the IP service requirements from the IP Type of Service header field. The values in the field are provided to the Intranet Layer protocol.

5.4.2.4 <u>Intranet send request</u>. After the SNDCF layer performs all of its functions, it issues an IL-Unitdata Request that includes the list of data link addresses and the Type of Service data.

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6.   NOTES

(This section contains information of a general or explanatory nature that may be helpful, but is not mandatory.)

6.1 Subject term (key word) listing. The follow key words and phrases apply to this document.

> Data Communications Protocol
> Digital Message Transfer Device
> Error Detection and Correction
> Interoperability
> Open Systems Interconnection
> Packets
> Radio
> Relay
> Segmentation

6.2 Issue of the DoD index of specifications and standards. When this document is used in procurement, the applicable issue of the DoDISS must be cited in the solicitation.

6.3 Interoperability considerations. This section addresses some of the aspects that terminal designers and systems engineers should consider when applying MIL-STD-188-220 in their communications system designs. The proper integration of MIL-STD-188-220 into the total system design will ensure the interoperability of stations that exchange information over a data communications link consisting of a DMTD, a transmission channel, and a DMTD or C4I system.

6.3.1 Transmission channel. For the purpose of this document, the transmission channel (from the transmitter to the receiver) is considered transparent to the DMTD subsystem. However, the transmission channel must be interoperable within itself. The transmission channel may be secured or non-secured, using such media as line-of-sight (LOS) radio, high frequency (HF) radio, wireline, and SATCOM.

6.3.2 Physical interface. The specific details of the physical interface for connecting DMTDs to the equipment that implements the transmission channel are beyond the scope of this document. The actual physical connections will depend on the interface characteristics required by the particular transmission equipment. These unique physical interface characteristics may be defined in the equipment specifications or in technical interface specifications. Therefore, the requirements for the electrical features (such as data, clock, and control) and mechanical features (such as connectors, pin assignments, and cable) of the connection between the DMTD and the associated transmission channel equipment are left to the equipment designer. The data signaling format (that is, NRZ, FSK, CDP) is specified in this document at the standard interface, because it is an interoperability parameter. The design philosophy is that what appears at the input end of the transmission channel should be the same at the output end. Requirements for effecting a working interface to specific radios are provided in the following subparagraphs.

6.3.2.1 <u>SINCGARS system improvement program (SIP) receiver/transmitter (R/T) interface</u>. The DTE (DMTD or C4I system) interacts with the DCE via an X.21 data interface and an External Control Interface. When the precedence level of the transmission changes, the DTE will set the precedence level for the new transmission via the External Control interface. This precedence level will correspond to the frame with the highest precedence value within the series of concatenated frames.

6.3.2.1.1 <u>Carrier sense multiple access (CSMA) network access</u>. Although all SINCGARS SIP R/Ts in a given network are not required to use the same CSMA slot offsets and limits for voice and/or precedence levels, it is highly recommended that the same slot settings be used within a network. All SINCGARS SIP R/Ts in a network must be using the same slot width (18ms - FH; 54ms - SC) and the same mode of operation (plain text or cypher text).

6.3.2.1.2 <u>Network busy sensing and receive status</u>. The presence of multiple stations on a single random access communications network requires voice/data Network Busy Sensing and the use of network access control to reduce the possibility of data collisions on the net. The combined Data and Voice Networks require cooperation between the DTE (DMTD or C4I system) and the DCE.

The DCE indicates the presence of receive data and voice via the X.21 Indication line "I" signal. A precise determination of the network status is obtained via the X.21 DTE Receive line "R" signal in combination with the "I" signal:

> I = OFF and R = 1's ->   Idle/Transmission Completed
>
> I = OFF and R = Flags ->   Data being transmitted
>
> I = ON and R = Flags ->   Data being received
>
> I = ON and R = 1's ->   Voice operation if this condition persists for more than 250 mSec. From 0 to 250 milliseconds the radio is busy, but voice or data reception can't be determined until either the presence of flags on the R-line for data or the expiration of 250 milliseconds when voice reception is assumed.

The transmission of data takes effect by driving the X.21 Control line "C" (push-to-talk) and DTE Transmit line "T", as follows:

> Verify I = OFF and R = 1's, then assert C = ON and send flags T = Flags
>
> Verify I = OFF and R = Flags, then transmit data T = Data
>
> Upon transmit completion, assert C = OFF and send T = 1's

The time between the SINCGARS SIP R/T detection of network busy and the determination of network busy with voice is added to any suspended timers. The timers are suspended in the INC

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only after network busy with voice is indicated. Therefore, adding the time period in which the radio detects network busy with "something" until network busy with voice is determined accounts for the period of time voice was actually present.

6.3.2.1.3 Network timing model parameters. The Network Timing Model is described in Appendix C. Parameter values specific to the SINCGARS SIP radio are provided in Table XV.

TABLE XV. SINCGARS SIP - Packet Mode: 16 kbps digital (milliseconds).

	EPRE*	PHASING	ELAG*	TURN
Frequency Hopping Cipher Text	21	0	600	30
Frequency Hopping Plain Text	21	0	600	30
Single Channel Cipher Text	57	0	143	30
Single Channel Plain Text	57	0	143	30

* **Note:** EPRE & ELAG assume RENAD & Coupled Acknowledgment (offset=0, Limit=0)

6.3.2.1.4 Other SINCGARS SIP implementation details.

a. The RE-NAD slot assignment for Type 3 PDUs is offset=0, limit=0. The "offset" is the number of the first slot while the "limit" is the number of slots associated with the particular parameter (e.g., a precedence level). Offset=0, limit=0 means there is no randomized delay associated with the Type 3 PDUs or the returned Type 3 acknowledgments in the SIP R/T due to the RE-NAD process. The 0-second Immediate Mode scheduler is used with these PDUs and returned acknowledgments so that no additional randomized delay is incurred from the INC (where the scheduler is implemented).

b. The SINCGARS SIP R/T does not manipulate any trailing flags included in the data stream presented to it. These flags are transmitted over the air.

c. From the SINCGARS SIP R/T perspective, any trailing flags are part of the data stream and should be calculated into DATA.

d. The DTE (e.g. INC) must achieve synchronization with the SINCGARS SIP R/T within four flag sequences. Data may be sent upon detection of a valid flag sequence.

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6.3.2.2 SINCGARS ICOM R/T interface.

6.3.2.2.1. NRZ physical interface between DTE and R/T. The SINCGARS ICOM digital data interface to a DTE is a synchronous, unbalanced, half-duplex serial interface.

    a.   The signaling format is non-return-to-zero (NRZ), at voltage levels compatible with those specified in MIL-STD-188-114A for a single receiver load termination.

    b.   Digital data rates of 600, 1200, 2400, 4800 and 16000 bps are supported by the ICOM R/T. When a data rate below 16000 bps is selected at a transmitter, a Data Rate Adapter (DRA) internal to the ICOM upconverts the data to 16000 bps, using majority logic forward error correction techniques.

    c.   The ICOM R/T also provides a receive squelch indication to the DTE when channel activity is sensed.

6.3.2.2.2. Network busy sensing and receive status. Network Busy Sensing provides a mechanism to manage channel access among members of a common network. Without managed channel access, multiple stations attempting simultaneous transmissions will collide, degrading network performance. Managing channel access also minimizes the network performance loss due to mixing both voice and data in a common net.

    a.   For both voice and digital data receptions, the DCE provides a receive squelch indication via the Analog Data Mode Control_Not (ADMC_N) line. This ADMC_N squelch indication is a composite signal from several internal sources. Using this signal, the worst case network busy detect times are 350 milliseconds for frequency hopping and 100 milliseconds for single channel.

    b.   For digital data receptions, the DCE presents a synchronous clock on the Digital Data Clock Out (DDCO) line. ADMC_N will typically precede DDCO for all digital data receptions. The exception is for PT 16000 bps data, when both ADMC_N and DDCO will be coincident.

    c.   For voice receptions, the DCE will provide a receive squelch indication via ADMC_N, but will not present DDCO.

    d.   If both ADMC_N and DDCO are considered as binary signals, there are four possible indications which a DTE can use to infer network status. Table XVI summarizes the four possible receive states and their interpretation.

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TABLE XVI. <u>SINCGARS ICOM receive states.</u>

	ADMC_N Active	ADMC_N Inactive
DDCO Active	Digital data reception	Not Applicable
DDCO Inactive	Voice reception	R/T idle

6.3.2.2.3 <u>Network timing model parameters.</u> The Network Timing Model is described in Appendix C. Parameter values specific to the SINCGARS ICOM radio are provided in Tables XVII through XX.

TABLE XVII. <u>SINCGARS ICOM: 16 kbps digital (milliseconds).</u>

	EPRE	PHASING	ELAG	TURN
Frequency Hopping Secure	340	0	154.42	90.58
Frequency Hopping Unsecure	200	0	153.42	36.58
Single Channel Secure	370	0	1.338	14.102
Single Channel Unsecure	300	0	0.42	155.958

TABLE XVIII. <u>SINCGARS ICOM: 4800 bps digital (milliseconds).</u>

	EPRE	PHASING	ELAG	TURN
Frequency Hopping Secure	370	0	156.96	88.04
Frequency Hopping Unsecure	230	0	155.986	34.014
Single Channel Secure	400	0	3.88	221.52
Single Channel Unsecure	329	0	2.96	160.84

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TABLE XIX. SINCGARS ICOM: 2400 bps digital (milliseconds).

	EPRE	PHASING	ELAG	TURN
Frequency Hopping Secure	370	0	157.52	87.48
Frequency Hopping Unsecure	230	0	156.58	33.42
Single Channel Secure	400	0	4.44	200.96
Single Channel Unsecure	329	0	3.51	161.49

TABLE XX. SINCGARS ICOM: 1200 bps digital (milliseconds).

	EPRE	PHASING	ELAG	TURN
Frequency Hopping Secure	370	0	158.8	86.2
Frequency Hopping Unsecure	230	0	157.8	32.2
Single Channel Secure	400	0	5.69	207.51
Single Channel Unsecure	329	0	4.75	171.85

6.3.2.3 HAVEQUICK II R/T interface.

6.3.2.3.1 Network timing model parameters. The Network Timing Model is described in Appendix C. Parameter values specific to the HAVEQUICK II radio are provided in Tables XXI and XXII.

6.3.2.4 COMSEC interoperability. The COMSEC function provides a link encryption capability. In the traditional COMSEC mode of operation, the COMSEC function (normally implemented in ancillary equipment) is considered part of the transmission channel. In the embedded COMSEC mode, the COMSEC function is an integral part of the DMTD subsystem.

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TABLE XXI. HAVEQUICK II: 16 kbps digital (milliseconds).

	EPRE	PHASING	ELAG	TURN
Frequency Hopping Convolutional (1/3) Secure	851 plus COMSEC	10 + 7.2/hr	0	930
Frequency Hopping No Convolutional Secure	851 plus COMSEC	10 + 7.2/hr	0	930 + 7.2/hr
Frequency Hopping No Convolutional Unsecure	851	105	0	930 + 7.2/hr
Single Channel Secure	174 plus COMSEC	0	0	176
Single Channel Unsecure	174	105	0	176

TABLE XXII. HAVEQUICK II: analog (milliseconds).

	EPRE	PHASING	ELAG	TURN
Frequency Hopping Secure	851 plus COMSEC	0	0	930
Frequency Hopping Unsecure	150	105	0	97
Single Channel Secure	174 plus COMSEC	0	0	176
Single Channel Unsecure	150	105	0	97

6.3.3 Data link layer. The following implementation details should be considered when implementing the data link layer of MIL-STD-188-220:

  a.   Figure 9 (5.3.1, Transmission Header) should be interpreted with the LSB on the left as in Figure 14. Therefore, the first bit of the Transmission Header that is transmitted (after the flag) will be the FEC selection bit and the last bit transmitted will be bit 9 of Figure 10.

  b.   The last 2 sentences of 5.3.1 says that the TDC block for the 12-bit TWC and 64-bit TH contains seven 24-bit codewords, encoded as a 168-bit TDC block. 5.3.14.2 says that if the (12+64=76, plus a few inserted zeros) data bits do not divide into an integral number of 12-bit segments, fill bits of zeros are added to the

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end. Note that this does NOT require the physical layer to parse the TH, since the length of the TH is fixed at 64 bits (see Figure 9).

c. Reliable broadcast involves the need for stations to return an acknowledgment to the originator of messages that are received with only the global data link address (see 5.3.4.2.2.2.6) -- the broadcast address is used at higher protocol layers) -- and the receiving station is not individually addressed in the message. There is no requirement for reliable broadcast at the Intranet or Data Link layer.

d. Type 4 acknowledgments (DRR and DRNR are discussed in 5.3.7.3.5.3.1.2 and 5.3.7.3.5.2.3, respectively) may be transmitted twice. The second transmission of the DRR/DRNR should be concatenated with other data link frame transmissions. The DTE should not access the network merely to transmit the second DRR/DRNR.

e. When a station receives an out-of-sequence I frame (see 5.3.7.2.5.4) it may send either an REJ or SREJ, depending upon whether the station can perform resequencing. A station should send SREJ when it can resequence received I frames and should send REJ otherwise.

f. N2 (see 5.3.8.1.1d) is the number of permitted re-transmissions. The number of times that a message may be transmitted is N2+1.

g. The following definition of Quiet Mode (see 5.3.11.2) will be used: When a station can not determine whether another station is in Quiet Mode, it should assume that the station is not in Quiet Mode. The fact that a station has entered Quiet Mode will be known globally over the internet. While there is a possibility that some stations will not get the information, or will ignore the information; the protocol will not try to fix the problem. Specifically, there is no requirement for the last relayer to issue a proxy acknowledgment for stations that are operating in Quiet Mode.

6.3.4 Intranet layer. The following implementation details should be considered when implementing the data link layer of MIL-STD-188-220:

a. Relayers optionally may collapse the Intranet Header to remove addresses that are not on the path to or from the relaying node (see 5.4.1.1.7.5.1). The destination node would still have sufficient information to return an acknowledgment. Interoperability is not affected because the complete path between originator and destination is not corrupted. Collapsing the Intranet Header would minimize bandwidth utilization but would probably increase processing time at each relayer and could destroy information that might be useful to network management functions.

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b.   The source node will be included as the first entry in every Topology Update (see 5.4.1.2) sent by the INC. The Node Address and Node Predecessor will be set to the station ID (link address) of the source node. The Quiet and Non-relay Status bits will be set to that station's current status. The hop length field will be set to 0. The remaining entries in the Topology Update have no implied ordering. A node aware only of itself will generate an initial update containing just its own entry.

c.   Topology Update messages (see 5.4.1.2) are broadcast unreliably.

d.   In the Topology Update Data Structure (Figure 28), the "node address" and "node predecessor address" (see 5.4.1.2.3 and 5.4.1.2.5, respectively) have been implemented in the INC and the IDM in the following manner:

> *Both of these addresses are "the link address of the node in the Intranet". The link address is seven bits long (see 5.3.4.2.2.1). The C/R bit associated with this link address is not required by the Intranet Layer. As such, bits 0 through 6 contain the "link address" used in the node address and node predecessor address. Bit 7 must be zero.*

e.   Topology Update (see 5.4.1.2) and Topology Update Request messages (see 5.4.1.3) use Data Link Type 1, unacknowledged, procedures.

f.   The precedence of Topology Update (see 5.4.1.2) and Topology Update Request messages (see 5.4.1.3) is user defined.

g.   Receiving a Topology Update Request (see 5.4.1.3) indicates an operational two-way (bi-directional) link.

h.   It is possible for the Min_Update_Per parameter (see H4.4.3) to take different values on a node-by-node basis within a net. There is essentially no problem unless one of the nodes takes the value 0. Assume node A has this value set to 0. Node A is not permitted to respond to topology requests. Nodes without traffic for this node issue topology update requests to try to set up links. Node A does not respond. Once a node (e.g. B) sets up a valid link with a link layer acknowledgment, a topology update listing this connection is advertised. All other nodes without a link will switch to a 2-hop path using node B as a relayer to node A. Therefore, it is logical that the Min_Update_Per value should be set on a network-wide basis. An alternative solution is available: The non-participant can announce this fact in a Topology Update message that identifies itself in the Node 1 Address field and the Node 1 Predecessor Address field and by setting the NR bit in the Node 1 Destination/Status Byte.

i.   I5.3 presents the solution to Source Directed Relay Example 3 as C-E-F-G-H-D. An equally valid solution is D-C-E-F-G-H.

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6.3.5 <u>CNR management process</u>.

    a.   The CNR Management process is recommended to reduce operator burden by providing automated support for the management function.

    b.   There is no requirement to respond to an XNP Join Request message (see E4.2.1). If operational conditions permit, an interval timer may be used to schedule the retransmission of an XNP Join Request message (see E6.2).

6.3.6 <u>Interoperation with internet protocols</u>.

    a.   The Technical Architecture requires the IP protocol. Systems implementing Intranet message type 7 (MIL-STD-2045-47001 Header) must also implement Intranet message type 4 (IP Packet).

    b.   Figure 4 of RFC 791 (Internet Protocol) is interpreted as having the LSB on the RIGHT. This means that the IHL field will be transmitted before the Version Number by the MIL-STD-188-220 lower layers.

    c.   Message exchanges using MIL-STD-188-220B over CNR should be accomplished using UDP. TCP should be reserved for upper layer services that require Transport Layer reliability.

    d.   The Internet Address Numbering Authority has assigned OSPF2 if Type Value 85 for CNR.

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APPENDIX A

ABBREVIATIONS AND ACRONYMS

A.1. General.

A.1.1 Scope. This appendix contains a list of abbreviations and acronyms pertinent to MIL-STD-188-220.

A.1.2 Application. This appendix is not a mandatory part of MIL-STD-188-220. The information contained herein is intended for guidance only.

A.2. Applicable documents. This section is not applicable to this Appendix.

A.3. Abbreviations and acronyms.

(n)	Repeatability Factor
ABM	Asynchronous Balanced Mode
ACK	Acknowledgment
ADM	Asynchronous Disconnected Mode
ARP	Address Resolution Protocol
ASD	Adverse State Detector
ASK	Amplitude Shift Keying
BCH	Bose-Chaudhuri-Hocquenghem
BER	Bit Error Rate
bps	bit(s) per second
C/R	command/response
C^4I	Command, Control, Communications, Computers, and Intelligence
CCITT	International Telephone and Telegraph Consultative Committee
CDP	Conditioned Diphase
CMD	Command
CNR	Combat Net Radio
COMSEC	Communications Security
CSMA	Carrier Sensed Multiple Access
D	RE-NAD Damping coefficient
d/c	Don't Care
DAP-NAD	Deterministic Adaptive Prioritized - Network Access Delay
DARPA	Defense Advanced Research Projects Agency
dB	decibel
DC	Direct Current
DCE	Data Circuit-terminating Equipment
Dec	Decimal
DES	Destination
DIA	Unnumbered Information (PDU) With Decoupled Acknowledgement

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DISC	Disconnect
DL	Data-Link Layer
DM	Disconnect Mode
DMTD	Digital Message Transfer Device
DoD	Department Of Defense
DoDISS	Department Of Defense Index Of Specifications and Standards
DPSK	Differential Phase-Shift Keying
DPTT	Delayed Push-to-Talk
DRA	Data Rate Adapter
DRNR	Decoupled Acknowledgement Receive Not Ready
DRR	Decoupled Acknowledgement Receive Ready
DTE	Data Terminal Equipment
ECP	Emergency Command Precedence
EDC	Error Detection and Correction
ETE	End-to-End
F	Final
FCS	Frame Check Sequence
FEC	Forward Error Correction
FED-STD	Federal Standard
FH	Frequency Hopping
FIPS	Federal Information Processing Standard
FPI	Field Presence Indicator
FRMR	Frame Reject
FSK	Frequency-Shift Keying
GPI	Group Presence Indicator
H-NAD	Hybrid Network Access Delay
HDLC	High-level Data Link Control
Hex	Hexadecimal
HF	High Frequency
HLEN	Header Length
HRT	Hop Recovery Time
Hz	Hertz
I PDU	Information PDU
IAB	Internet Architecture Board
IANA	Internet Assigned Number Authority
ICOM	Integrated COMSEC
IHL	Internet Header Length
IL	Intranet Layer
IP	Internet Protocol
ISN	Initial Sequence Number
ISO	International Organization for Standardization
JIEO	Joint Interoperability and Engineering Organization
kbps	kilobit(s) per second
KG	Key Generator
kHz	Kilohertz

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KT	Keytime Delay
LOS	Line of Sight
LSB	Least Significant Bit
MI	Message Indicator
MIL-STD	Military Standard
MMTU	Minimum MTU size
MSB	Most Significant Bit
MSS	Maximum Segment Size
MTU	Maximum Transmission Unit
N(R)	Receive sequence number
N(S)	Send sequence number
NAC	Network Access Control
NAD	Network Access Delay
NATO	North Atlantic Treaty Organization
NB	Narrowband
NETCON	Network Control
NP	Network Protocol
NPDU	Network Protocol Data Unit
NRZ	Non-Return-to-Zero
NS	Number of Stations
OSI	Open Systems Interconnection
OSPF	Open Shortest Path First
OTAR	Over-The-Air rekeying
P	Poll
P/F	Poll/Final
P-NAD	Priority - Network Access Delay
PDU	Protocol Data Unit
PL	Physical Layer
PN	Pseudo-Noise
PSK	Phase Shift Keying
QT	Quiet Timer
R/C	Receipt/Compliance
R-NAD	Random Network Access Delay
RARP	Reverse Address Resolution Protocol
RE-NAD	Radio Embedded - Network Access Delay
REJ	Reject
REL	Relay
RF	Radio Frequency
RFC	Request For Comments
RHD	Response Hold Delay
RNR	Receive Not Ready
RR	Receive Ready
RSET	Reset
R/T	Radio/Transmitter
S/N	Signal-to-Noise ratio

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S PDU	Supervisory PDU
SABME	Set Asynchronous Balanced Mode Extended
SATCOM	Satellite Communications
SC	Single Channel
SH	Segmentation/Reassembly Header Size
SINCGARS	Single Channel Ground and Airborne Radio System
SIP	System Improvement Program
SNDCF	Subnetwork Dependent Convergence Function
SOM	Start Of Message
SOP	Start Of Packet
SP	Subscriber Precedence
SREJ	Selective Reject
ST	Satellite Time delay
STD	Standard
TBD	To Be Determined
Tc	Continuous Scheduler Interval Timer
TCP	Transmission Control Protocol
TDC	Time-Dispersive Coding
TH	Transmission Header
TIDP	Technical Interface Design Plan
TL	Traffic Load
TOS	Type Of Service
TP	Timeout Period
TRANSEC	Transmission Security
TTL	Time To Live
TWC	Transmission Word Count
U PDU	Unnumbered PDU
UA	Unnumbered Acknowledgment
UDP	User Datagram Protocol
UI	Unnumbered Information
ULP	Upper Layer Protocol
URNR	Unnumbered Receive Not Ready
URR	Unnumbered Receive Ready
V(R)	Receive-state Variable
V(S)	Send-state Variable
VER	Version
VMF	Variable Message Format
WB	Wideband
XNP	Exchange Network Parameters

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APPENDIX B

PROFILE

B.1. General.

B.1.1 Scope. This appendix contains the minimum set of MIL-STD-188-220 features required for joint interoperability. It is intended to guide system developers and users.

B.1.2 Application. This appendix is a mandatory part of MIL-STD-188-220. The information contained herein is intended for compliance.

B.2. Applicable documents. None.

B.3. Implementation requirements. MIL-STD-188-220 requirements are described in Section 5 and Appendices C, D, E, H, I, J and K. This appendix categorizes requirements, identified by MIL-STD-188-220 paragraph numbers, as Mandatory, Conditional or Optional. Unless otherwise specified, the category assigned to a requirement applies to all subordinate subparagraphs for the requirement. Fully compliant systems shall implement all mandatory and conditional requirements. Minimally compliant systems shall implement all mandatory requirements and some conditional requirements as described in this appendix.

B.4. Detailed requirements.

B.4.1 Physical layer.

B.4.1.1 Transmission channel interfaces. Transmission channel interfaces should be implemented as dictated by the communication device (i.e. radio) to which the system will be connected. The transmission channel interfaces for MIL-STD-188-220 compliant systems are described in 5.1.1. Minimally compliant systems shall conform to at least one of the conditional transmission channel interfaces. Fully compliant systems shall conform to all conditional requirements identified in Table B-1.

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TABLE B-1. <u>Transmission channel interfaces.</u>

Reference	Requirement	Category
5.1.1.1	Non-return-to-zero (NRZ) interface	Conditional
5.1.1.2	Frequency-shift keying interface for voice frequency channels	Optional
5.1.1.3	Frequency-shift keying interface for single-channel radio	Optional
5.1.1.4	Conditioned diphase interface	Optional
5.1.1.5	Differential phase-shift keying interface for voice frequency channels	Optional
5.1.1.6	Packet Mode Interface	Conditional
5.1.1.7	Amplitude Shift Keying	Conditional

B.4.1.2 <u>Physical-layer protocol.</u> The requirements for the physical layer protocol of MIL-STD-188-220 compliant systems are described in 5.2. Fully compliant systems shall conform to all mandatory and conditional requirements identified in Table B-2.

TABLE B-2. <u>Physical layer protocol.</u>

Reference	Requirement	Category
5.2.1	Physical-layer protocol data unit	Mandatory
5.2.1.1	Communications security preamble and postamble	Conditional
5.2.1.2	Phasing	Conditional
5.2.1.3	Transmission synchronization field	Conditional
5.2.1.3.1	Asynchronous mode transmission synchronization field	Conditional
5.2.1.3.1.1	Frame synchronization subfield	Conditional
5.2.1.3.1.2	Robust frame format subfield	Optional
5.2.1.3.1.3	Message indicator	Conditional
5.2.1.3.1.4	Transmission wordcount	Conditional
5.2.1.3.2	Synchronous mode transmission synchronization field	Conditional
5.2.1.3.2.1	Frame synchronization subfield	Conditional
5.2.1.3.2.2	Robust frame format subfield	Optional
5.2.1.3.2.3	Message indicator	Conditional
5.2.1.3.2.4	Transmission wordcount	Conditional
5.2.1.3.3	Packet mode transmission synchronization field	Conditional
5.2.1.3.4	Multi-dwell protocol	Optional
5.2.1.4	Data field	Mandatory
5.2.1.5	Bit synchronization field	Conditional
5.2.2	Net access control related indications	Mandatory
5.2.3	Physical-layer to upper-layer interactions	Mandatory

Minimally compliant systems shall implement all mandatory physical layer protocol requirements. Also:

a) minimally compliant C^4I systems using the NRZ interface shall implement all conditional requirements for the synchronous mode transmission field (and conditional subparagraphs), communications security preamble and postamble and phasing.

b) minimally compliant C^4I systems using the Packet Mode interface shall implement all conditional requirements for the packet mode transmission field.

c) minimally compliant C^4I systems using the ASK interface shall implement all conditional requirements for the asynchronous mode transmission field (and conditional subparagraphs), communications security preamble and postamble and phasing.

B.4.2 <u>Data-link layer.</u> The requirements for the data layer protocol of MIL-STD-188-220 compliant systems are described in 5.3. Fully compliant system shall conform to all mandatory and conditional requirements identified in Table B-3.

Minimally compliant systems shall implement all mandatory data link layer requirements. Also:

a) minimally compliant C^4I systems using the synchronous mode transmission synchronization field shall implement all conditional requirements for time dispersive coding and error detection and correction (including subparagraphs).

b) minimally compliant C^4I systems using the packet mode transmission synchronization field shall implement all conditional requirements for the scheduler and the queue precedence and queue length fields of the transmission queue subfield.

c) minimally compliant C^4I systems using the asynchronous mode transmission synchronization field shall implement all conditional requirements for time dispersive coding and error detection and correction (including subparagraphs).

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TABLE B-3. <u>Data link layer.</u>

Reference	Requirement	Category
5.3.1	Transmission Header	Mandatory
5.3.1.1	Selection bits	Mandatory
5.3.1.2	Topology Update Identifier	Mandatory
5.3.1.3	Transmission queue subfield	Mandatory
5.3.1.3.1	T-bits	Mandatory
5.3.1.3.2	Queue precedence	Conditional
5.3.1.3.3	Queue length	Conditional
5.3.1.3.4	Data link precedence	Mandatory
5.3.1.3.5	First subscriber number	Mandatory
5.3.2	Net access control	Mandatory
5.3.2.1	Scheduler	Conditional
5.3.3	Types of procedures	Mandatory
5.3.3.1	Type 1 operation	Mandatory
5.3.3.2	Type 2 operation	Optional
5.3.3.3	Type 3 operation	Mandatory
5.3.3.4	Type 4 operation	Optional
5.3.3.5	Station Class	---
5.3.4	Data-link frame	Mandatory
5.3.4.1	Types of frames	Mandatory
5.3.4.1.1	Unnumbered frame	Mandatory
5.3.4.1.2	Information frame	Optional
5.3.4.1.3	Supervisory frame	Optional
5.3.4.2	Data-link frame structure	Mandatory
5.3.4.2.1	Flag sequence	Mandatory
5.3.4.2.2	Address fields	Mandatory
5.3.4.2.3	Control field	Mandatory
5.3.4.2.3.1	Type 1 operations	Mandatory
5.3.4.2.3.2	Type 2 operations	Optional
5.3.4.2.3.3	Type 4 operations	Optional
5.3.4.2.3.4	Poll/final bit	Mandatory
5.3.4.2.3.5	Sequence numbers	Optional
5.3.4.2.3.6	Identification numbers	Optional
5.3.4.2.3.7	Precedence	Optional
5.3.4.3	Data-link PDU construction	Mandatory
5.3.5	Operational parameters	Mandatory
5.3.5.1	Type 1 operational parameters	Mandatory
5.3.5.2	Type 2 operational parameters	Optional
5.3.5.3	Type 4 operational parameters	Optional

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TABLE B-3. <u>Data link layer</u> – Continued.

5.3.6	Commands and responses	Mandatory
5.3.6.1	Type 1 operation commands and responses	Mandatory
5.3.6.2	Type 2 operation commands and responses	Optional
5.3.6.3	Type 4 operation commands and responses	Optional
5.3.7	Description of procedures by type	Mandatory
5.3.7.1	Description of Type 1 procedures	Mandatory
5.3.7.2	Description of Type 2 procedures	Optional
5.3.7.3	Description of Type 4 procedures	Optional
5.3.8	Data-link initialization	Mandatory
5.3.8.1	List of data-link parameters	Mandatory
5.3.8.1.1	Type 1 logical data link parameters	Mandatory
5.3.8.1.2	Type 2 data link parameters	Optional
5.3.8.1.3	Type 4 data link parameters	Optional
5.3.9	Frame transfer	Mandatory
5.3.9.1	PDU transmission	Mandatory
5.3.9.2	Data-link concatenation	Mandatory
5.3.9.3	Physical-layer concatenation	Optional
5.3.9.4	PDU transmissions	Mandatory
5.3.10	Flow control	Mandatory
5.3.10.1	Type 1 flow control	Mandatory
5.3.10.2	Type 2 flow control	Optional
5.3.10.3	Type 4 flow control	Optional
5.3.11	Acknowledgment and response	Mandatory
5.3.11.1	Acknowledgment	Mandatory
5.3.11.1.1	Type 1 Acknowledgment	Mandatory
5.3.11.1.2	Type 2 Acknowledgment	Optional
5.3.11.1.3	Type 4 Acknowledgment	Mandatory
5.3.11.2	Quiet mode	Mandatory
5.3.11.3	Immediate retransmission	Optional
5.3.12	Invalid frame	Mandatory
5.3.13	Retransmission	Mandatory
5.3.14	Error detection and correction	Conditional
5.3.15	Data scrambling	Optional
5.3.16	Link layer interactions	Mandatory

B.4.3 <u>Intranet protocol.</u> The requirements for the Intranet protocol of MIL-STD-188-220 compliant systems are described in 5.4. Fully compliant systems shall conform to all mandatory requirements identified in Table B-4.

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TABLE B-4. Intranet protocol.

Reference	Requirement	Category
5.4.1.1	Intranet header	Mandatory
5.4.1.2	Topology update	Optional
5.4.1.3	Topology update request message	Optional
5.4.1.4	Intranet layer interactions	Mandatory
5.4.2	Subnetwork Dependent Convergence Function (SNDCF)	Mandatory
5.4.2.1	Determine destination function	Mandatory
5.4.2.2	Address mapping function	Mandatory
5.4.2.3	Type of service function	Mandatory
5.4.2.4	Intranet send request	Mandatory

B.4.4. Network access control algorithm. The requirements for network access control implementation in MIL-STD-188-220 compliant systems are described in Appendix C. Fully compliant system shall conform to all mandatory requirements identified in Table B-5. Requirements for RE-NAD are optional because the algorithm has not yet stabilized.

TABLE B-5. Network access control.

Reference	Requirement	Category
C3.	Network timing model	Mandatory
C3.1	Network timing model definitions	Mandatory
C3.2	Network timing model parameters	Mandatory
C4.	Network access control	Mandatory
C4.1	Network busy sensing function	Mandatory
C4.1.1	Data network busy sensing	Mandatory
C4.1.2	Voice network busy sensing	Mandatory
C4.1.3	Net busy detect time	Mandatory
C4.2	Response hold delay	Mandatory
C4.3	Timeout period	Mandatory
C4.4	Net access delay	Mandatory
C4.4.1	Random network access delay	Mandatory
C4.4.2	Prioritized network access delay	Mandatory
C4.4.3	Hybrid network access delay	Mandatory
C4.4.4	Radio embedded network access delay (RE-NAD)	Optional
C4.4.5	Deterministic Adaptable Priority-Net Access Delay	Mandatory
C4.5	Voice/data network sharing	Mandatory

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Minimally compliant systems shall implement all mandatory network access control requirements. Also minimally compliant C^{4}I systems using the packet mode interface shall implement all conditional requirements for radio embedded network access delay.

B.4.5 <u>Communications security standards.</u> The communications security requirements for MIL-STD-188-220 compliant systems are described in Appendix D. There are no communications security requirements for systems using the packet mode transmission synchronization field. Fully compliant systems shall implement all conditional requirements identified in Table B-6.

Minimally compliant systems using the synchronous mode or asynchronous mode transmission synchronization field shall implement the conditional requirements for the traditional COMSEC transmission frame.

TABLE B-6. <u>Communications security standards.</u>

Reference	Requirement	Category
D5.	Detailed requirements	Conditional
D5.1	Traditional COMSEC transmission frame	Conditional
D5.2	Embedded COMSEC transmission frame	Optional

B.4.6. <u>CNR management processes.</u> CNR management process requirements are defined in Appendix E. All CNR management process requirements are optional.

B.4.7. <u>Intranet topology update.</u> Intranet Topology Update requirements are described in Appendix H. All systems implementing the optional Topology Update and Topology Update Request message requirements described in 5.4 also shall implement all requirements in Appendix H.

B.4.8. <u>Source directed relay.</u> The Intranet relay requirements for MIL-STD-188-220 compliant systems are described in Appendix I. All systems shall implement all requirements in paragraph I4 (and its subparagraphs).

B.4.9. <u>Robust communications protocol.</u> Robust communications protocol requirements are described in Appendix J. All systems implementing the optional robust frame format subfield described in 5.2.1.3.1.2 or 5.2.1.3.2.2 also shall implement all requirements in Appendix J.

B.4.10. <u>Bose-Chaudhuri-Hocquenghem (15, 7) coding algorithm.</u> The Bose-Chaudhuri-Hocquenghem (15, 7) Coding Algorithm is described in Appendix I. All systems implementing the optional Robust Communications Protocol described in Appendix J also shall implement all requirements in Appendix K.

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APPENDIX C

NETWORK ACCESS CONTROL ALGORITHM

C.1. <u>General</u>.

C.1.1. <u>Scope</u>. This appendix describes the network access control (NAC) algorithm to be used in the DMTD and interfacing C.4I systems.

C.1.2. <u>Application</u>. This appendix is a mandatory part of MIL-STD-188-220. The information contained herein is intended for compliance.

C.2. <u>Applicable documents</u>. This section is not applicable to this appendix.

C.3 <u>Network timing model</u>. The network access control protocol shall be used to detect the presence of active transmissions on a multiple-subscriber-access communications network and shall provide a means to preclude data transmissions from conflicting on the network. The network access control protocol is based on a generic network timing model. All stations on a network shall use the same network access control protocol and timing parameter values in order to maintain network discipline.

C.3.1 <u>Network timing model definitions</u>. A network station consists of a DCE and a DTE. The DTE is the data device that performs the MIL-STD-188-220 protocol. The DCE includes all equipment external to the DTE (e.g., a radio with or without external COMSEC) that is used to provide a communications channel for the DTE. The interface between the DTE and DCE can operate in synchronous, asynchronous, or packet mode. The interface is synchronous if the DCE provides all required clocks to the DTE. The packet mode interface is a synchronous interface that conforms to CCITT X.21. For synchronous mode, the bit rate (n) is the rate of the transmit clock supplied by the DCE. If the DCE does not provide clocks to the DTE, the interface is asynchronous. For asynchronous mode, the bit rate (n) is the rate at which the DTE transmits. The data link bit rate is defined as the effective bit rate at which the physical layer transmits the data bits. The data link bit rate is usually the same as the bit rate (n) at the physical layer, except for the PSK/DPSK modems (refer to MIL-STD-188-110). The robust protocol case is separately described in Appendix J.

C.3.2 <u>Network timing model parameters</u>. The parameters of the network timing model are general enough to model interactions with a wide variety of DCEs. All parameters are specified at the DTE to DCE interface and are in units of milliseconds with a resolution of one millisecond. Parameters may have a value of zero if they are not applicable to the DCE being used. Network timing model parameters are shown in Figure C-1.

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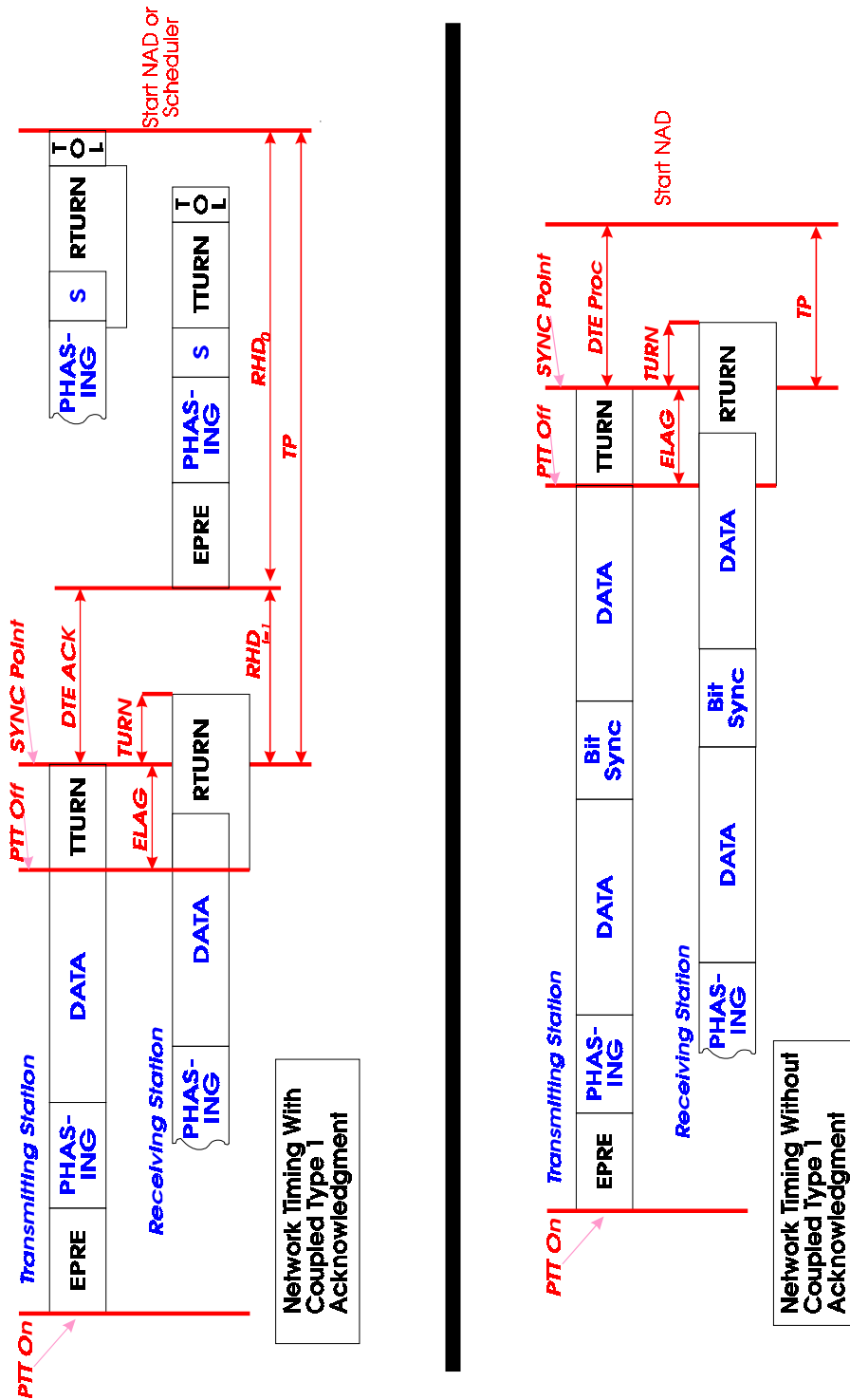
FIGURE C-1. Network timing model.

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C.3.2.1 Equipment preamble time (EPRE). EPRE is the time from when the DTE initiates a transmission, often by asserting Push-to-Talk (PTT), until the transmitting DTE sends to its DCE the first bit of information that will be delivered to the receiving DTE. EPRE is a characteristic of the DCE. It accounts for DCE start up time, including time required for radio power up and transmission of COMSEC and other DCE preambles. EPRE can have a value between 0 and 30,000 milliseconds.

      a.   For Synchronous mode, EPRE is measured from PTT until the DCE provides a clock to the DTE for its first bit of information. For the purposes of the Network Timing Model, it is assumed that the DTE will begin sending information to the DCE with the first clock edge provided by the DCE. During this time, the DTE sends nothing.

      b.   For Asynchronous mode, EPRE is measured from PTT until the first signal transmitted by the sending DTE is also transmitted by the sending DCE to receiving DCEs. This accounts for time that the transmitting DCE is not listening to signals sent by the transmitting DTE. During this time, the transmitting DTE may send an alternating sequence of one and zero bits.

      c.   For Packet mode, EPRE is measured from the time the DTE indicates it is ready to transmit (by asserting the C-lead and transmitting flags on the T-lead as described in 6.3.3.1.2) until the DCE indicates it is ready to accept information from the DTE (by transmitting flags to the DTE on the R-lead as described in 6.3.3.1.2).

C.3.2.2 Phasing transmission time (PHASING). PHASING is the time the DTE must send an alternating sequence of one and zero bits after the completion of EPRE and prior to sending the first bit of DATA. PHASING can be needed due to characteristics of the DCE, DTE, or both. PHASING can have a value between 0 and 10,000 milliseconds. The DTE shall use the DCE bit rate to compute the number of PHASING bits to transmit.

      a.   For Synchronous mode, PHASING can be needed if the DCE delivers extraneous clock edges to the DTE prior to the start of a valid, continuous transmit clock or if the DCE provides a transmit clock to the DTE before it is ready to reliably deliver bits from the DTE to receiving DCEs.

      b.   For Asynchronous mode, PHASING is often needed by the receiving DTE to achieve bit synchronization.

      c.   For Packet mode, PHASING is always zero.

C.3.2.3 Data transmission time (DATA). DATA is the time during which the transmitting DTE sends transmit data to its DCE. Transmit data includes all fields shown in Figure 5. This includes embedded COMSEC information shown in Figure 5b. It also includes transmission of concatenated frames (including bit synchronization between physically concatenated frames) as

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shown in Figure 3. DATA shall begin immediately after the end of PHASING. The transmitting DTE shall indicate end of transmission immediately after the last bit of data is sent to the DCE.

C.3.2.4 Coupled acknowledgment transmission time (S). S is a special case of DATA, where the Data Field shown in Figure 5 contains only one Type 1 URR, URNR or TEST response frame with the F-bit set and no information field. For these frames, the length of the fields in Figure 5 (including zero bit insertion) used in network timing equations when the Multi-Dwell protocol and convolutional coding are not used shall be:

        a.   the 64-bit message synchronization field,

        b.   an optional embedded COMSEC MI field,

        c.   the 168-bit Transmission Wordcount and Transmission Header TDC block, and

        d.   80 bits if neither the FEC nor TDC function is selected, 168 bits if only FEC is selected, and 384 bits if both FEC and TDC are selected.

                The sum of these components is transmitted at the data link bit rate.

C.3.2.5 Equipment lag time (ELAG). ELAG is the time from when the last bit of DATA is sent by the transmitting DTE until the time when the same last bit of DATA is delivered to the receiving DTE by the receiving DCE. ELAG is a characteristic of the DCEs. It accounts for frequency hopping throughput delays, satellite transmission delays, Packet Mode radio-embedded FEC delays and other related delays. The end of ELAG is the synchronization point for the Timeout Period (TP) and Response Hold Delay (RHD) Timers.

C.3.2.6 Turnaround time (TURN). TURN is the time from the end of ELAG until the end of TTURN or RTURN, whichever is later. TURN is computed using the equation:

$$TURN = Maximum((TTURN - ELAG), (RTURN - ELAG))$$

    where:

        a.   TTURN is the time from when the transmitting DTE indicates end of transmission at the end of DATA until the transmitting DCE is ready to begin a new transmit or receive operation. TTURN is a characteristic of the DCE. It includes time when the transmitting DCE sends COMSEC or other postambles after transmitting all DATA.

        b.   RTURN is the time from when the transmitting DTE indicates end of transmission at the end of DATA until the receiving DCE is ready to begin a new transmit or receive operation. RTURN is a characteristic of the DCE.

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c. ELAG may be either larger or smaller than TTURN, but is always less than or equal to RTURN, as shown in Figure C-2.
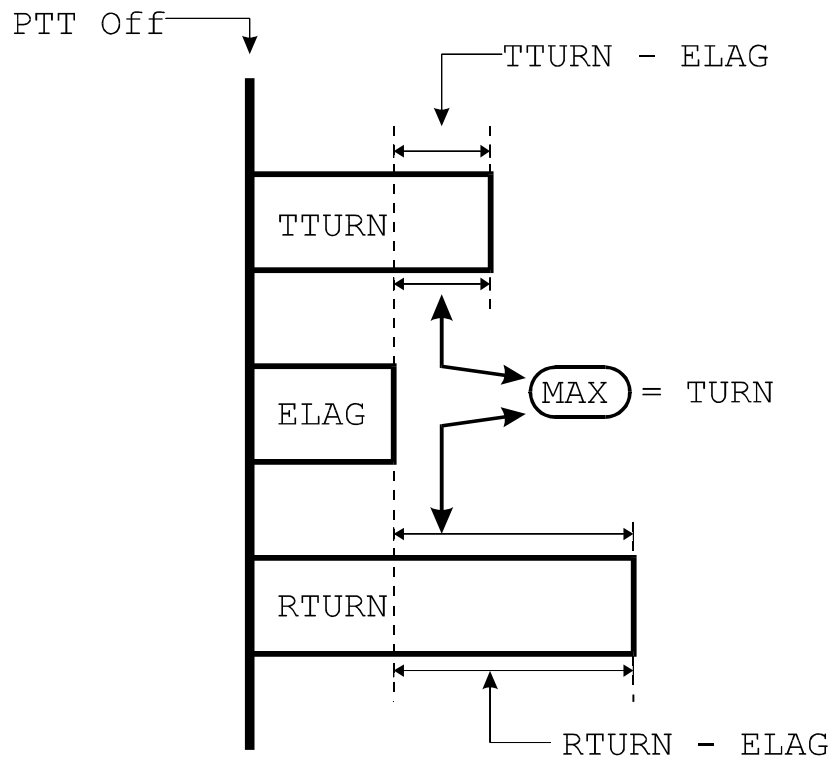
FIGURE C-2. Turnaround time (TURN) calculation

C.3.2.7 DTE ack preparation time (DTEACK). DTEACK is the time from the end of ELAG until the slowest DTE on the network can process any possible Type 1 frame requiring a coupled acknowledgment, prepare the coupled Type 1 acknowledgment frame, and begin sending its coupled acknowledgment frame to its DCE. DTEACK is a characteristic of the DTE. Unless a larger value is known, use the value TURN for the particular radio and operating environment as the default value for DTEACK.

C.3.2.8 DTE processing time (DTEPROC). DTEPROC is the time from the end of ELAG until the slowest DTE on the network can begin sending its next transmission to its DCE after receiving DATA not requiring a coupled, Type 1 acknowledgment. DTEPROC is a characteristic of the DTE. Unless a larger value is known, use the value TURN for the particular radio and operating environment as the default value for DTEPROC.

C.3.2.9 DTE turnaround time (DTETURN). DTETURN is the time required for the DTE to begin a transmit operation when starting in a listening for receive state. DTETURN is the time required for the DTE to stop listening for received data or squelch and to start transmitting

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(including time for transmit relays for PTT to close). DTETURN shall have a fixed value of 10 milliseconds.

C.3.2.10 Tolerance time (TOL). TOL is a time value used to compensate for variances in the time needed to transmit a coupled Type 1 acknowledgment frame. TOL shall not exceed 500 milliseconds. TOL shall be selectable with 50 milliseconds as its default value.

C.4. Network access control. The stations shall implement the following four basic NAC subfunctions:

      a.   network busy sensing

      b.   response hold delay (RHD)

      c.   timeout period (TP)

      d.   network access delay (NAD)

C.4.1. Network busy sensing function. The network busy function is used to establish the presence of a data or voice signal at the receiving station due to activity on the net. Network busy sensing for a data signal shall be provided. Network busy sensing for a voice signal may be provided.

C.4.1.1. Data network busy sensing. When receiving a data transmission, network busy shall be detected within a fixed time. Parameter B shall be used to compute this fixed time. For synchronous mode B shall be less than or equal to (32/n) seconds. For asynchronous mode B shall be less than or equal to (64/n) seconds. For packet mode B shall be less than or equal to 250 milliseconds. Upon detection of data network busy, the data-link network busy indicator shall be set. Setting the data-link network busy indicator shall inhibit all message transmissions, including coupled response messages. The data-link network busy indicator shall be reset upon indication from the physical layer that neither voice nor digital data is being detected by the station.

C.4.1.2. Voice network busy sensing. Network busy due to a voice transmission may be detected. If voice transmissions are not detected, this function shall report that the network is never busy due to a voice transmission. Upon detection of voice network busy, the data-link network busy indicator shall be set. Setting the data-link network busy indicator shall inhibit all message transmissions, including coupled response messages. The data-link network busy indicator shall be reset upon indication from the physical layer that neither voice nor digital data is being detected by the station.

C.4.1.3. Network busy detect time. The time allowed to detect data network busy shall be the same for all stations on the network. This Net_Busy_Detect_Time is a key factor in achieving both throughput and speed of service. Where a communication media provides capabilities to detect data network busy more quickly than given by the formula below, the use of these capabilities is strongly encouraged. In these cases, Net_Busy_Detect_Time can be set to reflect

the capabilities of the media. Where the communication media does not provide special capabilities or these capabilities cannot be used by all stations on the network, the station shall examine received data to detect data network busy. In these cases, the time allowed to detect data network busy shall be given by the formula:

$$Net\_Busy\_Detect\_Time = EPRE + ELAG + B$$

NOTE: Parameters EPRE and ELAG are initialized locally or learned using the XNP messages described in Appendix E. Net_Busy_Detect_Time can also be learned using the XNP messages described in Appendix E.

C.4.2. <u>Response hold delay</u>. An RHD_0 period and an individual RHD value are calculated to determine the time that an addressed receiving station delays before sending a Type 1 response PDU upon receiving a Type 1 command PDU (UI and TEST) requesting acknowledgment (that is, P-bit set to 1 and addressed to the station's individual or special address). The RHD controls network access and the NAD algorithm is suspended during this period. An RHD_0 period is the worst-case amount of time that a single response takes. The individual RHD is the time at which a particular station waits before accessing the network. If the scheduler is running, immediate scheduling should be used for Type 1 Acknowledgment. The individual RHD value to be used shall be determined by the position of the receiving station's individual or special address in the PDU destination portion of the address field. The Reserved Address (0) in the destination portion of the address field shall be ignored. That is, when calculating an individual RHD value, the Reserved Address shall not be considered to occupy a position in the destination portion of the address field. The calculated values for RHD_i, TP, and NAD are computed to the nearest millisecond. The RHD time shall start precisely at the end of ELAG. All stations on a subnetwork shall use the same values in calculating RHD. These values can be initialized locally or learned, using the XNP messages described in Appendix E.

    a.   The RHD_0 period shall be calculated by the following formula:

$$RHD_0 = EPRE + PHASING + S + ELAG + TURN + TOL$$

    b.   The TP shall be calculated by all stations on the network/link as follows:

$$TP = (j * RHD_0) + TOL + TURN$$

    where j = The total number of destination link addresses - to include special and individual but not group or global addresses - for this transmitted frame. The transmitting station shall not include special address 3 in the total for j, and the value of all non-integer variables (that is, RHD_0, TOL, and TURN) in the TP equation are rounded to the nearest one thousandth.

    c.   The individual addressed station's response hold delay (RHD_i) shall be calculated by

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$$RHD_i = (i - 1) * RHD_0 + \text{Maximum}(DTEACK, TURN)$$

The variable i (where $1 \leq i \leq 16$) is the individual station's position in the destination portion of the address field.

C.4.3 Timeout period. TP is the time all stations shall wait before they can schedule the NAD. During this window of time, the transmitting station shall wait to receive the anticipated Type 1 coupled acknowledgment response frame(s), if any, from all applicable addressed stations. The parameter values used to compute TP shall be the same for all stations on a subnet unless immediate retransmission has been selected. When immediate retransmission has been requested, the sending station shall compute the timeout period using only individual addresses and special addresses 1 and 2. All receiving stations shall compute the timeout period using the individual addresses and special addresses 1, 2 and 3. The calculated value of TP is computed to the nearest millisecond. The TP time shall start precisely at the end of ELAG. A retransmission of a Type 1 P-bit frame shall be executed whenever TP has been exceeded without expected acknowledgments having been received from all Type 1 individual and special destinations. Prior to retransmission, the address field of the frame shall be modified to delete the destination station(s) that previously acknowledged the frame. Operationally, TP shall be used as follows:

a.   Upon termination of a message transmission that requires an immediate response, the transmitting station shall set the TP timer. If the transmitting station does not receive all the expected responses (TEST, URR, or URNR) within the TP, and if the number of transmissions is less than the Maximum Number of Transmissions data link parameter, the station shall retransmit the frame when it is the highest precedence frame to send. For all stations, if a Type 1 (P-bit=0), Type 2 or Type 4 frame is received when a response-type frame is expected, the newly received frame shall be processed. The RHD and TP timers shall not be suspended and the TP procedures in use for the Type 1 (P-bit=1) frame shall be continued. Response procedures, if any, for the newly received frame shall commence after the conclusion of the ongoing TP procedures. If the unexpected frame is a Type 1 (P-bit=1) frame the current TP procedure is aborted and the newly received Type 1 (P-bit=1) TP procedure shall be started.

b.   After a station transmits or receives data that does not require a Type 1 coupled acknowledgment, and is not itself a Type 1 coupled acknowledgment, all stations except those using RE-NAD shall compute TP as:

$$TP = \text{Maximum}(DTEPROC, TURN)$$

c.   Upon receiving a Type 1 coupled acknowledgment, a station shall determine whether it thinks a timeout period is already in progress. If no timeout period is in progress, the station shall compute TP using the following equation and shall start a timeout period precisely at the time the last bit of data for the Type 1 coupled acknowledgment was received.

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$$TP = (15 * RHD_0) + TOL + TURN$$

NOTE: RHD_0 is as defined in 4.2.

C.4.4 <u>Network access delay</u>. NAD is defined as the time a station with a message to send shall wait to send a frame after the TP timer has expired. NAD discipline is based on an infinite sequence of "slots" that begin when the TP timer has expired. Slots are defined to be long enough so that all stations on the network will detect a station transmitting at the beginning of a slot prior to the beginning of the next slot. The duration of each slot is NET_BUSY_DETECT_TIME. All transmissions, except the coupled acknowledgments, shall begin at the start of the next NAD slot.

There are five schemes for calculating NAD. The five schemes are defined below. Four schemes (R-NAD, P-NAD, H-NAD AND DAP-NAD) compute a value F for each station on the net. The F value is the number of NAD slots that each station will wait before transmitting, if it has any information to send.

The random network access delay (R-NAD) scheme provides all stations with an equal chance to access the network. The prioritized network access delay (P-NAD) scheme ensures the highest precedence station with the highest priority message will access the network first. In the case of RE-NAD, network access delay is computed by the radio. With RE-NAD the DTE (DMTD or C^4I system) does not compute network access delay but does schedule channel access opportunities at which an access attempt can be initiated by the DTE. DAP-NAD, like P-NAD, ensures the highest priority message will access the network first. It does not ensure first access by highest precedence station however. The hybrid network access delay (H-NAD) scheme combines random access with the preferential access by frame priority. The random and hybrid schemes might result in a collision (the same NAD value for two stations). The P-NAD and DAP-NAD schemes always produce a unique NAD value for each station. In all of the NAD schemes, if the TP timer is active, the stations with frames to transmit shall wait for the TP timer to expire before the NAD is started. If the TP timer is not active, the station shall calculate its NAD using the proper NAD scheme for the network. Each NAD scheme produces a set of allowed access periods. The network may be accessed only at the beginning of one of those periods. If a station using P-NAD, DAP-NAD or H-NAD is waiting for its NAD time and a higher priority frame becomes available for transmission, the station may shorten its NAD time to a time it would have computed if it had computed its original NAD time using the new, higher frame priority. Below are the frame reception and transmission procedures:

      a.   A station shall analyze a received frame to determine if a TP timer must be set. After the frame check sequence has been verified, the address and control fields are analyzed. If the received frame is either a UI or TEST frame and the poll bit is set to 1, then a TP timer is set. Any other pending frames for transmission shall be placed on hold. If the received frame was not a UI or TEST frame with the poll bit set, a NAD value shall be computed and initiated after the TP timer expires. An R-NAD or H-NAD value shall be calculated and initiated if the network busy status is clear. DAP-NAD values need to be recalculated after each transmission. The calculated value of NAD is rounded to the nearest millisecond.

b. If a station does not have a frame to transmit, it shall compute a NAD time using routine priority for its calculations. If the NAD time arrives before a frame becomes available to transmit or frame(s) are not yet encoded for transmission, the station shall compute and use a new NAD time. The starting time for the new NAD shall be the same as the starting time for the NAD that was just completed. The F value used in computing the NAD shall be the sum of the F value used in the NAD just completed, plus a value dependent on the NAD in effect.

 1) For P-NAD this value shall be (NS + 1). This creates another group of NAD slots for all stations on the network. Adding this value at all stations preserves the algorithmic collision prevention property of P-NAD.

 2) For R-NAD this value shall be [(3/4) * NS + 1]. Adding the same constant value at all stations preserves the random property of R-NAD.

 3) For H-NAD this value shall be 1 if the station has an urgent or priority frame to transmit and (Routine MAX + 1 - Routine MIN) if a station has only a routine frame(s) or no frame(s) to transmit. The value 1 preserves the intent of H-NAD that is to grant preferential network access to stations with urgent or priority frames to send. The value (Routine MAX + 1 - Routine MIN) preserves the random property of H-NAD for stations with only routine frames to send.

 4) For RE-NAD, F is not used.

 5) For DAP-NAD this value shall be (NS). This creates another group of NAD slots for all stations on the network. Adding this value at all stations preserves the algorithmic collision prevention property of DAP-NAD.

c. All stations on the network shall continue to sense the link for data or voice network busy and shall withhold transmission until the appropriate NAD period has expired. NAD shall be calculated using the formula:

$$NAD = F * Net\_Busy\_Detect\_Time + Max(0, F\text{-}1) * DTETURN$$

where Net_Busy_Detect_Time is as defined in C.4.1.3 and DTETURN is as defined in C.3.2i.

C.4.4.1 <u>Random network access delay</u>. The R-NAD calculation method shall ensure that each station has an equal chance of accessing the network. The random nature also may provide a resolution if an access conflict occurs. Each attempt to access the network potentially can use a NAD value different from the station's previous value. The integer value of F shall be obtained from a pseudorandom number generator. The range of the pseudorandom number depends on the number of stations (NS) in the network. F shall be an integer value (truncated) in a range between 0 and (3/4)NS. NS can be learned through the XNP join exchange, or fixed by a system parameter established at initialization.

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C.4.4.2 <u>Prioritized network access delay</u>. The P-NAD calculation method shall ensure that the network access precedence order assigned to subscribers is preserved. Each station shall calculate three unique P-NAD values, one for each of the three frame precedence levels. The integer value of F shall be calculated as:

$$F = SP + MP + IS$$

where:

SP = the station priority:
        SP = (subscriber rank -1) for the initial transmission; and
        SP = 0 for subsequent transmissions.

MP = the message precedence:
        MP = 0 for all urgent messages;
        MP = (NS + 1) for all priority messages;
        MP = 2 * (NS + 1) for all routine messages,
        where NS is the number of subscribers on the network.

IS = the initial/subsequent factor:
        IS = 0 for the initial transmission, and
        IS = NS for subsequent transmissions.

Only one station on the network uses the subsequent factor. That is the station that transmitted last on the net. However, transmissions of coupled Type 1 acknowledgments do not count as transmissions for the purpose of determining which station transmitted last.

C.4.4.3 <u>Hybrid network access delay</u>. The H-NAD calculation method ensures that network access delay times are shorter for higher priority frames, while maintaining equal access chances for all stations. Each priority level has a distinct range of pseudorandom F values determined by the number of stations in the subnetwork, the network percentage of the particular priority level frames, and the traffic load. The integer value of F shall be calculated as

$$F = MIN + RAND * (MAX - MIN)$$

where:

RAND = pseudorandom number in the range 0.0 to 1.0

MAX and MIN are integer values defining the ranges:

        Urgent_MIN = 0, for urgent frames

        Urgent_MAX = USIZE + 1, for urgent frames

        Priority_MIN = Urgent_MAX + 1, for priority frames

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Priority_MAX = Priority_MIN + PSIZE + 1, for priority frames

Routine_MIN = Priority_MAX + 1, for routine frames

Routine_MAX = Routine_MIN + RSIZE + 1, for routine frames

USIZE = the additional number of random numbers generated for urgent frames

PSIZE = the additional number of random numbers generated for priority frames

RSIZE = the additional number of random numbers generated for routine frames

where the minimum MIN/MAX range size is 2.

The additional range sizes (xSIZE) are integers based on the percent of frames expected at a specific priority level (%priority_level) and the number of stations adjusted (ADJ_NS) by the expected traffic load (TL). NS, %priority_level, and TL, may be input using the XNP messages or by initialization input. xSIZE is rounded to the nearest non-negative integer.

USIZE = %U * ADJ_NS, %U = percentage of urgent frames (default 25%)

PSIZE = %P * ADJ_NS, %P = percentage of priority frames (default 25%)

RSIZE = %R * ADJ_NS, %R = percentage of routine frames or 100% - (%U + %P) (default 50%)

where the adjusted number of stations increases if the expected TL is heavy and decreases if the traffic load is light. The minimum random number range at each of the three priority levels is 2, so 6 stations are subtracted from the adjusted number of stations.

ADJ_NS = INTEGER (NS * TL) -6 or = 1 (whichever is greater)

where:

TL = 1.2 Heavy Traffic Load
    = 1.0 Normal Traffic Load
    = 0.8 Light Traffic Load

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C.4.4.4. <u>Radio embedded network access delay (RE-NAD)</u>.

C.4.4.4.1. <u>RE-NAD media access</u>. The radio embedded network access delay (RE-NAD) DTE data link layer uses a 1-persistent channel access protocol between the DTE (DMTD or C^{4}I system) and DCE. When the continuous scheduler interval timer (Tc) expires and the previous series of concatenated frames was successfully transmitted, a new series of frames is sent to the physical layer. If there is a pending series of concatenated frames, its transmission is requested again. It should be noted that the physical layer holds the series of concatenated frames when channel access has been denied. If channel access was denied a new Tc timer is calculated and channel access for transmission of the pending series of concatenated frames is requested when the new Tc timer expires. If a higher precedence individual frame becomes available for transmission, the concatenated frames shall be re-built to include the higher precedence frame.

For the Type 1 acknowledgment, the RE-NAD portions in both DTE and DCE are suspended and channel access is controlled by the RHD and TP processes. The RE-NAD algorithm is resumed following expiration of the TP timer.

C.4.4.4.1.1. <u>Random schedule interval</u>. In order to achieve high performance radio network communication, efficient channel access and multi-level precedence, a 1-persistence RE-NAD algorithm is implemented in the DTE. This algorithm uses the "continuous scheduler" concept to provide a random distribution of timing for channel access via the Tc interval timer. The Tc interval timer is the sum of a fixed interval and a random interval. Toffset is the fixed interval. The fixed interval is dependent on the local station's recent use of the channel and is described more fully in C.4.4.4.1.2. The random interval is dependent on network population, network connectivity, traffic load and the local station's recent use of the channel. It is discussed in C.4.4.4.1.3 and C.4.4.4.1.4.

The value of Tc is recalculated periodically from the expression:

$$Tc = Toffset + uniform\_random(schedint)$$

where uniform_random (schedint) is a uniform random number function using the range 0-schedint. Uniform_random returns an integer value.

The record of transmit traffic load at the local station is updated after every transmission attempt by the local station, which modifies the value of Toffset. Thus, Tc is to be updated after every local transmission attempt.

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C.4.4.4.1.2. <u>Calculation of the scheduler offset</u>. The parameter "Toffset" in C.4.4.4.1.1 is a function of the average transmit duration. A transmission is composed of unnumbered, supervisory and information frames. Combinations of these frames are concatenated into a series of frames for transmission. Toffset is calculated as follows:

Toffset = 2 * average transmit duration of the series of concatenated frames

Toffset = 2 * Ttrans, 1.0 <= Toffset <= 10 seconds

where Ttrans = Average concatenated frame transmit duration

The average transmit duration of a series of concatenated frames is determined from the knowledge of the average length of the series of frames in bits divided by the effective on the air information transfer rate. The average length of the series of concatenated frames is computed based on the length of the last four series of concatenated frames transmitted by the local station. Toffset is bounded by 1.0 to throttle the channel by not allowing a station continuous access to the channel. The maximum of 10 seconds places an upper bound on the amount of time a station must wait between channel access attempts when long messages on a low rate channel are used. Toffset is to be updated after every transmission by the local station.

If the scheduler expires and there are no PDUs to transmit, the number of bits equal to one half the effective on the air information transfer rate (bps) will be entered into the record containing the last four transmissions. The value of Ttrans will default to 0.5 second. This will allow the Toffset parameter to default to 1 second during extended periods of inactivity.

C.4.4.4.1.3. <u>Calculation of the scheduler random parameter</u>. The parameter schedint depends on queue lengths and average concatenated frame transmit duration as follows:

schedint = Fsched * Ttrans, min <= schedint <= max

where:

Ttrans = Average concatenated frame transmit duration.

Fsched = Scheduling Factor.

min = 3 seconds; max = 20 seconds.

schedint shall be recomputed after every transmission by the DTE.

C.4.4.4.1.4. <u>Calculation of the scheduling factor</u>. The scheduling factor, Fsched, is based on three other factors: 1) the Partition Factor, Fpart, 2) the Topology Factor, Ftop, and 3) the Load Factor, Fload as follows:

Fsched = ((T*Ftop) (Fload))/((P*Fpart) + D)

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such that min<=Fsched<=max

where:

	FH	SC
T =	1	2
P =	3	3
D =	7	7
min =	1	1
max =	20	20

and

FH = Frequency Hopping Mode
SC = Single Channel Mode
T = Topology Coefficient
P = Partition Coefficient
D = Damping Coefficient

Fload and Fsched are recomputed after every transmission attempt by the local station. Fpart and Ftop are computed after a topology update is generated or received. The T, P and D coefficients represent a compromise between high throughput and low delay, while promoting channel stability. The increase in coefficient T for single channel mode is compensating for the hidden terminal effect in multi-hop fixed frequency networks. The minimum value of 1 second has a throttling effect on the amount of time a station must wait between channel access attempts in a heavily congested, large network with multiple relayers.

C.4.4.4.1.4.1. Calculation of the partition factor. The Partition Factor is computed in a fully distributed manner by each node in the net. Partition Factor takes into account the one-hop connectivities experienced by each node in the network and is a measure of the connectivity between a node's neighbors. When a node's neighbors are strongly interconnected, i.e., the neighbors can hear each other, traffic will be routed directly between neighbors without a need for the node in question to relay the traffic. However, when a node's neighbors are weakly interconnected, for example the neighbors cannot hear each other, the node in question will see an increase in traffic due to relaying between neighbors.

The Partition Factor takes values between 1 for a strongly connected network and 7 for a weakly connected network. In the case of a higher partition factor the channel access scheduling interval is decreased, (the scheduling rate is increased), at the node doing the calculation, to meet the need for a higher percentage of the channel capacity to handle increased relay traffic. The Partition Factor for a non-relay node is set to 1 without executing the following algorithm.

Partition Factor is computed after a topology change is detected.

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ALGORITHM: Calculation of the Partition Factor, Fpart, at node *j*.

      1.   Set the number of neighbors to zero, set the number of broken links to zero.

      2.   For each node *i* in the network, if there is a one hop link from *i* to *j* then:

      2a.   Increment the number of neighbors.

      2b.   For each node *k* in the network, if there is a one hop link from *k* to *j* and there is no one hop link from *i* to *k* then increment the number of broken links.

      3.   max links = # of neighbors * (# of neighbors -1)

      4.   If max links less than 1 then max links = 1.

      5.   Fpart = broken links * 6 / max links.

      6.   Fpart = Fpart + 1.

      7.   FINISH.

The constant 6 in algorithm step 5 establishes a set of 7 different levels of expected relaying. Nodes that are expected to do a significant amount of relaying (because their neighbors are not strongly connected) will receive the value 7 for Fpart, which shortens their scheduling interval per the algorithm in C.4.4.4.1.4. Nodes that are not expected to do a significant amount of relaying (because their neighbors are fully connected, thus reducing the amount of relaying required and providing a number of nodes to share relaying responsibilities) will receive the value 1. This lengthens their scheduling interval Nodes whose neighbors are neither strongly nor weakly connected are assigned a value between 1 and 7, exclusive, that depends on the degree of connectivity between the node's neighbors. This provides a total range of 7 values to bias a node's scheduler, depending upon the degree of relaying that a node is expected to do.

C.4.4.4.1.4.2. Calculation of the topology factor. The Topology Factor is computed in a fully distributed manner by each node in the net. This algorithm computes the ratio of the number of nodes that are one and two hops away from the node doing the computation, to the number of neighbors of the node doing the computation. For the Topology Factor Calculation the following applies: (1) a neighbor is defined as a node which is one hop away from the node doing the calculation, and (2) a neighbor node can also be categorized as a two-hop away node, from the node doing the computation, as long as there is a way of reaching that node in two hops (i.e., a neighbor node can simultaneously be listed, if it meets the criteria, as a two-hop away node). Since this is computed at each node in a fully distributed manner, this enables each node to evaluate its own situation in the network with respect to competition for the shared channel. A node with a high ratio of nodes within two hops to number of neighbors should use a longer scheduling interval due to the fact that neighbor nodes will have to handle the relaying traffic between the node under consideration and all other nodes in the net. Also, neighbor nodes will

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experience a higher ratio of receive collisions since the node in question and the nodes two hops away are "hidden" from each other and thus cannot cooperate well in the channel access process.

Topology Factor takes values from 3 for a low ratio of nodes within two hops to neighbors, and 40 for a high ratio of nodes two hops to neighbors. In cases of higher Topology Factor values it is desirable to use a longer channel access scheduling interval to reduce the occurrence of channel access contention and collisions.

Topology Factor is computed after a topology change is detected.

ALGORITHM: Calculation of Topology Factor, Ftop, for node *j*

1.   Set "number of neighbors" to zero.

2.   Set "hearing within two hops" to zero.

3.   For each node *i* in the net, if there is a one hop link from unit *i* to unit *j* then

3a.   Increment the number of neighbors.

3b.   Hearing within two hops = hearing within two hops + (number of neighbors of unit *i*) - 1. (don't count unit *j*).

4.   If the number of neighbors is zero then set Ftop = 10. Go to step 10.

5.   Hearing within 2 hops = hearing within 2 hops + # of neighbors.

6.   Hearing within 2 hops = (hearing within 2 hops * 6)/4.

7.   Ftop = hearing within two hops/number of neighbors.

8.   If Ftop is less than 3 then Ftop = 3.

9.   If Ftop is greater than 40 then Ftop = 40.

10.   FINISH.

The constants 6 and 4 in algorithm step 6, and the constant 10 in algorithm step 4 are the default values which, when used in the Fsched equation (see C.4.4.4.1.4), restrict the channel access opportunities to a stable region offering good throughput and delay characteristics. The constants 6 and 4 in algorithm step 6 throttle the scheduler as the number of nodes increases, which preserves throughput. The values 6 and 4 give more range when using integer division than the values 3 and 2, respectively.

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C.4.4.4.1.4.3. <u>Calculation of the load factor</u>. The Load Factor is computed in a fully distributed manner by every node in the net. In the transmission header, one byte is dedicated to transmitting the number of messages at the highest priority level remaining in the information frame queue. The four most significant bits (MSB) indicate the level of the highest priority message. The three least significant bits (LSB) indicate the number of frame concatenation's required to transmit all of the messages at the above priority level. The four LSB are quantized as shown in Table C-1.

TABLE C-1. <u>Calculation of the load factor</u>.

Number of Concatenated Frames Required	Bit Pattern (LSB is on the right)
0.0	0 0 0 0
0.0 (exclusive) - 0.5 (inclusive)	0 0 0 1
0.5 (exclusive) - 1.0 (inclusive)	0 0 1 0
1.0 (exclusive) - 2.0 (inclusive)	0 0 1 1
2.0 (exclusive) - 3.0 (inclusive)	0 1 0 0
3.0 (exclusive) - 4.0 (inclusive)	0 1 0 1
4.0 (exclusive) - 5.0 (inclusive)	0 1 1 0
> 5.0	0 1 1 1

The Load Factor takes on values such that $1.0 < Fload < 18.0$. The minimum value of 1.0 places an upper limit on the speed of the scheduler per the Fsched equation in C.4.4.4.1.4. The value of 18.0 provides a useful range for adaptation of the scheduler due to differing traffic loads, and is divisible by 2 and 3, resulting in integer ranges for the three different precedence values. Higher values of the Load Factor indicate that the node has shorter queues of equal or lesser priority. In cases of high load factor, it is desirable to increase the scheduling interval to give neighboring nodes with higher priority or longer queues of equal priority more opportunities to transmit. The Load Factor is calculated after every expiration of the scheduler, prior to calculation of the next expiration.

ALGORITHM: Calculation of the Load Factor, Fload.

1.   Determine the number of unique neighboring node priority levels broadcast by all the nodes including this one. This data is taken from the last transmission received from each neighboring node.

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2. Divide the interval 0.0 to 18.0 into equal segments, one per unique announced priority level. The first segment (0.0 to 9.0 for two levels) is allocated to the highest priority traffic. Define the Segment Offset as the lower bound of the chosen segment. For two precedence levels, the Segment Offset is 0.0 for the highest precedence and 9.0 for the Lowest Precedence. Define the Segment width equal to 18.0/Number of precedence levels. For all three precedence levels, each precedence level has a segment width of 6.0.

3. Each segment is subdivided into n unique levels where n is the number of unique quantized concatenated frame lengths reported by the neighboring nodes and the node doing the computation. In the case of only one length, all nodes use the midpoint of the segment. In the case of multiple lengths, these lengths are ordered from longest to shortest (1 -> n). In the following computation of Load Factor, a node would use a value of m determined by its position in that ordering. All nodes with the longest quantized length use the value 1, while those with the shortest use the value n for variable m in the following equation:

Load Factor = Segment offset + (Segment width*m)/(n+1)

where

Segment Offset is the Lower bound of the segment chosen by precedence level from step 2.

Segment Width is the maximum Load Factor (18) divided by the number of unique precedence levels

n is the number of unique quantized queue lengths.

m is this nodes positioning within the ordering of quantized queue lengths.

TABLE C-2. Calculation of the load factor -- example 1.

Node Number	Highest Precedence	Quantized Queue Length	Load Factor
1	Routine	0 0 0 1	12.0
2	Routine	0 0 0 1	12.0
3	Routine	0 0 1 1	6.0
4	Routine	0 0 1 1	6.0

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All nodes compute the load factor in the following manner.

1. There is only 1 unique priority level (Routine).

2. The Segment is determined to encompass the whole range 0->18.

3. The Segment Offset is the lower bound (0).

4. The Segment Width is the entire range (18).

5. Two unique Quantized Queue Lengths are noted. The value of n is set to 2.

6. The unique Quantized Queue Lengths are ordered from longest to shortest (3,1).

7a. Nodes 1 and 2 note that their positioning in this sequence is 2 and set m to 2.

7b. Nodes 3 and 4 note that their positioning in this sequence is first and set m to 1.

8a. Nodes 1 and 2 compute their load factor from the equation.

Load_Factor = Segment Offset + (Segment Width*m)/(n+1)

$$= 0 \ + \ (18 * 2) / (2+1) = 12$$

8b. Likewise, Nodes 3 and 4 do the Load Factor computation.

Load_Factor = 0 + (18 * 1) / (2+1) = 6

TABLE C-3. <u>Calculation of the load factor -- example 2</u>.

Node Number	Highest Precedence	Quantized Queue Length	Load Factor
1	Routine	0 0 0 1	13.5
2	Routine	0 0 0 1	13.5
3	Urgent	0 0 1 0	6.0
4	Urgent	0 0 1 1	3.0

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All nodes compute the load factor in the following manner.

1. There are two unique precedence levels (Urgent and Routine).

2. The load Factor Range is divided into two segments 0-9, 9-18. The segment 0-9 is reserved for Urgent, while the segment 9-18 is reserved for Routine.

3. The Segment Offset is the lower bound of the segment. The Segment Offset is 0 for Urgent and 9 for Routine.

4. The Segment Width for both precedence levels is the entire range (0->18) divided by the number of precedence levels. Segment Width = 18/2 = 9.

Nodes 1, 2 perform the following computations:

5. There is only one Quantized Queue Length. Thus, n is equal to 1 and since there is only 1 length both nodes use the first position in the sequence and set m to 1.

6. Load Factor   = Segment Offset + (Segment Width*m)/(N+1)
   = 9 + (9 * 1) / (1+1) = 13.5

Nodes 3,4 perform the following computations.

7. The unique Quantized Queue Lengths are ordered from longest to shortest (3,2). There are two unique lengths which sets the value of n to 2.

8. Node 3 has a length of 2 which occupies position 2 in the ordering of step 7. Because it occupies position 2, the value of m is set to 2.

   Load_Factor   = Segment Offset + (Segment Width*m)/(n+1)
   = 0 + (9 * 2) / (2+1) = 6

   Node 4 has length of 3 which occupies position 1 in the ordering of step 7. Node 4 sets its value of m to 1.

   Load_Factor   = Segment Offset + (Segment Width*m)/(N+1)
   = 0 + (9 * 1) / (2+1) = 3

C.4.4.4.1.5 <u>Immediate mode scheduling</u>. The average scheduling interval of the continuous scheduler is a factor in determining intranetwork end-to-end delay. In a lightly loaded network the average end-to-end delay will not be less than the average scheduling interval. In large nets this contributes to unnecessarily large end-to-end delay under conditions of low input load.

This situation is corrected by use of "immediate mode" scheduling under certain specific conditions.

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The problem mentioned above is most obvious in large nets under conditions of light load. The Topology Factor incorporates network size in computing the scheduling interval increases as network size increases. However, in large nets under conditions of light input load channel utilization is low, yet end-to-end will be unnecessarily large due to the average scheduling interval of the continuous scheduler.

This situation is corrected using "immediate mode" scheduling as follows:

    a.   If the message is Type 1 and requires a coupled acknowledgment, set Tc to 0.0 seconds and initiate an immediate channel access attempt. If the DCE is busy, implement the 1-persistent DTE-DC channel access protocol and transmit when the busy period ends. All stations receiving this transmission will suspend their Tc timers and observe the Type 1 timing for coupled acknowledgments.

    b.   If the scheduler expires and there are no concatenated frames awaiting transmission, set Immediate Mode true. Compute and start the next random interval of the continuous scheduler (Tc).

    c.   When an information PDU arrives for transmission and Immediate Mode is true, compute a scheduling interval as follows:

$$Tc = 100 \text{ msec}$$

    d.   When this is done, Immediate Mode is reset to false. The previously scheduled Tc is to be canceled. The 100 msec allows an opportunity for messages which have been segmented/fragmented/received to be piggy-backed into the same series of concatenated frames. This increases efficiency without imposing delay.

    e.   When the scheduler expires due either to the Tc scheduled as a result of the immediate mode operation or due to normal continuous operation, and I-frame(s), S-frame(s), U-frame(s) or a frame concatenation are pending, perform concatenated frame processing as normally is done. Compute and start the next random interval of the continuous scheduler (Tc) in the normal manner.

    f.   The Tc interval timer set as a result of immediate mode operation is to be suspended and resumed for voice operation as is done for continuous mode operation.

C.4.4.4.2 <u>RE-NAD network access</u>. When the precedence level of the transmission changes, the DTE shall set the precedence level of the new transmission. This precedence level will correspond to the frame with the highest precedence value within the series of concatenated frames.

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C.4.4.4.3 <u>Network busy sensing and receive status</u>. The presence of multiple stations on a single random access communications network requires voice/data Network Busy Sensing and the use of network access control to reduce the possibility of data collisions on the net. The combined Data and Voice Nets require cooperation between the DTE (DMTD or C^{4}I system) and the DCE.

The DCE indicates the presence of receive data and voice by signaling the following conditions:

        a.   Data being received,

        b.   Voice operation,

        c.   Idle/Transmission completed,

        d.   Data being transmitted.

The transmission of data by the DTE is allowed only in the Idle/Transmission completed state.

C.4.4.5 <u>Deterministic adaptable priority-network access delay (DAP-NAD)</u>. DAP NAD is a method of generating Network Access Delays to control network accesses which provides every subscriber with an equal opportunity (when considering multiple access periods and equal message priorities) to use a radio/wireline net. It is deterministic in that every subscriber has an opportunity to access the network and given the device, network, and protocol parameter settings, the maximum time for network access can be calculated.

The mechanism for providing equal network access is to give the first "access opportunity" (the time at which a subscriber may transmit a message if one is available) to a different subscriber at each "network access period" (the time between message transmissions when all subscribers are determining when to transmit) and to give later access opportunities to all other subscribers in sequence. Each subscriber is assigned a Subscriber Rank that is in the range of 1 to the Number of Subscribers (NS in the equations that follow). During the first network access period, subscriber number 1 is given the first access opportunity, subscriber number 2 is given the second access opportunity, subscriber number 3 the third access opportunity, etc. After the last subscriber has been given an access opportunity, subscriber number 1 is again given an access opportunity, followed by subscriber number 2, etc. This continues until a subscriber transmits a message. The subscriber that transmits the message shall increment the First Subscriber Number subfield contained in the last message it received and place the number in the First Subscriber Number subfield of the Transmission Header. The very next access period (the first DAP-NAD time slot following the message transmission) is reserved, such that any node can interrupt the network in case the network priority is lower than the precedence of the message they have to transmit. This reserved slot is only used when the network is in Priority or Routine mode. All nodes having messages to transmit with a precedence that is greater than the current network priority would transmit a short Urgent control frame in the reserved slot. Upon receipt of this Urgent control frame or detection of a network busy condition during the reserved slot, all receiving nodes would assume that the network priority had gone to Urgent and act accordingly. In this manner, transmissions in the reserved slot would serve to interrupt the operation of a

network operating at Priority or Routine causing it to elevate to Urgent mode. The next station authorized to access the network is the First Station Number specified in the Transmission Header of the transmission that occurred before reverting to Urgent mode. Each subscriber calculates different NAD times for each network access period. There are three network priority modes: urgent, priority and routine. The reserved slot is not provided when the network is in the Urgent mode. The calculation of the NAD times are discussed in the following paragraphs.

    a.   Network in Urgent Mode. The first NS number of access opportunities of a network access period are reserved for subscribers that have an urgent message awaiting transmission. Those subscribers that do not have any urgent messages awaiting transmission must wait for at least the NS+1 access opportunity before they can transmit. The next NS number of access opportunities of the network access period are reserved for subscribers that have a priority (or an urgent if one has become available since the previous access opportunity) message awaiting transmission. Those subscribers that have only routine messages awaiting transmission must wait for at least the 2NS+1 access opportunity before transmitting. Those subscribers that have any messages awaiting transmission, regardless of priority, by the 2NS+1 access opportunity can transmit when their calculated access opportunity arrives.

    b.   Network in Priority Mode. The first NS+1 access opportunities are reserved. Access opportunities 2 through NS+1 are reserved for subscribers that have an urgent or priority message awaiting transmission. Those subscribers that only have routine messages awaiting transmission must wait for at least NS+2 access opportunity before they can transmit. Those subscribers that have any messages, regardless of priority, awaiting transmission by the NS+2 access opportunity can transmit when their calculated access opportunity arrives. The very first network access period following completion of the transmission while in Priority mode shall be reserved for any station with an Urgent message to notify all other subscribers to revert back to Urgent network mode. After reverting to Urgent mode, the subscriber with the station number matching the First Subscriber Number in the Transmission Header of the transmission completed just before the reserved slot shall have the first network access opportunity. The network shall then remain in the Urgent mode until all stations have had an opportunity to access the network.

    c.   Network in Routine Mode. Only the first access opportunity is reserved. After that, any subscriber that has a message, regardless of priority, can transmit when their calculated access opportunity arrives. The very first network access period following completion of the transmission shall be reserved for any station with an Urgent or Priority message to cause the network to go to Urgent mode. If no station transmits during the reserved slot, the network remains in the mode designated by the Data Link Precedence field in the Transmission Header provided by the last station accessing the network. Routine mode remains in effect until a message is transmitted.

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C.4.4.5.1. <u>DAP-NAD information field.</u> To allow for rapid recovery (resynchronization) to the DAP-NAD mechanism when messages are not received correctly due to noise, etc., and to provide subscribers information about the priority of a message, a DAP-NAD Information Field has been added to the Transmission Header. This field defines the next access opportunity. This field is present in all physical frames. This field contains the First Subscriber Number subfield which contains the number of the subscriber that is to have the first network access opportunity at the next network access period (the one immediately following this transmission). The number of the subscriber that has the first network access opportunity is the variable FSN in the equations below. The DAP-NAD Information Field also contains the Data Link Precedence subfield which indicates the highest priority of any message that is contained in the physical frame. It shall contain the value 0 if an urgent message is in the frame, 1 if a priority but no urgent message is in the frame and 2 if neither an urgent or priority message is in the frame. The Type 1 acknowledgment sent in response to a transmission will use the same Data Link Precedence and First Subscriber Number as used in the original message to which the acknowledgment applies. The variable NP in the equations below shall be set equal to the content of this subfield for the next network access period. If the transmission contained multiple frames, the variable NP is set equal to the highest value in any of the frames. If network busy is detected in the reserved network access period, the network reverts to the Urgent mode regardless of the setting in the Data Link Precedence subfield.

C.4.4.5.2 <u>DAP-NAD equations</u>. A sequence of NADs for each network access period is generated. A subscriber may transmit a message(s) when the time following the Timeout Period equals any one of the terms (NAD values) in the sequence. Equation 1 is used by each subscriber to calculate its DAP-NADs.

Equation 1: $NAD_n = F_n * Net\_Busy\_Detect\_Time + Max(0, F_n-1) * DTETURN$
                        for n=1 to 4

NAD_n is the nth term in the sequence of NADs that are associated with a subscriber during a network access period. Each term (NAD_1, NAD_2, NAD_3, etc.) is a point in time (a delay following the Timeout Period) at which a subscriber may begin transmitting. If a subscriber does not begin transmitting at one term (e.g. NAD_2), it must wait until at least the next term (e.g. NAD_3) before it can begin transmitting. For the DAP-NAD method, the values of the terms calculated by a subscriber will be different than the values of the terms that are calculated by all of the other subscribers (no two subscribers will have terms with the same values). Also, the values of the terms calculated by a subscriber for one network access period will be different than the values of the terms calculated by that subscriber for the next network access period. F_n is nth term in a sequence of factors that, when used in conjunction with DTETURN and Net_Busy_Detect_Time, yields the nth NAD term. F_n is an integer calculated per equation 2.

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Equation 2; F_n $= F_1 + (n-1)NS$ for $n=1$ to 4

F_n is the nth term in a sequence of factors. F_1 is the first term in the sequence and is the base from which all the other terms are calculated. It is calculated per equation 3. NS is the number of subscribers on the network and is the common difference between the terms of the sequence. The variable n is an integer and has a range of 1 to infinity.

Equation 3: F_1 $= F_{min} + I + P * NS$

F_1 is the first term in the sequence of factors. The first term that a subscriber can have is the minimum factor (F_{min}) plus the interrupt factor (I) plus an offset determined by priority of messages awaiting transmission. F_{min} is calculated using equation 4. P is the factor that accounts for message priority. It is calculated using equation 5. Interrupt factor I is computed using equation 6.

Equation 4: F_{min} $= SN - FSN$ if $SN \geq FSN$, else $F_{min} = NS+SN-FSN$

F_{min} is the minimum possible factor that a subscriber could have if message priority and network priority mode were ignored. SN is the number of the subscriber. It is an integer, has a range of 1 to NS, and is assigned at communications initialization. FSN is the number of the subscriber that has the first network access opportunity for the present network access period. It is set equal to the value received in the DAP-NAD information field of the Transmission Header of the last transmission on the net.

Equation 5;   P $= MP - NP$ if $MP \geq NP$. else $P = 0$

P is the factor that accounts for priority of messages awaiting transmission. It is used to generate the offset to add to F_{min} to generate F_1. MP is a variable indicating the highest priority of any messages awaiting transmission. It shall have a value of 0 if there are any urgent messages awaiting transmission, the value 1 if there are any priority messages and no urgent messages awaiting transmission, and the value 2 if there are no urgent or priority messages awaiting transmission. NP is a variable indicating the highest priority of any messages contained in the last transmission on the network. It shall have the value 0 if an urgent message was in the last transmission, 1 if a priority but no urgent message was in the last transmission, and 2 if neither an urgent or priority message was in the last transmission.

Equation 6:   I $= 0$ if NP is 0, else $I = 1$

I is a factor that provides a slot for stations to interrupt the network when the network is not already in Urgent mode.

C.4.4.5.3 <u>Initial condition state</u>. The above DAP-NAD operations and equations only apply to subscribers after they are on-line and have received a message. A subscriber that has just come on line and has not yet received a message is not in synchronism with other subscribers (this subscriber has not yet started any timers and if it had, they would not have been started at the

same time as other subscribers = timers). These subscribers shall be considered to be in the initial condition state. Regardless of what causes a subscriber to be in the initial condition state, transmissions must be delayed by at least the time specified by equation 7 while in that state.

Equation 7: $\text{INAD} = \text{TP} + ((3 * \text{NS}) + 1) * \text{Net\_Busy\_Detect\_Time} + (3 * \text{NS}) * \text{DTETURN}$

INAD (Initial condition state Network Access Delay) is the minimum time that a subscriber must delay transmission of a message after it has become capable of receiving and transmitting messages, but no more than 20 seconds. The TP in the equation shall be a worst case TP, i.e., as if there had just been a Type 1 message on the network that required acknowledgment and was addressed to 16 subscribers on the net.

C.4.5. <u>Voice/data network sharing</u>. A station may support this protocol on a network where both voice and data transmissions are allowed to occur. When operating in a mixed voice and data network, voice and data network sharing shall operate in the following manner:

a. A receive operation shall be considered a voice reception unless a valid synchronization pattern is identified. A receive operation that is less than 0.75 seconds in length shall be considered a noise burst instead of a voice reception. See Section 6, Notes, (6.3.2.2.2) for additional information.

b. The network shall be synchronized based on RHD and TP timers, which are driven only by data transmissions and receptions. Voice receptions and noise bursts shall not be used for resynchronizing network timers.

c. A station shall not transmit during a noise burst or a voice reception. After completion of a voice reception, a station shall wait at least TURN milliseconds before initiating transmission. When voice/noise reception begins and ends during a Type 1 acknowledgment sequence, an acknowledging station will begin transmission only at the beginning of its individual RHD and will not begin transmission after the start of its RHD period.

d. After completion of a voice reception, operation of the P-NAD network access scheme shall be reinitiated if P-NAD is being used. P-NAD consists of a sequence of NAD slot groups. Within each NAD slot group there is one NAD slot assigned to each station and one slot assigned to the station that transmitted last. After a voice reception is completed, the current, partially-completed NAD slot group and the next complete NAD slot group shall be used only by stations with urgent-precedence data transmissions. The NAD slot group after these groups shall be used only by stations with urgent-precedence or priority-precedence data transmissions. Subsequent NAD slot groups may be used by any station. This preserves the intent of P-NAD, which is to deterministically avoid collisions and to ensure that high-precedence traffic is always transmitted first.

e. RHD and TP timers shall not be suspended or resumed as a result of voice receptions.

f. Data link protocol timers shall be suspended and resumed as a result of voice receptions.

g. The Intranet layer timers shall not be suspended and resumed as a result of voice receptions.

h. Relative priorities of voice and data on the network shall be adjusted by selectively enabling or disabling physical and/or data link concatenation for a station. Concatenation may be disabled to give priority to voice and may be enabled to give priority to data.

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APPENDIX D

COMMUNICATIONS SECURITY STANDARDS

D.1. <u>General</u>.

D.1.1 <u>Scope</u>. This appendix describes the COMSEC interoperability parameters for DMTD and interfacing C^{4}I systems. It defines the technical requirements for backward-compatible (traditional) and forward-compatible (embedded) interface modes. See classified Appendix D-2 for additional information.

D.1.2 <u>Application</u>. This appendix is a mandatory part of MIL-STD-188-220. The information contained herein is intended for compliance.

D.1.3 <u>Interoperability</u>. This appendix cannot guarantee the user end-to-end interoperability. The selection of COMSEC and signaling is a function of communications media. Traditional COMSEC equipment is specific to communications media and may not be compatible due to signaling differences. The systems integrators and systems planners must ensure that compatible media and signaling are chosen if interoperability is desired. This COMSEC specification will provide for interoperability of the underlying encryption algorithm.

D.2. <u>Applicable Documents</u>.

      a.   (U) ON431125 WINDSTER Cryptographic Standards

      b.   (U) DS-68 INDICTOR Cryptographic Standards

D.3. <u>Definitions</u>. Refer to Appendix A.

D.4. <u>General requirements</u>. The backward-compatible mode applies when link encryption is provided by external COMSEC devices. These external COMSEC devices may be standalone equipment (such as the VINSON and KG-84) or communications equipment with built-in COMSEC. The forward-compatible mode shall apply for all DTE subsystems with embedded COMSEC. The backward-compatible mode may also be emulated using embedded COMSEC devices.

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D.5. Detailed requirements.

D.5.1 Traditional COMSEC transmission frame. The traditional COMSEC transmission frame shall be composed of the following components, as shown in Figure D-1. Figure D-1 provides additional detail to Figure 4a.

    a.   COMSEC Bit Synchronization

    b.   COMSEC Frame Synchronization

    c.   Message Indicator

    d.   Phasing

    e.   Transmission Synchronization (see 5.2.1.3).

    f.   Data Field (including Transmission Header)

    g.   COMSEC Postamble
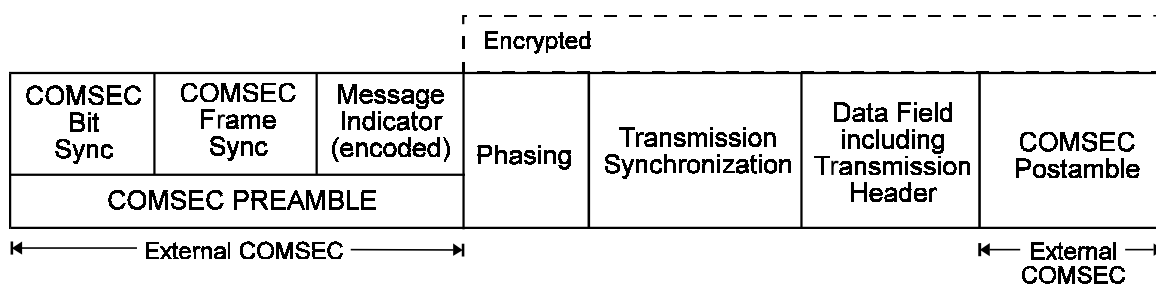
FIGURE D-1. Traditional COMSEC transmission frame structure.

D.5.1.1 COMSEC preamble field. The COMSEC preamble field shall consist of three components: a COMSEC bit synchronization subfield, a COMSEC frame synchronization subfield, and a Message Indicator (MI) subfield. This field is used to achieve cryptographic synchronization over the link.

D.5.1.1.1 COMSEC bit synchronization subfield. This subfield shall be used to provide a signal for achieving bit synchronization and for indicating activity on a data link to the receiver. The duration of the COMSEC bit synchronization subfield shall be selectable from 65 milliseconds to 1.5 seconds. The COMSEC bit synchronization subfield shall consist of the data-rate clock signal for the duration of the subfield.

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D.5.1.1.2 <u>COMSEC frame synchronization subfield</u>. This subfield shall be used to provide a framing signal indicating the start of the encoded MI to the receiving station. This subfield shall be 465 bits long, consisting of 31 Phi-encoded bits, as shown in Figure D-2. The Phi patterns are a method of redundantly encoding data bits. A logical 1 data bit shall be encoded as Phi(1)= 111101011001000, and logical 0 data bit shall be encoded as Phi(0)= 000010100110111. A simple majority voting process may be performed at the receiver to decode the Phi-encoded frame pattern to its original format.

LSB	MSB
1111111111111111111111111111110	

FIGURE D-2. <u>COMSEC frame synchronization pattern for Phi encoding</u>.

D.5.1.1.3 <u>Message Indicator subfield</u>. This subfield shall contain the COMSEC-provided MI, a stream of random bits that are redundantly encoded using Phi patterns. Cryptographic synchronization is achieved when the receiver acquires the correct MI.

D.5.1.2 <u>Phasing</u>. This field shall be a string of alternating ones and zeros, beginning with a one, sent by the DTE. The length of this field is between 0 and 10,000 milliseconds. Phasing is further described in C3.2b.

D.5.1.3 <u>Transmission synchronization field</u>. This field, consisting of the frame synchronization subfield, optional robust frame format subfield, and the TWC subfield, shall be as defined in 5.2.1.3.1.4.

D.5.1.4 <u>Data field</u>. This field, including Transmission Header as defined in 5.3.1, shall be as defined in 5.2.1.4.

D.5.1.5 <u>COMSEC postamble field</u>. This field shall be used to provide an end-of-transmission flag to the COMSEC at the receiving station. This will be automatically performed by the COMSEC key generator. Refer to 0N431125, WINDSTER Cryptographic Standards, or DS-68, INDICTOR Cryptographic Standards, as appropriate.

D.5.1.6 <u>COMSEC algorithm</u>. The COMSEC algorithm shall be backward-compatible with VINSON equipment. Refer to 0N431125, WINDSTER Cryptographic Standards.

D.5.1.7 <u>COMSEC modes of operation</u>. The COMSEC shall be operated in Mode A. The rekey functions shall be performed through the use of KY-57 rekeys for backward compatibility. Refer to 0N431125, WINDSTER Cryptographic Standards.

D.5.2 <u>Embedded COMSEC transmission frame</u>. The embedded COMSEC transmission frame shall be composed of the following components, as shown in Figure D-3:

    a. Phasing

    b. Frame synchronization

    c. Optional Robust Frame Format

    d. Message Indicator

    e. Transmission word count

    f. Data Field

    g. COMSEC Postamble

FIGURE D-3. <u>Embedded COMSEC transmission frame structure</u>.

D.5.2.1 <u>Phasing</u>. This field shall be a string of alternating ones and zeros, beginning with a one, sent by the DTE. The length of this field is between 0 and 10,000 milliseconds. Phasing is further described in C3.2b.

D.5.2.2 <u>Frame synchronization subfield</u>. This subfield shall be either the Robust Frame Synchronization subfield defined in 5.2.1.3.1.2 or the Frame Synchronization subfield defined in 5.2.1.3.1.1. In either case frame synchronization is to be provided for both the message frame and the COMSEC.

D.5.2.3 <u>Robust frame format subfield</u>. When the Robust Frame Synchronization subfield is used, the Robust Frame Format subfield defined in 5.2.1.3.1.2 also shall be used. The Robust Frame Format subfield shall not be used when the Robust Frame Synchronization subfield is not used.

D.5.2.4 <u>Message indicator field</u>. This field shall contain the MI, a stream of random data that shall be encoded using Golay, as defined in 5.3.14.1 and 5.3.14.2. Cryptographic synchronization is achieved when the receiver acquires the correct MI. The COMSEC shall provide the MI bits.

For backward compatibility, these MI bits must be redundantly encoded using Phi patterns, as described in D.5.1.1.2.

D.5.2.5 <u>Transmission word-count subfield</u>. This subfield shall be as defined in 5.2.1.3.1.4.

D.5.2.6 <u>Data field</u>. This field, including Transmission Header as defined in 5.3.1, shall be as defined in 5.2.1.4.

D.5.2.7 <u>COMSEC postamble field</u>. This field shall be used to provide an end-of-transmission flag to the COMSEC at the receiving station. The flag shall be a cryptographic function and may be used by the data terminal as an end-of-message flag as well.

D.5.2.8 <u>COMSEC algorithm</u>. Refer to 0N431125, WINDSTER Cryptographic Standards.

D.5.2.9 <u>COMSEC modes of operation</u>. COMSEC shall be operated in Mode A for all applications. The rekey functions will be performed through the use of KY-57 rekeys for backward-compatibility and will be performed through over-the-air-rekeying (OTAR) techniques for forward compatibility. Rekey signaling for OTAR must be supplied by the host equipment. Refer to 0N431125, WINDSTER Cryptographic Standards.

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APPENDIX E

CNR MANAGEMENT PROCESSES

E.1. General.

E.1.1 Scope. This appendix describes the management processes associated with the data link and network layer. Since the tactical network using CNR may not be fully connected and since it is critical that all stations are provided compatible operating parameters, an Exchange Network Parameters (XNP) message has been defined. XNP messages that are transmitted within Type 1 UI frames, can be relayed, allow disconnected stations to participate fully in the network, and can be used to change network parameters dynamically.

E.1.2 Application. This appendix is not a mandatory part of MIL-STD-188-220.

E.2. Applicable Documents. None

E.3. Network configuration. The CNR management process defined herein covers both centralized and distributed operations. The procedure for negotiation of parameters varies with network configuration. In a centralized network, a single network controller manages the network. In a distributed network, the network is managed by multiple network controllers. It is possible for any number of stations, even all stations, in an established network to be network controllers.

It is desirable that all stations be capable of performing the functions of network controller. The designation of network control station(s) will be done by a network authority. A configuration parameter or an operator command either at initialization or during normal operation times, may inform the station of its network control responsibility.

E.3.1 Centralized network control. Centralized Network Control requires that one network controller manage and control all aspects of the network. Although all stations within a network are expected to be capable of performing the functions of the network controller, only one station is designated the network controller at any one time. Access parameters may only be obtained from the one designated network controller.

E.3.2 Distributed network control. Distributed Network Control allows multiple stations to share the functions of network controller. This is especially useful in disconnected networks where unique access parameters, such as time slots for deterministic network access, are not required. Access parameters may be obtained from any station acting as the network controller. Control of parameters is maintained by interactions between the participating network controllers.

E.4. Exchange network parameters (XNP) message. XNP messages have been designed to provide CNR management capabilities. However, they are not required if the stations on the network have been configured with data link addresses and operating parameters.

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E.4.1 <u>XNP message structure</u>. XNP messages are composed of a one-octet Version Number field (set to 0), an optional Forwarding Header followed by the actual XNP message and one or more data blocks as shown in Figure E-1.

Most Significant Octet<————————————————————————————————>Least Significant Octet

Version Number	Forwarding Header (Optional)	XNP Message (Identification plus basic information fields)	One or More XNP Data Blocks
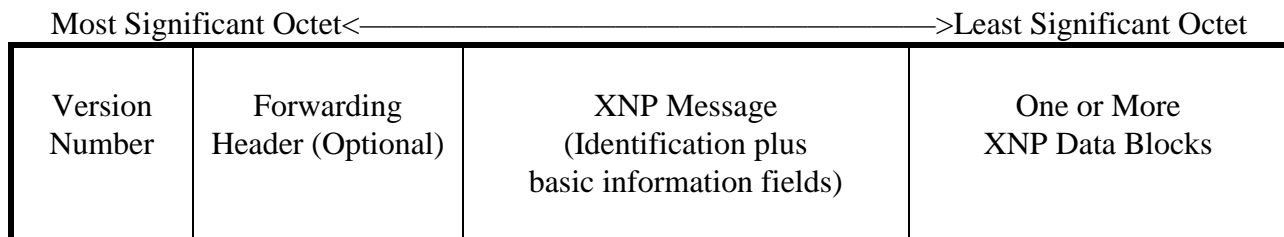
FIGURE E-1. <u>XNP message format</u>.

Detailed formatting of the Forwarding Header, each XNP Message and each Data Block is described in the following paragraphs and tables. The Forwarding Header, each XNP Message and each Data Block consists of data fields. The data fields may be one or more octets in length and may be value coded or bit mapped. When the data field size exceeds one octet, octets are transmitted from the most significant octet (low number) to the least significant octet (high number). Bit mapping uses each bit individually in an on/off representation such that multiple values may be represented by each octet. Bit 0 always represents the least significant bit (2^0). Figure E-2 depicts an example 4-octet data field.

Most Significant Octet<—————————————————————>Least Significant Octet

Octet	1		2		3		4	
Bit	7	0	7	0	7	0	7	0
Bit	31	24	23	16	15	8	7	0

Most Significant Bit<————————————————————————————————>Least Significant Bit

FIGURE E-2. <u>Example 4-octet XNP data field</u>.

Undefined bits shall be set to zero on transmission and ignored on receipt. Undefined values are invalid. The processing of XNP messages containing undefined/invalid values shall be:

    a.   Ignore any undefined bits in a bit map.

    b.   If the V<u>ersion Number</u> is invalid or unsupported, discard the XNP message.

    c.   If any field in the <u>Forwarding Header</u> is invalid, discard the XNP message.

    d.   If the <u>Message Number</u> field is invalid, discard the XNP message.

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    e.   If the <u>Block Number</u> field is invalid in any XNP message, discard the block and continue processing the XNP message.

    f.   If the <u>Length</u> field is invalid in any Data Block (i.e., the value indicates that there are more octets than actually exist in the XNP message), discard the rest of the XNP message but act on the preceding blocks if possible.

    g.   If any other field is invalid in any Data Block, discard the data block and continue processing the XNP message.

    h.   If any other field is invalid in an XNP message, discard the XNP message.

E.4.1.1 <u>Forwarding header</u>. A station joining a network might not have knowledge of the topology and might be unable to contact all stations in the network being joined (e.g. stations might be behind obstacles or out of range). The Forwarding Header provides a means for a joining station to make use of an adjacent station which has access to the entire network via Intranet Relay.

Relay assistance is required for the joining process in a centralized or distributed network when the joiner is unable to directly communicate with the network controller, and also used in distributed networks to ensure adequate distribution of the Hello message. The joining station fills in this header to request relay assistance by an established station. The selected established station distributes these messages using appropriate Intranet Relaying techniques. Any and all responses go back to the selected established station who then forwards to the joiner. When an established member of a network receives an XNP message that contains a Forwarding Header with a Forwarder Link Address that matches its own data link address, the XNP message is retransmitted (via Intranet Relay) to the Destination Link Address in the Forwarding Header.

The Forwarding Header is shown in Table E-1. It consists of the Source Link Address which identifies the originator, the Forwarder Link Address which designates the data link address of the station requested by the joiner to forward the XNP messages, and the Destination Link Address which identifies the final destination.

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TABLE E-1. Forwarding header.

OCTET	FIELD IDENTIFICATION	VALUE
1	Message/Block Number: Identifies this as Forwarding Header.	0
2	Source Link Address: Identifies the originator of the XNP message.	1, 2, 4-95
3	Forwarder Link Address: Station selected to forward XNP messages from/to joining station.	4-95
4	Destination Link Address: Identifies the intended recipient of the XNP.	1, 2, 4-95, 127

E.4.1.2 Message and data block structure. XNP messages and data blocks each have the structure shown in Table E-2. Each message and data block starts with a one-octet identifier (message or block number) and a one-octet length field. These are followed by η data fields. Some data fields consist of multiple octets.

XNP messages are listed in Table E-3. Each of these messages may be combined with one or more of the XNP Data Blocks listed in Table E-4, depending upon the level of detailed information required.

A Terminator Block (Table E-5) designates the end of the XNP message and all associated data blocks. The Terminator Block is required at the end of all XNP messages. Any blocks or messages appearing after the Terminator Block shall be ignored.

TABLE E-2. Message/Block structure.

Octet Number	Field Identification
1	identifier octet (message/block number)
2	message/block length
3	data field 1
•	•
•	•
•	•
η+2	data field η

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TABLE E-3. XNP messages.

MESSAGE NUMBER	TITLE	DESCRIPTION
20	Join Request	Requests operating parameters assignment, validation, or both.
21	Join Accept	Accepts the Join Request. Provides update of parameters
22	Join Reject	Rejects the Join Request with errors indicated
23	Hello	Announces that a station is entering the network.
24	Goodbye	Announces that station is leaving the network.
25	Parameter Update Request	Requests update of network access and other operational parameters.
26	Parameter Update	Provides update of parameters.
27	Delay Time	Announces a known delay. Provides timer information.

TABLE E-4. XNP data blocks.

BLOCK NUMBER	TITLE	DESCRIPTION
1	Station Identification	Provides a network wide unique identifier for a joiner.
2	Basic Network Parameters	Provides a list of network parameters
3	Hardware Parameters	Provides a list of the hardware parameters associated with reported station.
4	Type 3 Parameters	Provides Type 3 parameters to allow computation of RHD_i and TP.
5	Deterministic NAD Parameters	Provides listing of DAP-NAD and P-NAD parameters to allow computation of access slots.
6	Probabilistic NAD Parameters	Provides listing of R-NAD and H-NAD parameters to allow computation of access slots.
7	RE-NAD Parameters	Provides listing of RE-NAD parameters.
8	Wait Time	Notifies recipient of the amount of time to wait before making required updates.
9	Type 2 Parameters	Provides a list of Type 2 capabilities
10	Type 4 Parameters	Provides a list of Type 4 capabilities
11	NAD Ranking	System ranking for use in deterministic NAD computations.
12	Intranet Parameters	List of parameters for maintaining intranetworking.
13	Error	List of unacceptable parameters.
14-254	Undefined	
255	Terminator Block	Notification of end of block transmissions.

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TABLE E-5. Terminator block.

OCTET	FIELD IDENTIFICATION	VALUE
1	End of message designator: Identifies the end of the XNP message and associated data blocks.	255

E.4.2 XNP message formats. Six messages are used in the procedure for a station to join a network or to request or verify the network operating parameters. These are the Join Request, Join Accept, Join Reject, Parameter Update Request, Parameter Update and Delay Time messages. The Hello message allows an initiating station to announce that it is entering the network. The Goodbye message is issued to report that a station is leaving the network. These messages may be combined with one or more data blocks to provide detailed network operating parameters. These messages are described in the following paragraphs and are depicted in Tables E-6 through E-13.

E.4.2.1 Join request. The Join Request message (Table E-6) is sent by a station attempting to join a network. The joiner is expected to provide a unique identifier and indicate all implemented capabilities in order to lessen the probability of rejection by the network controller. The unique identifier is used to resolve ambiguities during the joining procedure. The unique identifier is the 24-bit Unit Reference Number (URN) with zeros in the eight most significant bits. If there is no URN a unique identifier must be assigned to each potential user by a mechanism outside the scope of this appendix.

TABLE E-6. Join request message.

OCTET	FIELD IDENTIFICATION	VALUE
1	Message Number: Identifies specific message content.	20
2-5	Station Identifier: Identifies the station trying to join the network	Unique identifier for the station

The joining station should include data block 2 and, if hardware parameters are known, data block 3. The joining station fills in the applicable data blocks with the parameters supported by the joiner.

Some fields within the Join Request data blocks allow the joiner to set all bits, indicating that all capabilities of that field are supported by the joining station, and the network controller is expected to provide the desired network operating parameters.

The Join Request message with no data blocks will suffice provided joiner has every capability listed in data block 2, has not been pre-assigned a data link address, is capable of all optional data link layer service types, and does not know hardware parameters.

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E.4.2.2 <u>Join accept</u>. The Join Accept message (Table E-7) is sent by a network controller in response to the Join Request message, provided entry to the network has been approved. If there is no network controller, any station may send a Join Accept message in response to the Join Request message. Actual network operating parameters will be provided in the appropriate data blocks combined with the Join Accept message. The appropriate data blocks appended to the Join Accept message depend upon the network configuration and the capabilities of the joining station. It will typically include data blocks 2, 4, 9 (if joiner indicated a Type 2 capability and there exists a network default), 10 (if joiner indicated a Type 4 capability) and either block 5, 6, or 7 (depending upon network access method in use).

The Join Accept message may include data block 8 to specify a period that the joining station should wait after sending a Hello message before it can assume its selected data link address has been accepted.

TABLE E-7. <u>Join accept message</u>.

OCTET	FIELD IDENTIFICATION	VALUE
1	<u>Message Number</u>: Identifies specific message content.	21
2-5	<u>Station Identifier</u>: Identifies the station trying to join the network.	Unique identifier for the station
6-17	<u>Address Map</u>: Bit map of addresses.	Bits correspond to data link addresses 0 through 95. Bit 0 corresponds to data link address 0. A bit set to one specifies the address is not available (i.e., it is already in use).
18	<u>Communications Functions</u>: An indication of the network type (centralized or distributed) in use.	0 = No Net Controller 1 = Centralized 2 = Distributed

E.4.2.3 <u>Join reject</u>. The Join Reject message (Table E-8) is sent by a network controller when entry to the network has not been approved. The Join Reject should be interpreted as being applied to the station identified in the Station Identifier field. Join Reject messages originated by any station other than a network controller should be discarded and ignored.

The Join Reject message is sent in response to the Join Request message when the reason for rejection is that the parameters provided are not presently acceptable in this network. An error indication is provided with the Join Reject to clearly identify the unacceptable parameter(s). This error indication may be data block 13, which lists the unacceptable parameters and/or one or more other data blocks correcting the unacceptable parameter(s).

The Join Reject message is also sent in response to a Hello message to indicate that the joiner has selected a data link address that is in use. Rejection of a joining station's use of a data link address can be accomplished with only the basic Join Reject information fields, no data blocks (except the Termination Block) are required. Unless the joining station can correct the error(s), entry via XNP is not possible.

When a station receives a Join Reject message, the station identified in the Station Identifier field shall be removed from its topology tables unless it is a static node (link quality is 7).

TABLE E-8. Join reject message.

OCTET	FIELD IDENTIFICATION	VALUE
1	Message Number: Identifies specific message content.	22
2-5	Station Identifier: Identifies the station trying to join the network.	Unique identifier for the station
6	Rejected Link Address. The data link address being rejected because it is already in use. Joining station must select another address.	Rejected data link address. 0 = Rejection is for a reason other than data link address.
7-18	Address Map: Bit map of addresses.	Bits correspond to data link addresses 0 through 95. Bit 0 corresponds to data link address 0. A bit set to one specifies the address is not available.
19	Communications Functions: An indication of the network type (centralized or distributed) in use.	0 = Unknown 1 = Centralized 2 = Distributed

E.4.2.4 Hello message. The Hello message (Table E-9) is sent by a station after the network operating parameters are known and the station is ready to enter the network. The message contains the data link address of the station entering the network. Address tables within receiving stations are updated, if necessary, with the new address information. When a station receives a Hello message, it shall update its topology tables.

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TABLE E-9. Hello message.

OCTET	FIELD IDENTIFICATION	VALUE
1	Message Number: Identifies specific message content.	23
2-5	Station Identifier: Identifies the station trying to join the network.	Unique identifier for the station
6	Selected Link Address: The actual data link address selected for use by this station.	Data link address selected by this station.

E.4.2.5 Goodbye message. The Goodbye message (Table E-10) is sent by a station to notify the network controller and other network subscribers that it is leaving the network. The data link address used by the receiving station is made available for re-use by another station. Address tables within the receiving stations are updated, if necessary.

Before a station sends a Goodbye message, it should disconnect all Type 2 connections and broadcast a URNR and DRNR to indicate it will no longer receive frames. When a station receives a Goodbye message, it shall update its topology tables.

TABLE E-10. Goodbye message.

OCTET	FIELD IDENTIFICATION	VALUE
1	Message Number: Identifies specific message content.	24
2-5	Station Identifier: Identifies the station leaving the network.	Unique identifier for this station
6	Released Link Address: The data link address of the station leaving the network.	Data link address of this station.

E.4.2.6 Parameter update request message. A station that is out of operation for some period of time or experiences a system failure may be unaware of changes to the network operating procedures/parameters or may have lost all record of the operating parameters. Once the outage or failure is corrected, the station may send this Parameter Update Request message (Table E-11) to obtain new/changed parameters. The station may use this message to obtain an update of any or all parameters by attaching data blocks identifying the parameters that need to be updated.

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TABLE E-11. Parameter update request message.

OCTET	FIELD IDENTIFICATION	VALUE
1	Message Number: Identifies specific message content.	25
2-5	Station Identifier: Identifies this station.	Unique identifier for the station
6	Update Requested: Update of parameters for requesting station or for all stations on the network. Actual parameters requested shall be stated in attached data blocks.	Bits set to one designate the following: 0 = Requesting Station 1 = All Stations 2 - 7 = Undefined

E.4.2.7 Parameter update message. The Parameter Update message (Table E-12) shall be sent in response to the Parameter Update Request message. It may be sent by the network controller before sending a Join Accept message in response to a Join Request message. The Parameter Update message may include data block 8 to specify the time period, after receipt of the message that the network parameters become effective.

TABLE E-12. Parameter update message.

OCTET	FIELD IDENTIFICATION	VALUE
1	Message Number: Identifies specific message content.	26
2-5	Station Identifier: Identifies a station.	Unique identifier for the station
6-17	Address Map: Bit map of addresses.	Bits correspond to data link addresses 0 through 95. Bit 0 corresponds to data link address 0. A bit set to one specifies address not available.
18	Communications Functions: An indication of the network type (centralized or distributed) in use.	0 = Unknown 1 = Centralized 2 = Distributed

E.4.2.8 Delay time message. The Delay Time message (Table E-13) is sent by a Forwarder in response to a broadcast Join Request message. It provides an indication to the joiner of how long a delay should be expected before the Forwarder will return a Join Accept message from the network controller after a Forwarded Join Request message is received from the joining station.

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TABLE E-13. Delay time message.

OCTET	FIELD IDENTIFICATION	VALUE
1	Message Number: Identifies specific message content.	27
2-5	Station Identifier: Identifies the station trying to join the network.	Unique identifier for the station
6	Time: The amount of time the joiner should expect to wait for a Join Accept message after sending a Join Request through this Forwarder.	1 to 255 seconds in 1 second increments

E.4.3 XNP data block formats. One or more additional XNP Data Blocks may appear before the Terminator Block in each XNP message to either provide specific network operating parameters or to request specific parameters. The additional XNP Data Blocks are described in the following paragraphs and are depicted in Tables E-14 through E-26.

E.4.3.1 Block 1, Station identification. Block 1 (Table E-14) consists of one field which is used to identify the station being reported. It is used with the Parameter Update message to identify the station to which the parameters apply, in Block 2, and/or Block 11 (that must be preceded by Block 1).

TABLE E-14. Station ID.

OCTET	FIELD IDENTIFICATION	VALUE
1	Block Number: Identifies specific data block.	1
2	Length: Indicates the length of the Station ID block in octets.	6
3-6	Unique Identifier: Identifies the station trying to join the network or being updated.	Unique identifier for the station

E.4.3.2 Block 2, Basic network parameters. This block (Table E-15) is used to define basic network capabilities of a joining station, a requesting station or any other station identified by Block 1. It is mandatory in the Join Request message to identify capabilities of the joining station, unless the joining station has all possible capabilities listed. It is optional with the Join Accept message, Hello message, Parameter Update Request message and Parameter Update message.

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TABLE E-15. Basic network parameters.

OCTET	FIELD IDENTIFICATION	VALUE
1	Block Number: Identifies specific data block.	2
2	Length: Indicates the length of the Basic Network Parameters block in octets.	13
3	Link Address: Identifies the data link address of the station.	0 = Unknown 4 to 95 = actual data link address
4	Station Class: The types of data link services available (See 5.3.3.5).	0 = Class A 1 = Class B 2 = Class C 3 = Class D
5	NAD Methods: Identifies either the NAD methods available by a station or the specific NAD method being used in a network.	Bit map: 0=R-NAD 1=H-NAD 2=P-NAD 3=DAP-NAD 4=RE-NAD
6-9	Group Address: Bit map that identifies the group address(es) that the station is a member of.	Bit map: LSB = 96 MSB-1 = 126
10	Concatenation Capability: Indicates the types of concatenation supported by the reporting station.	Bit map: 0 = Physical layer 1 = Data link layer
11	EDC/TDC/Scrambling Mode: Bit map which identifies the FEC, TDC and Scrambling capabilities.	Bit Map: 0=Half-rate Golay FEC 1=TDC 2=V.33 Scrambling 3=V.36 Scrambling 4=Robust Comm. Protocol
12-13	Max. UI, DIA and I Info. Octets: Indicates the largest information field size that can be handled by the reporting station or that is allowed on the network.	708 - 3345 octets 65535 = requested

E.4.3.3 Block 3, Hardware parameters. Hardware parameters defined by Block 3 (Table E-16) are required to enable computation of TP, RHD and Net_Busy_Detect_Time described in Appendix C. Although not mandatory with any message, it could lead to erroneous network control computations resulting in collisions if the information is not provided in a Join Request message.

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TABLE E-16. Hardware parameters.

OCTET	FIELD IDENTIFICATION	VALUE
1	Block Number: Identifies specific data block	3
2	Length: Indicates the length of the Hardware Parameters block in octets	18
3	Equipment Preamble Time (EPRE): Network Access Control parameter defined in Appendix C.	from 0 in 1 msec increments
5-6	Phasing Time: Network Access Control parameter defined in Appendix C.	0 - 10000 in 1 msec increments
7-8	Equipment Lag Time (ELAG): Network Access Control parameter defined in Appendix C.	from 0 in 1 msec increments
9-10	Turnaround Time (TURN): Network Access Control parameter defined in Appendix C.	from 0 in 1 msec increments
11-12	Tolerance Time (TOL): Network Access Control parameter defined in Appendix C.	0 - 500 msec in 1 msec increments
13-14	DTE Processing Time (DTEPROC): Network Access Control parameter defined in Appendix C.	from 0 in 1 msec increments
15	DTE Acknowledgment Time (DTEACK): Network Access Control parameter defined in Appendix C.	0 - 254 in 1 msec increments
16-17	Net Busy Detect Time, B: The time to detect data network busy.	from 0 in 1 msec increments
18	Mode Of Operation: Identifies the Physical Layer protocol capabilities of the station or being used in the network. Multiple bits may be set.	Bit Map: 0=Synchronous Mode 1=Asynchronous Mode 2=Packet Mode 3=Robust Comm. Protocol

E.4.3.4 Block 4, Type 3 parameters. These parameters (Table E-17) are required for data link Type 3 (acknowledged Type 1) operations and are mandatory with the Join Accept message to provide the joining station with sufficient information to use Type 3 in the network. This block is optional with the Parameter Update Request message and the Parameter Update message.

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TABLE E-17. Type 3 parameters.

OCTET	FIELD IDENTIFICATION	VALUE
1	Block Number: Identifies specific data block.	4
2	Length: Indicates the length of the Type 3 Parameters block in octets	3
3	Type 3 Retransmissions: The maximum number of times to retransmit an unacknowledged frame.	0 to 5

E.4.3.5 Block 5, Deterministic NAD parameters. This block (Table E-18) defines parameters needed to allow operation in a network configured for deterministic network access (DAP-NAD or P-NAD) operations. It is mandatory with the Join Accept message if the network being joined is operating with P-NAD or DAP-NAD. It may also be used with the Parameter Update Request message and the Parameter Update message. This block is required in the Parameter Update message if it is being used to announce the network's access procedures are changing to either P-NAD or DAP-NAD.

TABLE E-18. Deterministic NAD parameters.

OCTET	FIELD IDENTIFICATION	VALUE
1	Block Number: Identifies specific data block	5
2	Length: Indicates the length of the Deterministic NAD Parameters block in octets	6
3	Number Of Stations: Indicates the number of stations participating on the network. Used in NAD calculations.	2 - 95
4	Number Of NAD Priorities: Number of priorities to be considered in P-NAD and DAP-NAD method.	1 - 8
5	Number Of NAD Slots: Indicates the number of NAD slots available for P-NAD and DAP-NAD operations.	1 - 127
6	NAD Slot Duration: Duration of the NAD time slot for NAD operations.	0 - 2540 msec in 10 msec increments

E.4.3.6 Block 6, Probabilistic NAD parameters. Block 6 (Table E-19) provides network access delay operating parameters for probabilistic networks (R-NAD or H-NAD). It is mandatory with the Join Accept message to provide the joining station with required operating parameters if the network is configured for either R-NAD or H-NAD. It is optional with the Parameter Update Request message and the Parameter Update message. This block is required in the Parameter Update message if it is being used to announce the network's access procedures are changing to either R-NAD or H-NAD.

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TABLE E-19. Probabilistic NAD parameters.

OCTET	FIELD IDENTIFICATION	VALUE
1	Block Number: Identifies specific data block	6
2	Length: Indicates the length of the Probabilistic NAD Parameters block in octets	7
3	Number Of Stations: Indicates the number of stations participating on the network. Used in NAD calculations.	2 - 95 stations on the network
4	Number Of NAD Priorities: Number of priorities to be considered in R-NAD and H-NAD method.	1 - 8
5	Urgent Percent: The percentage of urgent (%U) frames expected in an average 24-hour period. Used in the H-NAD calculation.	0 - 100% This value plus Priority Percent value must be less than or equal to 100%
6	Priority Percent: The percentage of priority (%P) frames expected in an average 24-hour period. Used in the H-NAD calculation.	0 - 100% This value plus Urgent Percent value must be less than or equal to 100%
7	Traffic Load: The amount of network traffic expected. Used in the H-NAD calculation.	0=Normal, 1=Heavy, 2=Light

E.4.3.7 Block 7, RE-NAD parameters. These parameters (Table E-20) are required for stations in a network operating with RE-NAD. It is mandatory with the Join Accept message to provide joining stations with network access parameters if the network being joined is configured for RE-NAD. It is optional with the Parameter Update Request message and the Parameter Update message. This block is required in the Parameter Update message if it is being used to announce the network's access procedures are changing to RE-NAD.

TABLE E-20. RE-NAD parameters.

OCTET	FIELD IDENTIFICATION	VALUE
1	Block Number: Identifies specific data block.	7
2	Length: Indicates the length of the RE-NAD Parameters block in octets	TBD
3-	Undefined	

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E.4.3.8 Block 8, Wait time. This block (Table E-21) is used with the Join Accept message and Parameter Update message to specify a delay. When used with the Join Accept message, it indicates how long the Joining station should wait after sending a Hello message before it can assume its entry to the network is accepted. When used with the Parameter Update message, it indicates when new operating parameters become effective.

TABLE E-21. Wait time.

OCTET	FIELD IDENTIFICATION	VALUE
1	Block Number: Identifies specific data block	8
2	Length: Indicates the length of the Wait Time block in octets	3
3	Wait Time: Delay period.	1 to 255 seconds in 1 second increments

E.4.3.9 Block 9, Type 2 parameters. This block (Table E-22) identifies individual or network operating parameters for stations capable of optional Type 2 operations. It may be used with the Join Accept message, Parameter Update Request message and Parameter Update message.

E.4.3.10 Block 10, Type 4 parameters. Type 4 parameters (Table E-23) are required for stations in a network which are capable of Type 4 operations. It may be used with the Join Accept message, Parameter Update Request message and Parameter Update message.

E.4.3.11 Block 11, NAD ranking. This block (Table E-24) provides ranking of a station in a deterministic network access configured network. It is mandatory if the network is configured for either P-NAD or DAP-NAD. It may be used with the Join Accept message or the Parameter Update message. In the Parameter Update message, it may be repeated to identify ranking of each station in the network. In this case, this block will appear once for each station on the network and will be preceded by block 1 to identify the station to which the ranking applies.

E.4.3.12 Block 12, Intranet parameters. The Intranet parameters (Table E-25) must be provided to joining stations to provide information for Intranet relaying within the local network. This block shall be included with the Join Accept and Parameter Update messages.

E.4.3.13 Block 13, Error. Block 13 (Table E-26) is encoded in Block/Byte number pairs indicating the starting byte number of the field containing the error.

Block 13 may be included with the Join Reject message to indicate the reasons that a Join Request is being rejected.

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TABLE E-22. Type 2 parameters.

OCTET	FIELD IDENTIFICATION	VALUE
1	Block Number: Identifies specific data block.	9
2	Length: Indicates the length of the Type 2 Parameters block in octets	12
3-4	ACK Timer: The amount of time before Waiting Acknowledgment procedures are initiated.	10 - 1800 seconds in 1 second increments.
5	P-Bit Timer: The amount of time before Waiting Acknowledgment procedures are initiated when P-bit was set to 1.	10-60 seconds in 1 second increments.
6-7	Reject Timer: The amount of time before re-sending the REJ or SREJ if no response is received.	20 - 3600 seconds in 1 second increments.
8	Max. Transmissions, N2: The maximum number of times an I frame may be transmitted.	0 - 5
9	K Window: The maximum number of outstanding I PDUs allowed on a connection.	1 - 127
10	K2 Threshold: The maximum number of unacknowledged I PDUs on a connection before an acknowledgment is requested.	1 - 127
11	K3 Threshold: The maximum number of unacknowledged I PDUs on a connection before an acknowledgment must be sent.	1 - 127
12	Response Delay Timer: The amount of time that a station waits after an I PDU with its P-bit set to 0 is received before sending an acknowledgment.	1 - 1800 seconds in 1 second increments.

TABLE E-23. Type 4 parameters.

OCTET	FIELD IDENTIFICATION	VALUE
1	Block Number: Identifies specific data block	10
2	Length: Indicates the length of the Type 4 Parameters block in octets	6
3-4	ACK Timer: The amount of time before a DIA is retransmitted.	50 - 1200 tenths of seconds
5	K Window: The maximum number of outstanding DIA frames allowed for a station.	5 - 20
6	Max. Transmissions: The maximum number of times a DIA frame may be transmitted.	0 - 5

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TABLE E-24. NAD ranking.

OCTET	FIELD IDENTIFICATION	VALUE
1	Block Number: Identifies specific data block	11
2	Length: Indicates the length of the NAD Ranking Parameters block in octets	3
3	Subscriber Rank: Identifies the ranking of this station relative to other stations on the network. Used in P-NAD and DAP-NAD calculations to determine the actual order of network access.	1-127 with 1 being highest.

TABLE E-25. Intranet parameters.

OCTET	FIELD IDENTIFICATION	VALUE
1	Block Number: Identifies specific data block	12
2	Length: Indicates the length of the Intranet Parameters block in octets	11
3	Min Update Per: Topology updates should not be transmitted more often than once every Min_Update_Per.	1 minute increments 0=No Updates
4	Topology Update Precedence: The precedence of Topology Update messages.	0 = Routine 1 = Priority 2 = Immediate 3 = Flash 4 = Flash Override 5 = CRITIC/ECP 6 = Internet Control 7 = Network Control 8 - 255 = Undefined
5	Relayer Status: Indicates if the station is a relayer or non-relayer.	0=No Relay 1=Relay
6-7	ACK Timer (fixed factor): The base time to wait before retransmitting an unacknowledged Intranet message.	0 to 600 in seconds
8-9	ACK Timer (proportional factor): The amount of time to add to the fixed factor for each hop to the furthest destination of an Intranet message.	0 to 600 in seconds
10	Retransmit Count: The maximum number of retransmissions of an Intranet message.	1 to 4
11	Link Failure Threshold: The number of data link acknowledgment failures required to change a station's status to failed.	1 to 7

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TABLE E-26. Error.

OCTET	FIELD IDENTIFICATION	VALUE
1	Block Number: Identifies specific data block	13
2	Length: Indicates the length of the Error block in octets	4 + 2n, where n = the number of errors
3	Message/Block Number 1: Indicates the message or block containing the first error.	1 through 12, 20 through 27
4	Byte Number 1: Indicates the first octet of the field within the message or block that contains the first error.	1 through 255
	• • •	
3 + 2n	Message/Block Number n: Indicates the message or block containing the nth error.	1 through 13, 20 through 27
4 + 2n	Byte Number n: Indicates the first octet of the field within the message or block that contains the nth error.	1 through 255

E.5. XNP message exchange. XNP messages shall be exchanged using a UI command frame as shown in Figure E-3.

FLAG	Source Address	Destination Address	Control Field	Intranet Header	XNP Information	FCS	FLAG

FIGURE E-3. UI frame containing XNP message.

E.5.1 Data link addressing. Data link address 1 is a special address for a station to use while joining the network if it has not been pre-assigned a data link address. If a station has not been assigned a data link address, it shall use this special data link address for network entry until an individual data link address has been assigned or selected. Since multiple stations may be attempting to join the network at the same time, the Station Identifier field in each XNP message is used to uniquely identify the station.

Data link address 2 is a special address reserved for the network control station. Joining stations, forwarders and relayers use the special address 2 to address the network control station. The forwarder shall provide the full source directed relay path to the network controller at the Intranet layer. The network controller shall use this same path in reverse to reach the joining station

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through the forwarder. The Station Identifier field in the XNP messages used to uniquely identify stations during the joining process.

In a network using distributed control there may be more than one network controller. Network controllers in a network using distributed control may use their individual address at the data link layer of the UI frame carrying the Join Accept message. Also, in networks with no network controller, any station may respond to a Join Request message with a Join Accept message using their own individual address.

E.5.2 Poll/Final bit. Use of UI poll/final bits is allowed but not recommended for use with XNP Join Request, Join Accept and Join Reject messages because network timing parameters for Type 1 final-bit responses are either unknown or subject to change during the network joining process.

E.5.3 Network access. MIL-STD-188-220 allows a network to choose among the network access delay methods defined in Appendix C. Each station that operates on the network must use the same method. If the station does not know this information before joining the network, the Join Request message allows a station to learn the network access method. In the case that the network access method is unknown, a random method (R-NAD or RE-NAD) shall be used for the Join Request message. When R-NAD is used, the default number of stations shall be 7 unless another number is known.

E.6. Network joining procedures. Joining procedures depend upon the network configuration prevailing at the time of attempted entry. If the network is operating with a centralized network controller, operating parameters will be provided only by the network controller. If operating with distributed network control, any existing network controller is capable of providing operating parameters. The joining station may or may not be aware of the network configuration.

E.6.1 Joining concept. In general, the basic network joining procedure depicted in Figure E-4 is followed. The joining station sends a Join Request message that contains its MIL-STD-188-220 capabilities and unique identifier. The responding network controller compares the joiner's capabilities with current network operating parameters. If an error is found which precludes acceptance into the network, the network controller returns a Join Reject message to the joiner. The Join Reject message may include all of the correct parameters in appropriate data blocks of the message and/or use the error message to identify errors. If the errors can be corrected by the joiner, a new Join Request message with corrected parameters can be sent. If the errors are not correctable, automatic joining using XNP is not possible.

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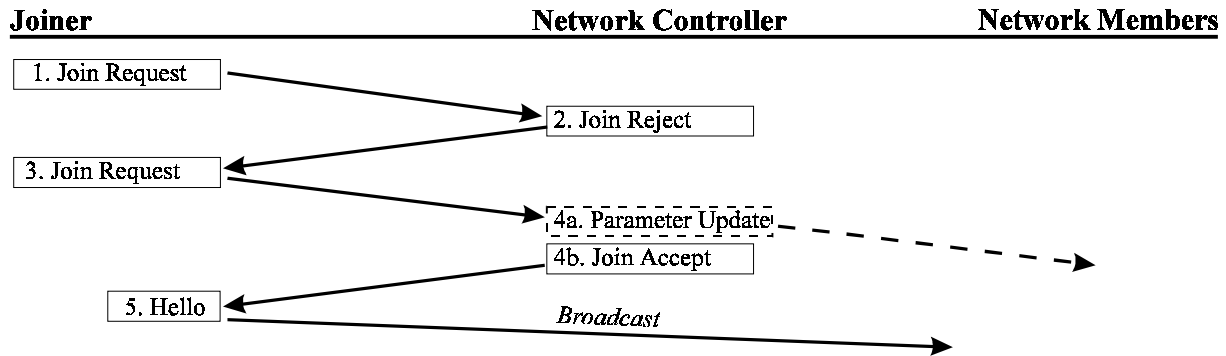
FIGURE E-4. Joining concept.

If there are no errors in the parameters contained in the Join Request message, a Join Accept message is sent by the network controller after entering the parameters for any empty or updated parameter fields. The network controller may have to update the data fields filled in by the joiner since it is possible that the joining station has capabilities above and beyond those being used within the network. If adding the joiner to the network will cause a change to the network operating parameters (e.g., number of stations), the network controller may announce the new network parameters with the Parameter Update message.

The Join Accept message contains an address bit map identifying data link addresses that can be selected by the joining station. When the joining station receives a Join Accept message response from the network controller, it shall select a data link address from the address bit map and broadcast a Hello message announcing entry to the network. Other members of the network shall update their topology tables upon receipt of the Hello message.

A network controller may send a Join Reject to remove any station from the network at any time. Since the Join Reject may be sent to prevent a joining station from selecting an already used address, the Join Reject message should be interpreted as being applied to the station identified in the Station Identifier field of the message. Other network members of the network shall update their topology tables upon receipt of the Join Reject message.

When a station leaves a network, it shall send a Goodbye message to announce that the data link address is available for use by another station. Other members of the network shall update their topology tables upon receipt of the Goodbye message.

E.6.2 Procedures for joining a network with centralized network control. The procedure for joining a network with centralized network control is depicted in Figure E-5. To simplify the discussion and the figure, Join Reject and Parameter Update messages discussed in the basic Joining Concept are not included.

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Joiner	Forwarder	Network Controller
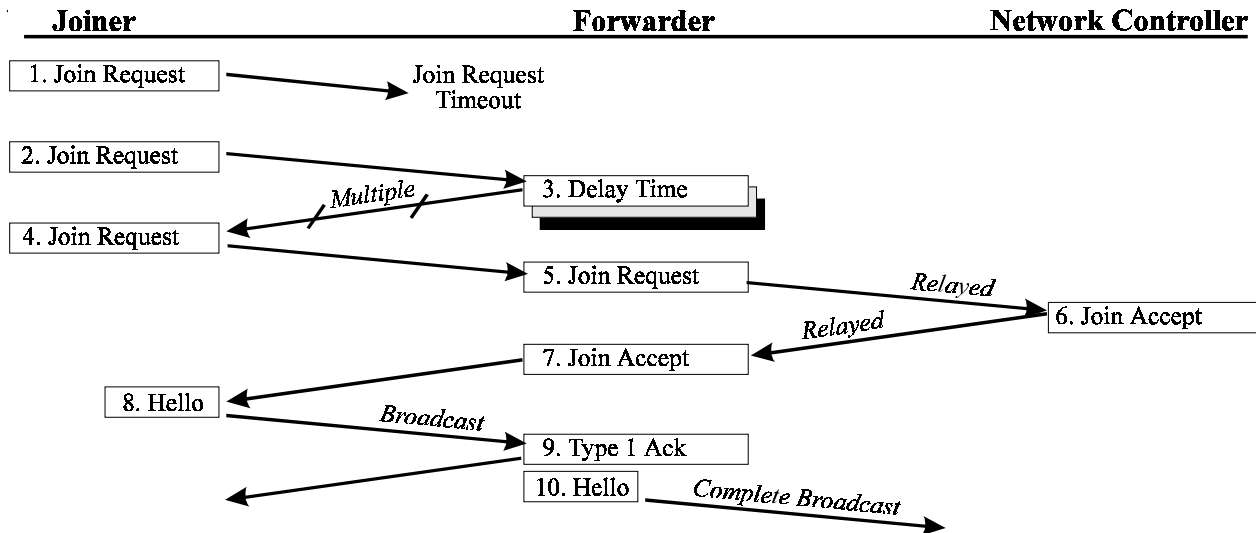
FIGURE E-5. Joining a centralized network.

The joining station shall send a Join Request message to the network controller. The Join Request message shall be addressed to the network controller using the special data link address of 2 as the destination and the special data link address of 1 as the source in the UI frame. If the joining station is unable to contact the network controller because of distance or topology, there will be no response to the Join Request message. In this event, the joining station shall retransmit the Join Request message after the Join Request interval timer expires until the Maximum Number of Join Retries has been exceeded or until either a Join Reject or Join Accept message is received.

If the maximum number of Join Retries is exceeded, the joining station shall then address a UI frame containing the Join Request message to the Global address. The joining station shall continue sending the Join Request message to the Global address after the Join Request interval expires until a response is received from an existing network member.

All network members that receive the globally addressed Join Request message, and intend to participate in the joining procedure, shall send a Delay Time message with an XNP Forwarding Header in response to the joining station. The joining station shall select one of the responding stations as forwarder and resend the Join Request to the network controller using the forwarding parameters in the Forwarding Header received from the selected station. The selected forwarder shall relay this Join Request to the network controller and forward the network controller's response (Join Accept or Join Reject message) back to the joining station. The Join Accept message shall specify a list of unused data link addresses.

The joining station shall expect the network controller response before expiration of the Delay Timer (the period of time specified in the selected forwarder's Delay Time message). If the Delay Timer expires, the joining station shall try each responder in turn in an attempt to contact the network controller.

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When the joining station receives a Join Accept message response from the network controller, it shall prepare a Hello message announcing entry to the network. The Hello message shall use the joining station's assigned individual address (selected from the Join Accept's list of unused data link addresses) as the source address and shall include both the forwarder's individual address and the Global multicast address as destinations in the UI frame. The UI frame carrying this Hello message shall have the P-bit set.

The forwarder shall return a Type 1 acknowledgment to the joining station and then complete the broadcast of the Hello message to all network members. This complete broadcast involves relaying the Hello message, including Forwarding Header, using appropriate Intranet procedures (e.g., Source Directed Relay). The forwarder shall set the maximum hop count in the Intranet Header of the message to restrict the amount of relaying.

E.6.3 <u>Procedures for joining a network with distributed network control</u>. The procedure for joining a network with distributed network control is depicted in Figure E-6. To simplify the discussion and the figure, Join Reject and Parameter Update messages discussed in the basic Joining Concept are not included.

The joining station shall send a Join Request message to a network controller using the special data link address of 2 as the destination and the special data link address of 1 as the source in the UI frame. One or more existing network members operating as network controller shall respond with a Join Accept message or a Join Reject message. Each Join Accept message shall specify a list of unused data link addresses and a Wait Time.

If the joining station is unable to contact a network controller because of distance or topology, there will be no response to the Join Request message. The joining station shall retransmit the Join Request message after the Join Request interval timer expires until the Maximum Number of Join Retries has been exceeded or until either a Join Reject or Join Accept message is received.

If the maximum Number of Join Retries is exceeded, the joining station shall then address a UI frame containing the Join Request message to the Global address. The joining station shall continue sending the Join Request message to the Global address after the Join Request interval expires until a response is received from an existing network member.

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Joiner	Network Controller	Network Members

1. Join Request

Multiple

2. Join Accept

3. Hello

Broadcast

4. Type 1 Ack

5. Hello

Complete Broadcast

6. Join Reject

Forwarded & Broadcast

7. Join Reject

8. Hello

Broadcast

9. Type 1 Ack

10. Hello

Complete Broadcast

Wait Timeout

Network Join is Successful.
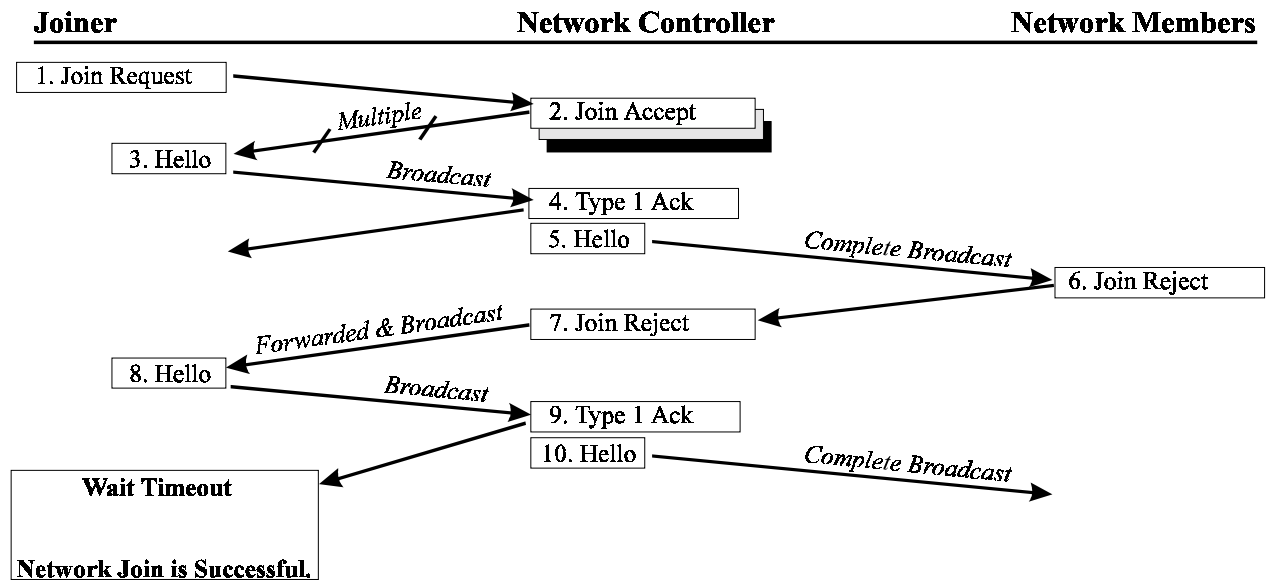
FIGURE E-6. Joining a distributed network.

All network members that receive the globally addressed Join Request, and intend to participate in the joining procedure, shall send a Delay Time message with an XNP Forwarding Header in response to the joining station. The joining station shall select one of the responding stations as forwarder and resend the Join Request to a network controller using the forwarding parameters in the Forwarding Header received from the selected station. The selected forwarder shall relay this Join Request to the network controller and forward the network controller's response (Join Accept or Join Reject message) back to the joining station.

When the joining station receives the Join Accept message responses from the network controllers (via forwarding if necessary), it shall prepare a Hello message announcing entry to the network. The Hello message shall use the joining station's individual address (selected from the Join Accept's list of unused data link addresses) as the source address and shall use the Global multicast address and the selected network controller or forwarder as destinations in the UI frame. The UI frame carrying this Hello message shall have the P-bit set.

The selected network controller or forwarder shall return a Type 1 acknowledgment to the joining station and then complete the broadcast of the Hello message to all network members. This complete broadcast involves relaying the Hello message, including Forwarding Header, using appropriate Intranet procedures (e.g., Source Directed Relay). The selected forwarder shall set the maximum hop count in the Intranet Header of the message to restrict the amount of relaying.

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The joining station shall start a Wait Timer upon receipt of the Type 1 acknowledgment from the forwarder. If the Wait Timer expires, the selected individual address may be used by the Joiner in the network.

If a Join Reject response is received before expiration of the Wait Timer, it indicates the selected address is already in use and the joining station shall select another data link address and send another Hello message. A Join Reject message is sent by the rejecting network controller to the forwarder. The forwarder forwards the Join Reject message to the joiner using the individual address selected by the joiner and also completes the broadcast of the Join Reject to all network members. This complete broadcast involves relaying the Join Reject message, including Forwarding Header, using appropriate Intranet procedures (e.g. Source Directed Relay). The forwarding network controller shall set the maximum hop count in the Intranet Header of the message to restrict the amount of relaying.

E.6.4. Joining procedure examples.

E.6.4.1 Centralized network control, fully connected network. In this example, there is a single, centralized network controller and it is in direct line of sight to the joiner. The network is using data link Type 1 only and is using DAP-NAD. The joining station has all optional capabilities. Therefore the sequence of events is shown in Figure E-7 and is described in section E.6.4.1.1. Detailed message formats are provided in section E.6.4.1.2.
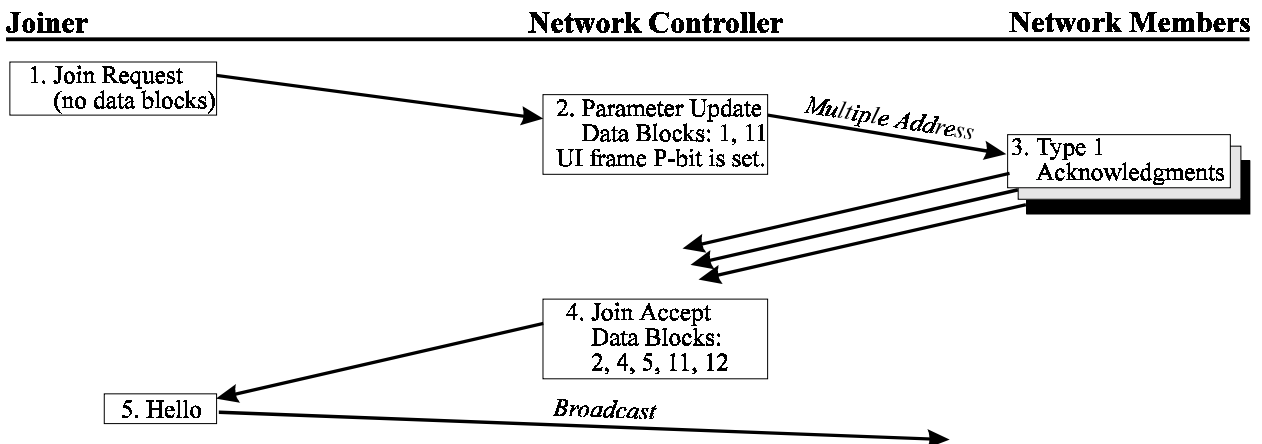
FIGURE E-7. Joining a fully connected, centralized network.

E.6.4.1.1 Sequence of events.

1.   The joining station sends a UI frame with a Join Request message to the network controller requesting entry to the network. No data blocks are appended since the

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joining station does not have knowledge of hardware parameters, but does have all optional capabilities.

2.　　The network controller computes the ranking for DAP-NAD and transmits a Parameter Update message to all network members. This Parameter Update message includes blocks 1 and 11 to designate the order of NAD access for all stations in the network. It is sent with the P-bit set to 1 to provide some level of assurance that it has been received and implemented by all participants.

3.　　Each network participant sends a Type 1 Acknowledgment of the UI frame carrying the Parameter Update message to the network controller.

4.　　The network controller responds with a Join Accept message to the joiner with the Communications Functions field set to Centralized and only one bit set to 0 in the Address Map to specify the address assigned to the joining station. Data block 2, block 4, block 5, and block 12 are appended to the Join Accept message to provide the network operating parameters to the joining station. The Join Accept also contains Blocks 1 and 11 to provide the relative NAD rankings for each network member.

5.　　The joining station sends a Hello message to announce its entry into the network.

E.6.4.1.2 Message formats.

1. Join Request Message

    Transmission Header (bits, LSB on right):
      Selection Bits　　　　　　011　　(FEC/TDC/No Scrambling)
      Topology Update ID　　　000　　(Initial)
      T-bits　　　　　　　　　00　　(No Info)
    Link Layer Header (bits, LSB on right):
      Source Address　　　　　00000010　　(Net Entry)
      Destination Address　　　00000101　　(network controller)
      Control Field　　　　　　00000011　　(UI)
    Intranet Header (octets):
      Version #　　　　　　　0　　(Current version)
      Message Type　　　　　6　　(XNP)
      Header Length　　　　　3　　(Minimum)
      Type of Service　　　　48　　(00110000: Priority, low delay)
    XNP Message　(octets):
      Message Number　　　　20　　(Join Request)
      Station Identifier　　　　[in the least significant 24-bits,
      　　　　　　　　　　　Unit Reference Number of joiner]
    Terminator Block　　　　255

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2. Parameter Update Message

Transmission Header (bits, LSB on right):
    Selection Bits   011   (FEC/TDC/No Scrambling)
    Topology Update ID   000   (Initial)
    T-bits   01   (DAP-NAD)
    Data Link Precedence   00   (Urgent)
    First Subscriber Number   000010 (network controller)
Link Layer Header (bits, LSB on right):
    Source Address   00000100   (network controller)
    Destination Address(es) [up to 16 data link addresses]
    Control Field   00010011   (UI, ACK required)
Intranet Header (octets):
    Version #   0   (Current version)
    Message Type   6   (XNP)
    Header Length   3   (Minimum)
    Type of Service   240   (11110000: Network Control, low delay)
XNP Message   (octets):
    Message Number   26   (Parameter Update)
    Station Identifier   [in the least significant 24-bits,
                             Unit Reference Number of joiner]
XNP Data Blocks
    Data Block 1   Station Identification (station #1)
    Data Block 11   NAD Ranking (station #1)
        •
        •
        •
    Data Block 1   Station Ident. (last station)
    Data Block 11   NAD Ranking (last station)
Terminator Block   255

3. Type 1 Acknowledgment

Transmission Header (bits, LSB on right):
    Selection Bits   011   (FEC/TDC/No Scrambling)
    Topology Update ID   yyy   (each station's current #)
    T-bits   01   (DAP-NAD)
    Data Link Precedence   00   (Urgent)
    First Subscriber Number   zzzzzz (using old ranking)
Link Layer Header (bits, LSB on right):
    Source Address   0aaaaaa1   (Acknowledging station)
    Destination Address   00000101   (network controller)
    Control Field   00110011   (URR response)

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4. Join Accept Message

Transmission Header (bits, LSB on right):
    Selection Bits   011   (FEC/TDC/No Scrambling)
    Topology Update ID   000   (Initial)
    T-bits   01   (DAP-NAD)
    Data Link Precedence   01   (Priority)
    First Subscriber Number   xxxxxx (Joiner)
Link Layer Header (bits, LSB on right):
    Source Address   00000100   (network controller)
    Destination Address   00000011   (Net Entry)
    Control Field   00000011   (UI)
Intranet Header (octets):
    Version #   0   (Current Version)
    Message Type   6   (XNP)
    Header Length   3   (Minimum)
    Type of Service   48   (00110000: Priority, low delay)
XNP Message (octets):
Version Number   0   (current version)
Message Number   21   (Join Accept)
    Station Identifier   [in the least significant 24-bits,
                              Unit Reference Number of joiner]
    Address Map   [one bit set to 0, specifying the joiner's link address
    Comm. Functions   1   (Centralized)
XNP Data Blocks:
    Data Block 2   Basic Network Parameters
    Data Block 4   Type 3 Network Parameters
    Data Block 5   Deterministic NAD Parameters
    Data Block 12   Intranet Parameters
    Data Block 1   Station Identification (station #1)
    Data Block 11   NAD Ranking (station #1)
       •
       •
       •
    Data Block 1   Station Ident. (last station)
    Data Block 11   NAD Ranking (last station)
Terminator Block   255

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5. Hello Message

    Transmission Header (bits, LSB on right):
        Selection Bits   011   (FEC/TDC/No Scrambling)
        Topology Update ID   000   (Initial)
        T-bits   01   (DAP-NAD)
        Data Link Precedence   00   (Urgent)
        First Subscriber Number   000010 (network controller)
    Link Layer Header (bits, LSB on right):
        Source Address   0xxxxxx0   (Joiner)
        Destination Address   11111111   (Global Multicast)
        Control Field   11000000   (UI)
    Intranet Header (octets):
        Version #   0   (Current Version)
        Message Type   6   (XNP)
        Header Length   3   Minimum)
        Type of Service   240   (11110000: Network Control, low delay)
    XNP Message (octets):
    Version Number   0   (current version)
        Message Number   23   (Hello)
        Station Identifier   [in the least significant 24-bits,
                                  Unit Reference Number of joiner]
    Terminator Block   255

E.6.4.2 <u>Centralized network control, disconnected joiner</u>. In this example, there is a single, centralized network controller and it is not in direct line of sight to the joiner. The network is using data link Types 1 and 2, but not Type 4, and is using DAP-NAD. The joining station has all optional capabilities. Therefore the sequence of events is shown in Figure E-8 and is described in section E.6.4.2.1. Detailed message formats are provided in section E.6.4.2.2.

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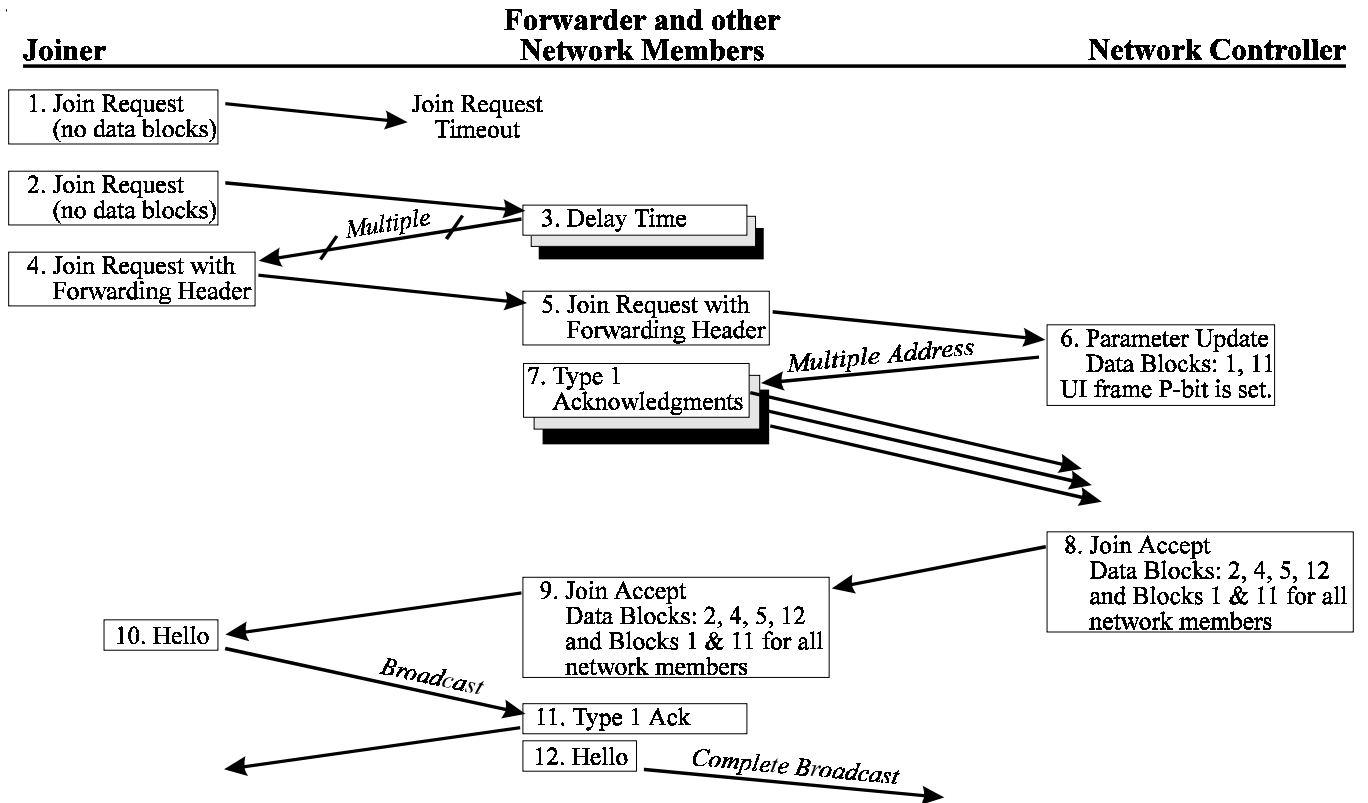
FIGURE E-8. Joining a disconnected, centralized network.

E.6.4.2.1 Sequence of events.

1.   The joining station sends a UI frame with a Join Request message to the network
        controller requesting entry to the network. No data blocks are appended since the
        joining station does not have knowledge of hardware parameters, but does have all
        optional capabilities.

        Because the joiner is not in direct line of sight with the network controller, network
        controller does not receive the Join Request and there is no response.

2.   The joining station sends a UI Command with a Join Request message to the
        Global Multicast data link address requesting entry to the network. This Join
        Request message has a Forwarding Header identifying the network controller as
        the Destination.

3.   The Join Request message is received by stations 44, 25 and 31. These three
        stations send a Delay Time message to the joining station.

4.   The joining station selects station 25 as the forwarder and uses this station to
        forward a Join Request message to the network controller.

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5.   Station 25 forwards the Join Request message to the network controller for the joining station.

6.   The network controller computes the ranking for DAP-NAD and transmits a Parameter Update message to all network members. This Parameter Update message includes blocks 1 and 11 to designate the order of NAD access for all stations in the network. It is sent with the P-bit set to 1 to provide some level of assurance that it has been received and implemented by all participants.

        All stations update to new subscriber order.

7.   Each network participant sends a Type 1 Acknowledgment of the UI frame carrying the Parameter Update message to the network controller.

8.   The network controller responds with a Join Accept message to the joiner with the Communications Functions field set to Centralized and only one bit set to 0 in the Address Map to specify the address assigned to the joining station. Data block 2, block 4, block 5, block 9 and block 12 are appended to the Join Accept message to provide the network operating parameters to the joining station. The Join Accept also contains Blocks 1 and 11 to provide the relative NAD rankings for each network member.

9.   Station 25 forwards network controller's Join Accept message (and all data blocks) to the joining station.

10.   The joining station sends a Hello message to announce its entry into the network. This Hello message is broadcast locally, and also addressed to forwarding station 25 so that it can be broadcast completely through the network.

11.   Forwarding station 25 sends a Type 1 Acknowledgment for the UI frame carrying the Hello message to the joining station.

12.   Station 25 forwards the Hello message throughout the network using Intranet Relay.

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E.6.4.2.2 <u>Message formats</u>.

1. Join Request Message to Network Controller

    Transmission Header (bits, LSB on right):
        Selection Bits   011   (FEC/TDC/No Scrambling)
        Topology Update ID   yyy   (station's current #)
        T-bits   00   (No Info)
    Link Layer Header (bits, LSB on right):
        Source Address   00000010   (Net Entry)
        Destination Address   00000101   (network controller)
        Control Field   00000011   (UI)
    Intranet Header (octets):
        Version #   0   (Current version)
        Message Type   6   (XNP)
        Header Length   3   (Minimum)
        Type of Service   48   (00110000: Priority, low delay)
    XNP Message   (octets):
        Message Number   20   (Join Request)
        Station Identifier   [in the least significant 24-bits,
                                 Unit Reference Number of joiner]
    Terminator Block   255

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2. Join Request Message to Global Multicast Address

Transmission Header (bits, LSB on right):
    Selection Bits   011   (FEC/TDC/No Scrambling)
    Topology Update ID   000   (Initial)
    T-bits   00   (No Info)
Link Layer Header (bits, LSB on right):
    Source Address   00000010   (Net Entry)
    Destination Address   11111111   (Global Multicast)
    Control Field   00000011   (UI)
Intranet Header (octets):
    Version #   0   (Current version)
    Message Type   6   (XNP)
    Header Length   3   (Minimum)
    Type of Service   48   (00110000: Priority, low delay)
XNP Message   (octets):
    Forwarding Header:
     Message Number   0   (Forwarding Header)
     Source Address   1   (Net Entry)
     Forwarder Address   0   (Unknown)
     Destination Address   2   (network controller)
    Message Number   20   (Join Request)
    Station Identifier   [in the least significant 24-bits,
                                Unit Reference Number of joiner]
Terminator Block   255

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3. Delay Time Message

    Transmission Header (bits, LSB on right):
        Selection Bits   011   (FEC/TDC/No Scrambling)
        Topology Update ID   yyy   (station's current #)
        T-bits   01   (DAP-NAD)
        Data Link Precedence   01   (Priority)
        First Subscriber Number   zzzzzz (next ranked station)
    Link Layer Header (bits, LSB on right):
        Source Address   0ffffff0   (forwarder's address)
        Destination Address   00000011   (Net Entry)
        Control Field   00000011   (UI)
    Intranet Header (octets):
        Version #   0   (Current version)
        Message Type   6   (XNP)
        Header Length   3   (Minimum)
        Type of Service   48   (00110000: Priority, low delay)
    XNP Message   (octets):
        Forwarding Header:
         Message Number   0   (Forwarding Header)
         Source Address   00ffffff   (Forwarder)
         Forwarder Address   00ffffff   (Forwarder)
         Destination Address   1   (Net Entry)
        Message Number   27   (Delay Time)
        Station Identifier   [in the least significant 24-bits,
                             Unit Reference Number of joiner]
        Time   tttttttt   (Seconds)
    Terminator Block   255

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4. Join Request Message to Forwarder

    Transmission Header (bits, LSB on right):
        Selection Bits   011   (FEC/TDC/No Scrambling)
        Topology Update ID   000   (Initial)
        T-bits   00   (No Info)
    Link Layer Header (bits, LSB on right):
        Source Address   00000010   (Net Entry)
        Destination Address   00110011   (forwarder #25)
        Control Field   00000011   (UI)
    Intranet Header (octets):
        Version #   0   (Current version)
        Message Type   6   (XNP)
        Header Length   3   (Minimum)
        Type of Service   48   (00110000: Priority, low delay)
    XNP Message   (octets):
        Forwarding Header:
          Message Number   0   (Forwarding Header)
          Source Address   1   (Net Entry)
          Forwarder Address   25   (station #25)
          Destination Address   2   (network controller)
        Message Number   20   (Join Request)
        Station Identifier   [in the least significant 24-bits,
                                  Unit Reference Number of joiner]
    Terminator Block   255

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5. Join Request Message to Network Controller from Forwarder

Transmission Header (bits, LSB on right):
    Selection Bits   011   (FEC/TDC/No Scrambling)
    Topology Update ID   yyy   (station's current #)
    T-bits   01   (DAP-NAD)
    Data Link Precedence   01   (Priority)
    First Subscriber Number   000010 (network controller)
Link Layer Header (bits, LSB on right):
    Source Address   00110010   (forwarder #25)
    Destination Address   00000101   (network controller)
    Control Field   00000011   (UI)
Intranet Header (octets):
    Version #   0   (Current version)
    Message Type   6   (XNP)
    Header Length   3   (Minimum)
    Type of Service   48   (00110000: Priority, low delay)
XNP Message   (octets):
    Forwarding Header:
      Message Number   0   (Forwarding Header)
      Source Address   1   (Net Entry)
      Forwarder Address   25   (station #25)
      Destination Address   2   (network controller)
    Message Number   20   (Join Request)
    Station Identifier   [in the least significant 24-bits,
                             Unit Reference Number of joiner]
Terminator Block   255

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6. Parameter Update Message

  Transmission Header (bits, LSB on right):
    Selection Bits   011 (FEC/TDC/No Scrambling)
    Topology Update ID 000 (Initial)
    T-bits   01 (DAP-NAD)
    Data Link Precedence 00 (Urgent)
    First Subscriber Number 000010 (network controller)
  Link Layer Header (bits, LSB on right):
    Source Address   00000100 (network controller)
    Destination Address(es) [up to 16 data link addresses]
    Control Field   00010011 (UI, ACK required)
  Intranet Header (octets):
    Version #   0 (Current version)
    Message Type   6 (XNP)
    Header Length   3 (Minimum)
    Type of Service 240 (11110000: Network Control, low delay)
  XNP Message (octets):
    Message Number 26 (Parameter Update)
    Station Identifier [in the least significant 24-bits,
              Unit Reference Number of joiner]
    XNP Data Blocks
    Data Block 1   Station Identification (station #1)
    Data Block 11   NAD Ranking (station #1)
      •
      •
      •
    Data Block 1   Station Ident. (last station)
    Data Block 11   NAD Ranking (last station)
  Terminator Block 255

7. Type 1 Acknowledgment to UI Carrying Parameter Update Message

  Transmission Header (bits, LSB on right):
    Selection Bits   011 (FEC/TDC/No Scrambling)
    Topology Update ID yyy (each station's current #)
    T-bits   01 (DAP-NAD)
    Data Link Precedence 00 (Urgent)
    First Subscriber Number zzzzzz (using old ranking)
  Link Layer Header (bits, LSB on right):
    Source Address   0aaaaaa1 (Acknowledging station)
    Destination Address 00000101 (network controller)
    Control Field   00110011 (URR response)

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8. Join Accept Message to Forwarder
    Transmission Header (bits, LSB on right):
        Selection Bits   011   (FEC/TDC/No Scrambling)
        Topology Update ID   000   (Initial)
        T-bits   01   (DAP-NAD)
        Data Link Precedence   01   (Priority)
        First Subscriber Number   011001 (forwarder #25)
    Link Layer Header (bits, LSB on right):
        Source Address   00000100   (network controller)
        Destination Address   00110011   (forwarder #25)
        Control Field   00000011   (UI)
    Intranet Header (octets):
        Version #   0   (Current Version)
        Message Type   6   (XNP)
        Header Length   3   (Minimum)
        Type of Service   240   (Network Control, low delay)
    XNP Message (octets):
    Version Number   0   (current version)
        Forwarding Header:
          Message Number   0   (Forwarding Header)
          Source Address   2   (network controller)
          Forwarder Address   25   (station #25)
          Destination Address   1   (Net Entry)
        Message Number   21   (Join Accept)
        Station Identifier   [in the least significant 24-bits,
                                 Unit Reference Number of joiner]
        Address Map   [one bit set to 0, specifying the joiner's link address
        Comm. Functions   1   (Centralized)
    XNP Data Blocks:
        Data Block 2   Basic Network Parameters
        Data Block 4   Type 3 Network Parameters
        Data Block 5   Deterministic NAD Parameters
        Data Block 9   Type 2 Parameters
        Data Block 12   Intranet Parameters
        Data Block 1   Station Identification (station #1)
        Data Block 11   NAD Ranking (station #1)
           •
           •
           •
        Data Block 1   Station Ident. (last station)
        Data Block 11   NAD Ranking (last station)
    Terminator Block   255

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9. Join Accept Message to Joiner from Forwarder
    Transmission Header (bits, LSB on right):
        Selection Bits   011   (FEC/TDC/No Scrambling)
        Topology Update ID   yyy   (forwarder's current #)
        T-bits   01   (DAP-NAD)
        Data Link Precedence   01   (Priority)
        First Subscriber Number   000001 (Net Entry)
    Link Layer Header (bits, LSB on right):
        Source Address   00110010   (forwarder #25)
        Destination Address   00000011   (Net Entry)
        Control Field   00000011   (UI)
    Intranet Header (octets):
        Version #   0   (Current Version)
        Message Type   6   (XNP)
        Header Length   3   (Minimum)
        Type of Service   48   (00110000: Priority, low delay)
    XNP Message (octets):
    Version Number   0   (current version)
        Forwarding Header:
          Message Number   0   (Forwarding Header)
          Source Address   2   (network controller)
          Forwarder Address   25   (station #25)
          Destination Address   1   (Net Entry)
        Message Number   21   (Join Accept)
        Station Identifier   [in the least significant 24-bits,
                                     Unit Reference Number of joiner]
        Address Map   [one bit set to 0, specifying the joiner's link address]
        Comm. Functions   1   (Centralized)
    XNP Data Blocks:
        Data Block 2   Basic Network Parameters
        Data Block 4   Type 3 Network Parameters
        Data Block 5   Deterministic NAD Parameters
        Data Block 9   Type 2 Parameters
        Data Block 12   Intranet Parameters
        Data Block 1   Station Identification (station #1)
        Data Block 11   NAD Ranking (station #1)
             •
             •
             •
        Data Block 1   Station Ident. (last station)
        Data Block 11   NAD Ranking (last station)
   Terminator Block   255

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10. Hello Message from Joiner

Transmission Header (bits, LSB on right):
 Selection Bits 011 (FEC/TDC/No Scrambling)
 Topology Update ID 000 (Initial)
 T-bits 01 (DAP-NAD)
 Data Link Precedence 00 (Urgent)
 First Subscriber Number 011001 (forwarder #25)
Link Layer Header (bits, LSB on right):
 Source Address 0xxxxxx0 (Joiner)
 Destination Addresses 00110010 (forwarder #25)
 11111111 (Global Multicast)
 Control Field 00010011 (UI)
Intranet Header (octets):
 Version # 0 (Current Version)
 Message Type 6 (XNP)
 Header Length 3 (Minimum)
 Type of Service 240 (11110000: Network Control, low delay)
XNP Message (octets):
Version Number 0 (current version)
 Forwarding Header:
 Message Number 0 (Forwarding Header)
 Source Address XX (Joiner)
 Forwarder Address 25 (station #25)
 Destination Address 127 (Global Broadcast)
 Message Number 23 (Hello)
 Station Identifier [in the least significant 24-bits,
 Unit Reference Number of joiner]
Terminator Block 255

11. Type 1 Acknowledgment to UI Carrying Hello Message

Transmission Header (bits, LSB on right):
 Selection Bits 011 (FEC/TDC/No Scrambling)
 Topology Update ID yyy (each station's current #)
 T-bits 01 (DAP-NAD)
 Data Link Precedence 00 (Urgent)
 First Subscriber Number zzzzzz (using old ranking)
Link Layer Header (bits, LSB on right):
 Source Address 00110010 (forwarder #25))
 Destination Address 0xxxxxx1 (Joiner)
 Control Field 00110011 (URR response)

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12. Hello Message from Forwarder

    Transmission Header (bits, LSB on right):
        Selection Bits   011   (FEC/TDC/No Scrambling)
        Topology Update ID   000   (Initial)
        T-bits   01   (DAP-NAD)
        Data Link Precedence 00   (Urgent)
        First Subscriber Number 011001 (forwarder #25)
    Link Layer Header (bits, LSB on right):
        Source Address   00110010   (forwarder #25)
        Destination Addresses 11111111   (Global Multicast)
        Control Field   00100011   (UI)
    Intranet Header (octets):
        Version #   0   (Current Version)
        Message Type   6   (XNP)
        Header Length   3   (Minimum, assuming Relaying is not required)
        Type of Service   240   (11110000: Network Control, low delay)
    XNP Message (octets):
    Version Number   0   (current version)
        Forwarding Header:
         Message Number   0   (Forwarding Header)
         Source Address   XX   (Joiner)
         Forwarder Address   25   (station #25)
         Destination Address 127   (Global Broadcast)
        Message Number   23   (Hello)
        Station Identifier   [in the least significant 24-bits,
                                Unit Reference Number of joiner]
    Terminator Block   255

E.6.4.3 <u>Distributed network control, all stations are network controllers</u>. In this example, the network is using multiple distributed network controllers, and all stations in the network have network controller capabilities. The network is using data link Types 1, 3 and 4, and RE-NAD. The joining station has all optional capabilities. Therefore the sequence of events is shown in Figure E-6 and is described in section E.6.4.3.1. Detailed message formats are provided in section E.6.4.3.2.

E.6.4.3.1 <u>Sequence of events</u>.

    1.   The joining station sends a UI frame with a Join Request message to the network controller requesting entry to the network. No data blocks are appended since the joining station does not have knowledge of hardware parameters, but does have all optional capabilities.

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2.　　One or more network controllers respond with a Join Accept message to the joiner. The Communications Functions field in the Join Accept message is set to Distributed, and the Address Map has bits set to 0 for all available addresses. Data block 2, block 4, block 7, block 10 and block 12 are appended to the Join Accept message to provide the basic operating parameters to joining station. Block 8 is appended to specify a Wait Timer that the joiner must use to verify that its selected data link address is accepted.

3.　　The joining station selects an address from the Address Map provided in the Join Accept message and sends a Hello message to validate the selected address. Since the joining station has no knowledge of topology, the Hello message is sent with a forwarding header to one of the network controllers which responded with a Join Accept message. The UI frame carrying the Hello message has the P-bit set to one, uses the selected data link address as the source address, and uses the selected network controller address and the Global multicast address as destinations.

4.　　The selected network controller sends a Type 1 Acknowledgment in response to the UI frame carrying the Hello message. The joining station starts the Wait Timer.

5.　　The selected network controller forwards the Hello message to all other stations.

6.　　If another station determines that the selected address is already in use, it sends a Join Reject message through the forwarding network controller to the joiner.

7.　　The forwarding network controller sends the Join Reject message to the joining station and broadcasts the Join Reject to all network members.

8.　　The joining station selects a new address from the address map and sends another Hello message to validate the selected address. This address is also sent through the forwarding network controller.

9.　　The selected network controller sends another Type 1 Acknowledgment in response to the UI frame carrying the Hello message. The joining station restarts the Wait Timer.

10.　　The selected network controller again forwards the Hello message to all other stations.

If the address selected by the joiner is unique, no Join Reject will be provided. The joiner has successfully entered the network after the Wait Timer expires.

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E.6.4.3.2 Message formats.

1. Join Request Message

    Transmission Header (bits, LSB on right):
        Selection Bits   000   (No FEC, TDC or Scrambling)
        Topology Update ID   000   (Initial)
        T-bits   00   (No Info)
    Link Layer Header (bits, LSB on right):
        Source Address   00000010   (Net Entry)
        Destination Address   00000101   (network controller)
        Control Field   00000011   (UI)
    Intranet Header (octets):
        Version #   0   (Current version)
        Message Type   6   (XNP)
        Header Length   3   (Minimum)
        Type of Service   48   (00110000: Priority, low delay)
    XNP Message   (octets):
        Message Number   20   (Join Request)
        Station Identifier   [in the least significant 24-bits,
                                  Unit Reference Number of joiner]
    Terminator Block   255

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2. Join Accept Message

Transmission Header (bits, LSB on right):
    Selection Bits   000   (No FEC, TDC or Scrambling)
    Topology Update ID   000   (Initial)
    T-bits   10   (RE-NAD)
    Queue Precedence   01   (Priority)
    Queue Length   00zzzz (network accesses needed to
                                              empty the transmit queue)
Link Layer Header (bits, LSB on right):
    Source Address   nnnnnnn0   (network controller's link address)
    Destination Address   00000011   (Net Entry)
    Control Field   00000011   (UI)
Intranet Header (octets):
    Version #   0   (Current Version)
    Message Type   6   (XNP)
    Header Length   3   (Minimum)
    Type of Service   48   (00110000: Priority, low delay)
XNP Message (octets):
Version Number   0   (current version)
    Message Number   21   (Join Accept)
    Station Identifier   [in the least significant 24-bits,
                                  Unit Reference Number of joiner]
    Address Map   [bits set to 0, specifying available data link addresses]
    Comm. Functions   2   (Distributed)
XNP Data Blocks:
    Data Block 2   Basic Network Parameters
    Data Block 4   Type 3 Network Parameters
    Data Block 7   RE-NAD Parameters
    Data Block 10   Type 4 Parameters
    Data Block 12   Intranet Parameters
    Data Block 8   Wait Time
Terminator Block   255

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3. Hello Message from Joiner

Transmission Header (bits, LSB on right):
    Selection Bits   000   (No FEC, TDC or Scrambling)
    Topology Update ID   000   (Initial)
    T-bits   10   (RE-NAD)
    Queue Precedence   00   (Urgent)
    Queue Length   0000
Link Layer Header (bits, LSB on right):
    Source Address   0xxxxxx0   (Joiner)
    Destination Addresses   yyyyyyy0   (selected network controller)
                          11111111   (Global Multicast)
    Control Field   00010011   (UI)
Intranet Header (octets):
    Version #   0   (Current Version)
    Message Type   6   (XNP)
    Header Length   3   (Minimum)
    Type of Service   240   (11110000: Network Control, low delay)
XNP Message (octets):
Version Number   0   (current version)
    Forwarding Header:
      Message Number   0   (Forwarding Header)
      Source Address   XX   (Joiner's selected address)
      Forwarder Address   YY   (selected network controller)
      Destination Address   127   (Global Broadcast)
    Message Number   23   (Hello)
    Station Identifier   [in the least significant 24-bits,
                             Unit Reference Number of joiner]
Terminator Block   255

4. Type 1 Acknowledgment to UI Carrying Hello Message

Transmission Header (bits, LSB on right):
    Selection Bits   000   (No FEC, TDC or Scrambling)
    Topology Update ID   000   (Initial)
    T-bits   10   (RE-NAD)
    Queue Precedence   00   (Urgent)
    Queue Length   0000
Link Layer Header (bits, LSB on right):
    Source Address   yyyyyyy0   (Forwarding network controller)
    Destination Address   0xxxxxx1   (Joiner)
    Control Field   00110011   (URR response)

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5. Hello Message from Forwarding Network Controller

Transmission Header (bits, LSB on right):
    Selection Bits   000   (No FEC, TDC or Scrambling)
    Topology Update ID   zzz   (network controller's current #)
    T-bits   10   (RE-NAD)
    Queue Precedence   00   (Urgent)
    Queue Length   0000

Link Layer Header (bits, LSB on right):
    Source Address   yyyyyyy0   (selected network controller)
    Destination Addresses   11111111   (Global Multicast)
    Control Field   00000011   (UI)

Intranet Header (octets):
    Version #   0   (Current Version)
    Message Type   6   (XNP)
    Header Length   3   (Minimum, if no Relay required)
    Type of Service   240   (11110000: Network Control, low delay)

XNP Message (octets):
Version Number   0   (current version)
    Forwarding Header:
      Message Number   0   (Forwarding Header)
      Source Address   XX   (Joiner)
      Forwarder Address   YY   (selected network controller)
      Destination Address   127   (Global Broadcast)
    Message Number   23   (Hello)
    Station Identifier   [in the least significant 24-bits,
                            Unit Reference Number of joiner]
Terminator Block   255

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6. Join Reject Message to Forwarding Network Controller

Transmission Header (bits, LSB on right):
    Selection Bits   000   (No FEC, TDC or Scrambling)
    Topology Update ID   zzz   (station's current #)
    T-bits   10   (RE-NAD)
    Queue Precedence   00   (Urgent)
    Queue Length   0000

Link Layer Header (bits, LSB on right):
    Source Address   00000100   (network controller)
    Destination Address   yyyyyyy1   (Forwarding network controller)
    Control Field   00000011   (UI)

Intranet Header (octets):
    Version #   0   (Current Version)
    Message Type   6   (XNP)
    Header Length   3   (Minimum, if no Relay required)
    Type of Service   240   (11110000: Network Control, low delay)

XNP Message (octets):
Version Number   0   (current version)
    Forwarding Header:
      Message Number   0   (Forwarding Header)
      Source Address   2   (network controller)
      Forwarder Address   Y   (forwarder's address)
      Destination Address   X   (address selected by joiner)
    Message Number   22   (Join Reject)
    Station Identifier   [in the least significant 24-bits,
                           Unit Reference Number of joiner]
    Rejected Link Address   X   (address selected by joiner)
    Address Map   [bits set to 0, specifying
                           available data link addresses]
    Comm. Functions   2   (Distributed)
Terminator Block   255

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7. Join Reject Message to Joiner from Forwarding Network Controller

Transmission Header (bits, LSB on right):
    Selection Bits   000   (No FEC, TDC or Scrambling)
    Topology Update ID   zzz   (forwarder's current #)
    T-bits   10   (RE-NAD)
    Queue Precedence   00   (Urgent)
    Queue Length   0000
Link Layer Header (bits, LSB on right):
    Source Address   yyyyyyy0   (forwarder)
    Destination Address   0xxxxxx0   (Rejected Joiner)
                                11111111   (Global Multicast)
    Control Field   00000011   (UI)
Intranet Header (octets):
    Version #   0   (Current Version)
    Message Type   6   (XNP)
    Header Length   3   (Minimum)
    Type of Service   240   (11110000: Network Control, low delay)
XNP Message (octets):
Version Number   0   (current version)
    Forwarding Header:
      Message Number   0   (Forwarding Header)
      Source Address   2   (network controller)
      Forwarder Address   Y   (forwarder's address)
      Destination Address   X   (address selected by joiner)
    Message Number   22   (Join Reject)
    Station Identifier   [in the least significant 24-bits,
                                Unit Reference Number of joiner]
    Rejected Link Address   X   (address selected by joiner)
    Address Map   [bits set to 0, specifying
                                available data link addresses]
    Comm. Functions   2   (Distributed)
Terminator Block   255

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8. Second Hello Message from Joiner

Transmission Header (bits, LSB on right):
    Selection Bits   000   (No FEC, TDC or Scrambling)
    Topology Update ID   000   (Initial)
    T-bits   10   (RE-NAD)
    Queue Precedence   00   (Urgent)
    Queue Length   0000
Link Layer Header (bits, LSB on right):
    Source Address   0xxxxxx0   (Joiner)
    Destination Addresses   yyyyyyy0   (selected network controller)
                              11111111   (Global Multicast)
    Control Field   00010011   (UI)
Intranet Header (octets):
    Version #   0   (Current Version)
    Message Type   6   (XNP)
    Header Length   3   (Minimum)
    Type of Service   240   (11110000: Network Control, low delay)
XNP Message (octets):
Version Number   0   (current version)
    Forwarding Header:
      Message Number   0   (Forwarding Header)
      Source Address   XX   (Joiner)
      Forwarder Address   YY   (selected network controller)
      Destination Address   127   (Global Broadcast)
    Message Number   23   (Hello)
    Station Identifier   [in the least significant 24-bits,
                              Unit Reference Number of joiner]
Terminator Block   255

9. Type 1 Acknowledgment to UI Carrying Second Hello Message

Transmission Header (bits, LSB on right):
    Selection Bits   000   (No FEC, TDC or Scrambling)
    Topology Update ID   000   (Initial)
    T-bits   10   (RE-NAD)
    Queue Precedence   00   (Urgent)
    Queue Length   0000
Link Layer Header (bits, LSB on right):
    Source Address   yyyyyyy0   (Forwarding network controller)
    Destination Address   0xxxxxx1   (Joiner)
    Control Field   11001100   (URR response)

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10. Second Hello Message from Forwarding Network Controller

Transmission Header (bits, LSB on right):
    Selection Bits   000   (No FEC, TDC or Scrambling)
    Topology Update ID   zzz   (forwarder's current #)
    T-bits   10   (RE-NAD)
    Queue Precedence   00   (Urgent)
    Queue Length   0000

Link Layer Header (bits, LSB on right):
    Source Address   yyyyyyy0   (forwarder)
    Destination Addresses   11111111   (Global Multicast)
    Control Field   00000011   (UI)

Intranet Header (octets):
    Version #   0   (Current Version)
    Message Type   6   (XNP)
    Header Length   3   (Minimum, if no Relay required)
    Type of Service   240   (11110000: Network Control, low delay)

XNP Message (octets):
Version Number   0   (current version)
    Forwarding Header:
      Message Number   0   (Forwarding Header)
      Source Address   XX   (Joiner)
      Forwarder Address   YY   (selected network controller)
      Destination Address   127   (Global Broadcast)
    Message Number   23   (Hello)
    Station Identifier   [in the least significant 24-bits,
                            Unit Reference Number of joiner]
Terminator Block   255

E.6.4.4 Distributed network control, disconnected joiner. In this example, the network is using multiple distributed network controllers, although all stations are not network controllers. The joiner in this example is not in direct line of sight to a network controller. The network is using data link Types 1, 3 and 4, and RE-NAD. The joining station has all optional capabilities. Therefore the sequence of events is shown in Figure E-9 and is described in section E.6.4.4.1. Detailed message formats are provided in section E.6.4.4.2.

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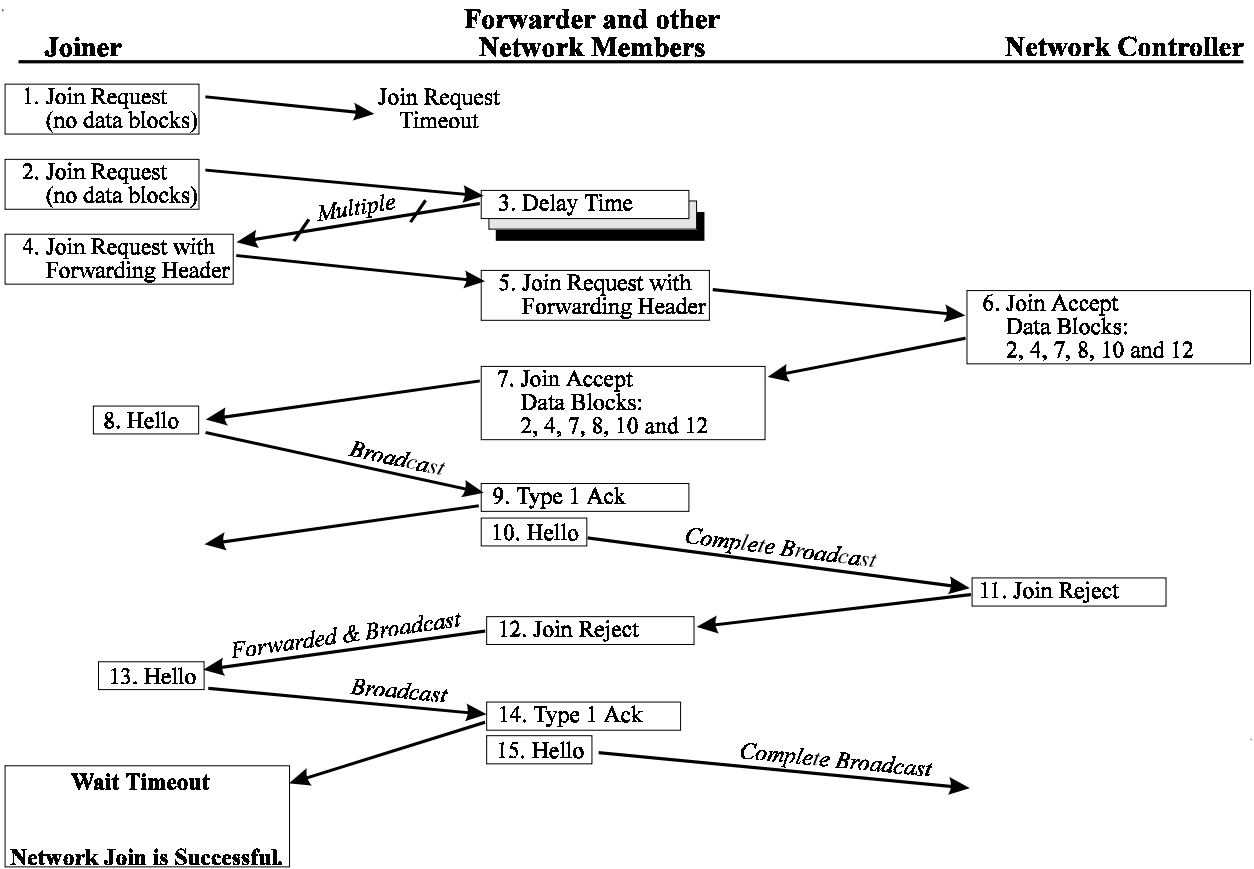
FIGURE E-9. Joining a disconnected, distributed network.

E.6.4.4.1 Sequence of events.

1.   The joining station sends a UI frame with a Join Request message to the network controller requesting entry to the network. No data blocks are appended since the joining station does not have knowledge of hardware parameters, but does have all optional capabilities.

Because the joiner is not in direct line of sight with the network controller, network controller does not receive the Join Request and there is no response.

2.   The joining station sends a UI Command with a Join Request message to the Global Multicast data link address requesting entry to the network. This Join Request message has a Forwarding Header identifying the network controller as the Destination.

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3.   The Join Request message is received by stations 44, 25 and 31. These three stations have a path to a network controller and send a Delay Time message to the joining station.

4.   The joining station selects station 25 as the forwarder and uses this station to forward a Join Request message to the network controller.

5.   Station 25 forwards the Join Request message to a network controller for the joining station. Station 25 will use the network controller's individual address at the data link layer and employ appropriate relaying to reach the network controller at the Intranet layer.

6.   The network controller responds with a Join Accept message to the joiner, using station 25 as a forwarder. The Communications Functions field in the Join Accept message is set to Distributed, and the Address Map has bits set to 0 for all available addresses. Data block 2, block 4, block 7, block 10 and block 12 are appended to the Join Accept message to provide the basic operating parameters to the joining station. Block 8 is appended to specify a Wait Timer that the joiner must use to verify that its selected data link address is accepted.

7.   Station 25 forwards network controller's Join Accept message (and all data blocks) to the joining station.

8.   The joining station selects an address from the Address Map provided in the Join Accept message and sends a Hello message to validate the selected address. This Hello message is broadcast locally, and also is addressed to forwarding station 25 so that it can be broadcast completely through the network. The UI frame carrying the Hello message has the P-bit set to one, uses the selected data link address as the source address, and uses the selected forwarder's address and the Global multicast address as destinations.

9.   Forwarding station 25 sends a Type 1 Acknowledgment for the UI frame carrying the Hello message to the joining station. The joining station starts the Wait Timer.

10.   Station 25 forwards the Hello message throughout the network using Intranet Relay.

11.   If another station determines that the selected address is already in use, it sends a Join Reject message through the forwarder to the joiner.

12.   The forwarder sends the Join Reject message to the joining station and broadcasts the Join Reject to all network members.

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13.   The joining station selects a new address from the address map and sends another Hello message to validate the selected address. This address is also sent through the forwarder, station 25.

14.   Forwarding station 25 sends another Type 1 Acknowledgment in response to the UI frame carrying the Hello message. The joining station restarts the Wait Timer.

15.   Station 25 again forwards the Hello message to all other stations using Intranet Relay.

If the address selected by the joiner is unique, no Join Reject will be provided. The joiner has successfully entered the network after the Wait Timer expires.

E.6.4.4.2 Message formats.

1. Join Request Message

    Transmission Header (bits, LSB on right):
        Selection Bits   000   (No FEC, TDC or Scrambling)
        Topology Update ID   000   (Initial)
        T-bits   00   (No Info)
    Link Layer Header (bits, LSB on right):
        Source Address   00000010   (Net Entry)
        Destination Address   00000101   (network controller)
        Control Field   00000011   (UI)
    Intranet Header (octets):
        Version #   0   (Current version)
        Message Type   6   (XNP)
        Header Length   3   (Minimum)
        Type of Service   48   (00110000: Priority, low delay)
    XNP Message   (octets):
        Message Number   20   (Join Request)
        Station Identifier   [in the least significant 24-bits,
                                Unit Reference Number of joiner]
    Terminator Block   255

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2. Join Request Message to Global Multicast address

Transmission Header (bits, LSB on right):
    Selection Bits   000   (No FEC, TDC or Scrambling)
    Topology Update ID   000   (Initial)
    T-bits   00   (No Info)
Link Layer Header (bits, LSB on right):
    Source Address   00000010   (Net Entry)
    Destination Address   11111111   (Global Multicast)
    Control Field   00000011   (UI)
Intranet Header (octets):
    Version #   0   (Current version)
    Message Type   6   (XNP)
    Header Length   3   (Minimum)
    Type of Service   48   (00110000: Priority, low delay)
XNP Message   (octets):
    Forwarding Header:
     Message Number   0   (Forwarding Header)
     Source Address   1   (Net Entry)
     Forwarder Address   0   (Unknown)
     Destination Address   2   (network controller)
    Message Number   20   (Join Request)
    Station Identifier   [in the least significant 24-bits,
                         Unit Reference Number of joiner]
Terminator Block   255

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3. Delay Time Message

Transmission Header (bits, LSB on right):
    Selection Bits   000   (No FEC, TDC or Scrambling)
    Topology Update ID   yyy   (station's current #)
    T-bits   10   (RE-NAD)
    Queue Precedence   01   (Priority)
    Queue Length   00zzzz (network accesses needed to
                                        empty the transmit queue)
Link Layer Header (bits, LSB on right):
    Source Address   0ffffff0   (forwarder's address)
    Destination Address   00000011   (Net Entry)
    Control Field   00000011   (UI)
Intranet Header (octets):
    Version #   0   (Current version)
    Message Type   6   (XNP)
    Header Length   3   (Minimum)
    Type of Service   48   (00110000: Priority, low delay)
XNP Message   (octets):
    Forwarding Header:
     Message Number   0   (Forwarding Header)
     Source Address   00ffffff   (Forwarder)
     Forwarder Address   00ffffff   (Forwarder)
     Destination Address   1   (Net Entry)
    Message Number   27   (Delay Time)
    Station Identifier   [in the least significant 24-bits,
                            Unit Reference Number of joiner]
    Time   tttttttt   (Seconds)
Terminator Block   255

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4. Join Request Message to Forwarder

Transmission Header (bits, LSB on right):
    Selection Bits   000   (FEC/TDC/No Scrambling)
    Topology Update ID   000   (Initial)
    T-bits   00   (No Info)
Link Layer Header (bits, LSB on right):
    Source Address   00000010   (Net Entry)
    Destination Address   00110011   (forwarder #25)
    Control Field   00000011   (UI)
Intranet Header (octets):
    Version #   0   (Current version)
    Message Type   6   (XNP)
    Header Length   3   (Minimum)
    Type of Service   48   (00110000: Priority, low delay)
XNP Message   (octets):
    Forwarding Header:
     Message Number   0   (Forwarding Header)
     Source Address   1   (Net Entry)
     Forwarder Address   25   (station #25)
     Destination Address   2   (network controller)
    Message Number   20   (Join Request)
    Station Identifier   [in the least significant 24-bits,
                                Unit Reference Number of joiner]
    Station Identifier   [24-bit Unit Reference Number, followed by 8 zero-bits]
Terminator Block   255

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5. Join Request Message to Network Controller from Forwarder

Transmission Header (bits, LSB on right):
    Selection Bits   000   (No FEC, TDC or Scrambling)
    Topology Update ID   yyy   (station's current #)
    T-bits   10   (RE-NAD)
    Queue Precedence   01   (Priority)
    Queue Length   00zzzz (network accesses needed to
                                    empty the transmit queue)
Link Layer Header (bits, LSB on right):
    Source Address   00110010   (forwarder #25)
    Destination Address   00000101   (network controller)
    Control Field   00000011   (UI)
Intranet Header (octets):
    Version #   0   (Current version)
    Message Type   6   (XNP)
    Header Length   3   (Minimum)
    Type of Service   48   (00110000: Priority, low delay)
XNP Message   (octets):
    Forwarding Header:
     Message Number   0   (Forwarding Header)
     Source Address   1   (Net Entry)
     Forwarder Address   25   (station #25)
     Destination Address   2   (network controller)
    Message Number   20   (Join Request)
    Station Identifier   [in the least significant 24-bits,
                         Unit Reference Number of joiner]
Terminator Block   255

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6. Join Accept Message to Forwarder

    Transmission Header (bits, LSB on right):

Selection Bits	000	(No FEC, TDC or Scrambling)
Topology Update ID	yyy	(station's current #)
T-bits	10	(RE-NAD)
Queue Precedence	01	(Priority)
Queue Length	00zzzz	(network accesses needed to empty the transmit queue)

    Link Layer Header (bits, LSB on right):

Source Address	nnnnnnn0	(network controller's link address)
Destination Address	00110011	(forwarder #25)
Control Field	00000011	(UI)

Intranet Header (octets):

Version #	0	(Current Version)
Message Type	6	(XNP)
Header Length	3	(Minimum)
Type of Service	48	(00110000: Priority, low delay)

XNP Message (octets):

Version Number	0	(current version)

    Forwarding Header:

Message Number	0	(Forwarding Header)
Source Address	2	(network controller)
Forwarder Address	25	(station #25)
Destination Address	1	(Net Entry)
Message Number	21	(Join Accept)
Station Identifier		[in the least significant 24-bits, Unit Reference Number of joiner]
Address Map		[bits set to 0, specifying available data link addresses]
Comm. Functions	2	(Distributed)

XNP Data Blocks:

Data Block 2	Basic Network Parameters
Data Block 4	Type 3 Network Parameters
Data Block 7	RE-NAD Parameters
Data Block 10	Type 4 Parameters
Data Block 12	Intranet Parameters
Data Block 8	Wait Time
Terminator Block	255

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7. Join Accept Message to Joiner from Forwarder

    Transmission Header (bits, LSB on right):

Selection Bits	000	(No FEC, TDC or Scrambling)
Topology Update ID	yyy	(station's current #)
T-bits	10	(RE-NAD)
Queue Precedence	01	(Priority)
Queue Length	00zzzz	(network accesses needed to empty the transmit queue)

    Link Layer Header (bits, LSB on right):

Source Address	00110010	(forwarder #25)
Destination Address	00000011	(Net Entry)
Control Field	00000011	(UI)

    Intranet Header (octets):

Version #	0	(Current Version)
Message Type	6	(XNP)
Header Length	3	(Minimum)
Type of Service	48	(00110000: Priority, low delay)

    XNP Message (octets):

Version Number	0	(current version)

      Forwarding Header:

Message Number	0	(Forwarding Header)
Source Address	2	(network controller)
Forwarder Address	25	(station #25)
Destination Address	1	(Net Entry)
Message Number	21	(Join Accept)
Station Identifier		[in the least significant 24-bits, Unit Reference Number of joiner]
Address Map		[bits set to 0, specifying available data link addresses]
Comm. Functions	2	(Distributed)

    XNP Data Blocks:

Data Block 2	Basic Network Parameters
Data Block 4	Type 3 Network Parameters
Data Block 7	RE-NAD Parameters
Data Block 10	Type 4 Parameters
Data Block 12	Intranet Parameters
Data Block 8	Wait Time
Terminator Block	255

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8. Hello Message from Joiner

Transmission Header (bits, LSB on right):
    Selection Bits   000   (No FEC, TDC or Scrambling)
    Topology Update ID   000   (station's current #)
    T-bits   10   (RE-NAD)
    Queue Precedence   00   (Urgent)
    Queue Length   00zzzz (network accesses needed to
                                       empty the transmit queue)
Link Layer Header (bits, LSB on right):
    Source Address   0xxxxxx0   (Joiner)
    Destination Addresses 00110010   (forwarder #25)
                          11111111   (Global Multicast)
    Control Field   00010011   (UI)
Intranet Header (octets):
    Version #   0   (Current Version)
    Message Type   6   (XNP)
    Header Length   3   (Minimum)
    Type of Service   240   (Network Control. low delay)
XNP Message (octets):
Version Number   0   (current version)
    Forwarding Header:
      Message Number   0   (Forwarding Header)
      Source Address   XX   (Joiner)
      Forwarder Address   25   (station #25)
      Destination Address   127   (Global Broadcast)
    Message Number   23   (Hello)
    Station Identifier   [in the least significant 24-bits,
                         Unit Reference Number of joiner]
Terminator Block   255

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9. Type 1 Acknowledgment to UI Carrying Hello Message

    Transmission Header (bits, LSB on right):
        Selection Bits   000   (No FEC, TDC or Scrambling)
        Topology Update ID   yyy   (station's current #)
        T-bits   10   (RE-NAD)
        Queue Precedence   00   (Urgent)
        Queue Length   00zzzz (network accesses needed to
                                        empty the transmit queue)
    Link Layer Header (bits, LSB on right):
        Source Address   00110010   (forwarder #25))
        Destination Address   0xxxxxx1   (Joiner)
        Control Field   00110011   (URR response)

10. Hello Message from Forwarder

    Transmission Header (bits, LSB on right):
        Selection Bits   000   (No FEC, TDC or Scrambling)
        Topology Update ID   yyy   (station's current #)
        T-bits   10   (RE-NAD)
        Queue Precedence   00   (Urgent)
        Queue Length   00zzzz (network accesses needed to
                                        empty the transmit queue)
    Link Layer Header (bits, LSB on right):
        Source Address   00110010   (forwarder #25)
        Destination Addresses 11111111   (Global Multicast)
        Control Field   00010011   (UI)
    Intranet Header (octets):
        Version #   0   (Current Version)
        Message Type   6   (XNP)
        Header Length   3   (Minimum, assuming Relaying is not required)
        Type of Service   240   (11110000: Network Control, low delay)
    XNP Message (octets):
    Version Number   0   (current version)
        Message Number   0   (Forwarding Header)
        Source Address   XX   (Joiner)
        Forwarder Address   25   (station #25)
        Destination Address   127   (Global Broadcast)
        Message Number   23   (Hello)
        Station Identifier   [in the least significant 24-bits,
                                  Unit Reference Number of joiner]
    Terminator Block   255

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11. Join Reject Message to Forwarder

Transmission Header (bits, LSB on right):
    Selection Bits   000   (No FEC, TDC or Scrambling)
    Topology Update ID   zzz   (station's current #)
    T-bits   01   (RE-NAD)
    Queue Precedence   00   (Urgent)
    Queue Length   00zzzz (network accesses needed to
                                        empty the transmit queue)
Link Layer Header (bits, LSB on right):
    Source Address   00000100   (network controller)
    Destination Address   00110011   (forwarder #25)
    Control Field   00000011   (UI)
Intranet Header (octets):
    Version #   0   (Current Version)
    Message Type   6   (XNP)
    Header Length   3   (Minimum, if no Relay required)
    Type of Service   240   (11110000: Network Control, low delay)
XNP Message (octets):
Version Number   0   (current version)
    Message Number   0   (Forwarding Header)
    Source Address   2   (network controller)
    Forwarder Address   25   (station 25)
    Destination Address   X   (address selected by joiner)
    Message Number   22   (Join Reject)
    Station Identifier   [in the least significant 24-bits,
                                Unit Reference Number of joiner]
    Rejected Link Address   X   (address selected by joiner)
    Address Map   [bits set to 0, specifying available data link addresses]
    Comm. Functions   2   (Distributed)
Terminator Block   255

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12. Join Reject Message to Joiner from Forwarder

    Transmission Header (bits, LSB on right):
        Selection Bits   000   (No FEC, TDC or Scrambling)
        Topology Update ID   zzz   (network controller's current #)
        T-bits   01   (RE-NAD)
        Queue Precedence   00   (Urgent)
        Queue Length   00zzzz (network accesses needed to
                                      empty the transmit queue)
    Link Layer Header (bits, LSB on right):
        Source Address   00110010   (forwarder #25)
        Destination Address   0xxxxxx0   (Rejected Joiner)
                              11111111   (Global Multicast)
        Control Field   00000011   (UI)
    Intranet Header (octets):
        Version #   0   (Current Version)
        Message Type   6   (XNP)
        Header Length   3   (Minimum)
        Type of Service   240   (11110000: Network Control, low delay)
    XNP Message (octets):
    Version Number   0   (current version)
        Message Number   0   (Forwarding Header)
        Source Address   2   (network controller)
        Forwarder Address   25   (station 25)
        Destination Address   X   (address selected by joiner)
        Message Number   22   (Join Reject)
        Station Identifier   [in the least significant 24-bits,
                                Unit Reference Number of joiner]
        Rejected Link Address   X   (address selected by joiner)
        Address Map   [bits set to 0, specifying
                                available data link addresses]
        Comm. Functions   2   (Distributed)
    Terminator Block   255

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13. Second Hello Message from Joiner

Transmission Header (bits, LSB on right):
    Selection Bits   000   (No FEC, TDC or Scrambling)
    Topology Update ID   000   (station's current #)
    T-bits   10   (RE-NAD)
    Queue Precedence   00   (Urgent)
    Queue Length   00zzzz (network accesses needed to
                                   empty the transmit queue)
Link Layer Header (bits, LSB on right):
    Source Address   0xxxxxx0   (Joiner)
    Destination Addresses   00110010   (forwarder #25)
                         11111111   (Global Multicast)
    Control Field   00010011   (UI)
Intranet Header (octets):
    Version #   0   (Current Version)
    Message Type   6   (XNP)
    Header Length   3   (Minimum)
    Type of Service   240   (11110000: Network Control, low delay)
XNP Message (octets):
Version Number   0   (current version)
    Message Number   0   (Forwarding Header)
    Source Address   XX   (Joiner)
    Forwarder Address   25   (station #25)
    Destination Address   127   (Global Broadcast)
    Message Number   23   (Hello)
    Station Identifier   [in the least significant 24-bits,
                             Unit Reference Number of joiner]
Terminator Block   255

14. Type 1 Acknowledgment to UI Carrying Second Hello Message

Transmission Header (bits, LSB on right):
    Selection Bits   000   (No FEC, TDC or Scrambling)
    Topology Update ID   yyy   (station's current #)
    T-bits   10   (RE-NAD)
    Queue Precedence   00   (Urgent)
    Queue Length   00zzzz (network accesses needed to
                                   empty the transmit queue)
Link Layer Header (bits, LSB on right):
    Source Address   00110010   (forwarder #25))
    Destination Address   0xxxxxx1   (Joiner)
    Control Field   00110011   (URR response)

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15. Second Hello Message from Forwarder

Transmission Header (bits, LSB on right):
    Selection Bits   000   (No FEC, TDC or Scrambling)
    Topology Update ID   yyy   (station's current #)
    T-bits   10   (RE-NAD)
    Queue Precedence   00   (Urgent)
    Queue Length   00zzzz (network accesses needed to
                                      empty the transmit queue)
Link Layer Header (bits, LSB on right):
    Source Address   00110010   (forwarder #25)
    Destination Addresses   11111111   (Global Multicast)
    Control Field   00010011   (UI)
Intranet Header (octets):
    Version #   0   (Current Version)
    Message Type   6   (XNP)
    Header Length   3   (Minimum, assuming Relaying is not required)
    Type of Service   240   (11110000: Network Control, low delay)
XNP Message (octets):
Version Number   0   (current version)
    Message Number   0   (Forwarding Header)
    Source Address   XX   (Joiner)
    Forwarder Address   25   (station #25)
    Destination Address   127   (Global Broadcast)
    Message Number   23   (Hello)
    Station Identifier   [in the least significant 24-bits,
                            Unit Reference Number of joiner]
Terminator Block   255

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APPENDIX F

GOLAY CODING ALGORITHM

F.1. <u>General</u>.

F.1.1 <u>Scope</u>. This appendix contains amplifying information in support of MIL-STD-188-220.

F.1.2 <u>Application</u>. This appendix is not a mandatory part of MIL-STD-188-220. The information contained herein is intended for guidance only.

F.2. <u>Applicable documents</u>. None.

F.3. <u>Forward error correction</u>. The FEC method requires the receiver to detect and automatically correct errors in a received block of information. The number of errors the receiver can detect and correct depends on the coding method. The information bits (k) are separated into blocks that contain both information bits and code bits. The length of the block, including the information and code bits, is (n). The code is described as (n, k), where n is the length of the block and k is the number of information bits in the block.

F.4. <u>Golay code</u>. The Golay code is a linear, block, perfect, and cyclic (23,12) code capable of correcting any combination of three or fewer errors in a block of 23 digits. The generator polynomial for this code is

$$g(x) = x^{11} + x^{10} + x^6 + x^5 + x^4 + x^2 + 1$$

where g(x) is a factor of $x^{23} + 1$

F.4.1 <u>Half-rate Golay code</u>. The half-rate Golay code (24,12) is formed by adding a fill bit to the Golay (23, 12) code. The fill bit is not checked on reception. The (24,12) code is preferable to the (23,-12) because it has a code rate of exactly one-half. This code rate simplifies system timing.

F.4.2 <u>Golay code implementation</u>. The Golay code may be implemented in either hardware or software. The hardware implementation uses shift-registers for encoding and decoding, as described in F.4.2.1 and F.4.2.2, respectively. The software implementation uses a generator matrix and conversion table, as described in F.4.2.3.

F.4.2.1 <u>Hardware implementation</u>. Golay code encoding can be performed with an 11-stage feedback shift register with feedback connections selected according to the coefficients of g(x). A shift register corresponding to the coefficients of g(x) is shown in Figure F-1. The k information bits are located at the beginning of the n symbol block code. With the gate open, the information bits are loaded into the shift register stages and simultaneously into the output channel. At this time the shift register contains the check symbols. With the gate closed, register contents are then shifted onto the output channel. The last n - k symbols are the check symbols that form the whole codeword.

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Encoder for $g(x) = 1 + x^2 + x^4 + x^5 + x^6 + x^{10} + x^{11}$
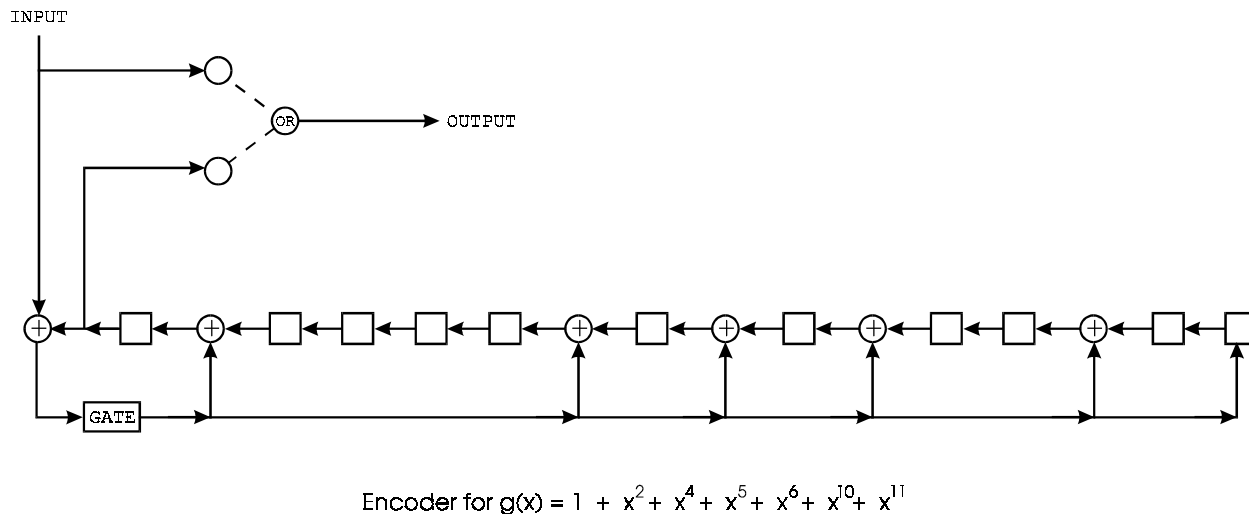
FIGURE F-1. Shift register encoding for the (23, 12) Golay code.

F.4.2.2 Hardware decoding. The Golay code is decoded using a number of techniques such as the error-trapping process developed by T. Kasami. The Kasami error-trapping decoder for the Golay code is shown in Figure F-2. It works as follows:

a.   Gates 1, 3, and 5 are opened, and gates 2 and 4 are closed. The received codeword r(x) is then shifted into both the 23-stage shift register and the syndrome register. At the same time, the previously corrected codeword is shifted out to the user. The syndrome

$$S(x) = S_0 + S_1x + \ldots + S_{10}x^{10}$$

is then formed and subjected to threshold tests.

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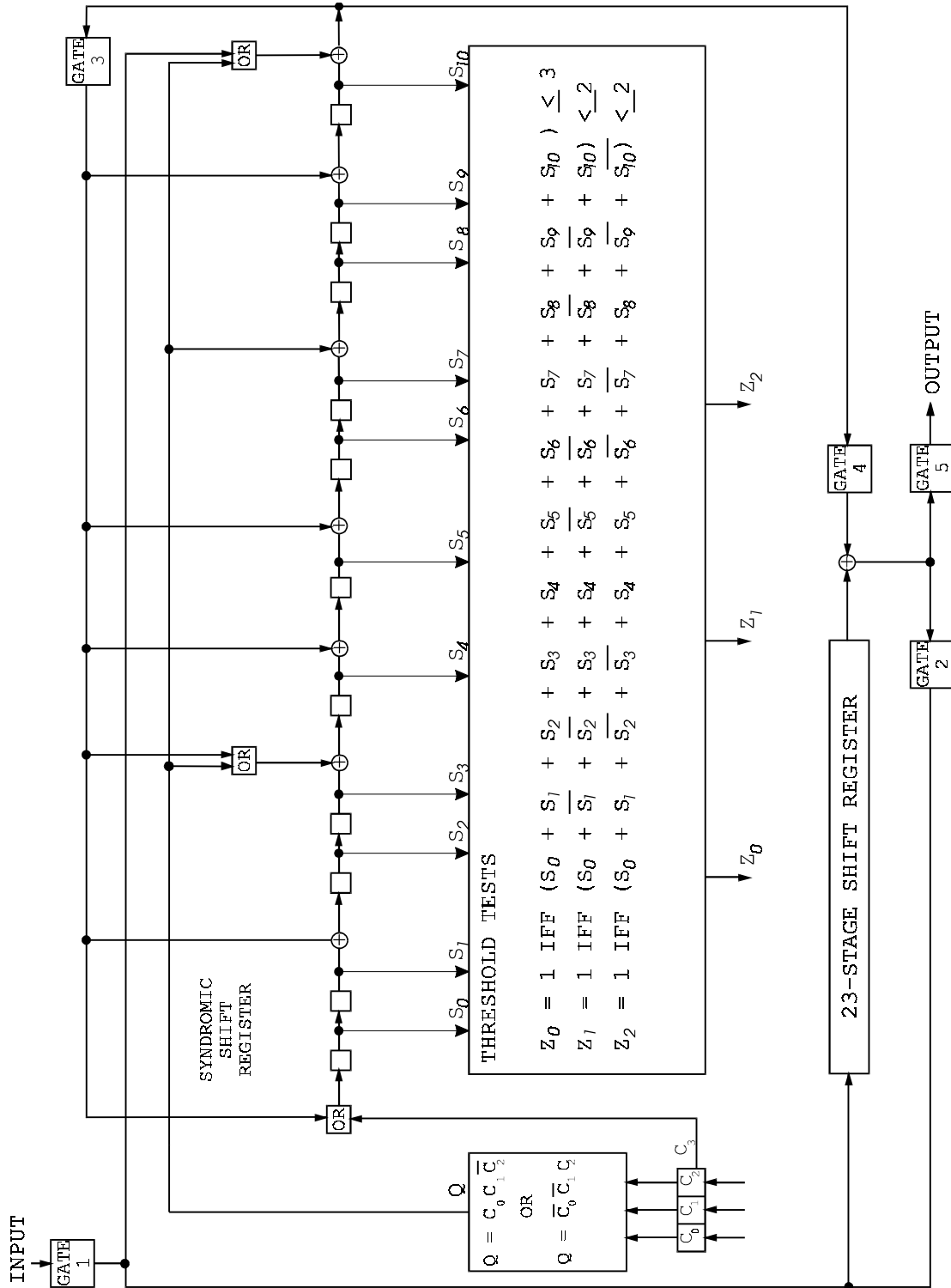
FIGURE F-2. Kasami error-trapping decoder for the (24, 12) Golay code.

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b.   Gates 1, 4, and 5 are closed and gate 2 is opened. Gate 3 remains open. The threshold tests occur in the following order:

1.   If Z_0 is unity, then all the errors are confined to the 11 high-order positions of r(x), and S(x) matches the errors. Z_0 opens gate 4 and closes gate 3. Contents of both the 23-stage shift register and the syndrome shift register are then shifted 11 times, and the errors are corrected. Then gate 4 is closed and the contents of the 23-stage shift register are shifted until the received codeword is in its original position. The decoder then goes to step 3 below.

2.   If Z_1 is unity, the error pattern in S(x) is the same as the errors in the 11 high-order bits of the codeword r(x), and a single error exists at location x^5. Gate 4 is opened and gate 3 is closed. The counter is preloaded with a count of 2, and both the syndrome shift register and the 23-stage shift register are shifted until the error in x^5 is corrected. Then gate 4 is closed, and the contents of the 23-stage shift register are shifted until the received codeword is in its original position. The decoder then goes to step 3.

3.   If Z_2 is unity, the error pattern in S(x) is the same as the errors in the 11 high-order bits of the codeword r(x), and there is a single error in location x^6. The same steps are followed as in b (above) except that the counter is preloaded with a count of 3. The decoder then goes to step 3.

4.   If neither of the three thresholds is unity, the decoder goes directly to step 3.

c.   Gates 1, 4, and 5 are closed, and gates 2 and 3 are opened. Contents of both the 23-stage shift register and the syndrome shift register are then shifted once to the right. The decoder then goes to step 2.

d.   This action continues until step 3 has been executed 46 times. Then the decoder returns to step 1 to process the next received codeword.

The decoder always yields an output. The output is correct if there were 3 or fewer errors in the received codeword, and erroneous if there were more than 3 errors in the codeword.

F.4.2.3 Software implementation. The transmitting DMTD shall generate the check bits using the following generator polynomial:

$$g(x) = x^{11} + x^{10} + x^6 + x^5 + x^4 + x^2 + 1$$

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Note that using modulo 2 addition,

$$x^{23}+1=(x^{11}+x^{10}+x^6+x^5+x^4+x^2+1)(x^{11}+x^9+x^7+x^6+x^5+x+1)(x+1)$$

The 11 check bits shall be as derived from the generator matrix G, shown in Figure F-3, where the matrix contains the coefficients of the polynomials on the left.

```
                                          2 2 2 1 1 1 1 1 1 1 1 1 1
                                          2 1 0 9 8 7 6 5 4 3 2 1 0 9 8 7 6 5 4 3 2 1 0
                                          X                                             X
                   x¹¹ * g(x)        =  │ 1 1 0 0 0 1 1 1 0 1 0 1 0 0 0 0 0 0 0 0 0 0 0 │
                   x¹⁰ * g(x)        =  │ 0 1 1 0 0 0 1 1 1 0 1 0 1 0 0 0 0 0 0 0 0 0 0 │
            x⁹ * g(x) + x¹¹ * g(x)   =  │ 1 1 1 1 0 1 1 0 1 0 0 0 0 1 0 0 0 0 0 0 0 0 0 │
            x⁸ * g(x) + x¹⁰ * g(x)   =  │ 0 1 1 1 1 0 1 1 0 1 0 0 0 0 1 0 0 0 0 0 0 0 0 │
            x⁷ * g(x) + x⁹ * g(x)    =  │ 0 0 1 1 1 1 0 1 1 0 1 0 0 0 0 1 0 0 0 0 0 0 0 │
         (x⁶ + x⁸ + x¹¹) * g(x)      =  │ 1 1 0 1 1 0 0 1 1 0 0 0 0 0 0 0 1 0 0 0 0 0 0 │ = G
         (x⁵ + x⁷ + x¹⁰) * g(x)      =  │ 0 1 1 0 1 1 0 0 1 1 0 0 0 0 0 0 0 1 0 0 0 0 0 │
         (x⁴ + x⁶ + x⁹) * g(x)       =  │ 0 0 1 1 0 1 1 0 0 1 1 0 0 0 0 0 0 0 1 0 0 0 0 │
      (x³ + x⁵ + x⁸ + x¹¹) * g(x)    =  │ 1 1 0 1 1 1 0 0 0 1 1 0 0 0 0 0 0 0 0 1 0 0 0 │
 (x² + x⁴ + x⁷ + x¹⁰ + x¹¹) * g(x)   =  │ 1 0 1 0 1 0 0 1 0 1 1 0 0 0 0 0 0 0 0 0 1 0 0 │
(x + x³ + x⁶ + x⁹ + x¹⁰ + x¹¹) * g(x)=  │ 1 0 0 1 0 0 1 1 1 1 1 0 0 0 0 0 0 0 0 0 0 1 0 │
(1 + x² + x⁵ + x⁸ + x⁹ + x¹⁰ + x¹¹) * g(x) = │ 1 0 0 0 1 1 1 0 1 0 1 0 0 0 0 0 0 0 0 0 0 0 1 │

                                              _____Parity_____/   _____Identity_____/
```

FIGURE F-3. Generator matrix G.

By interchanging the I and P columns to obtain matrix T, shown in Figure F-4, that is,

$$G=[P,I]_{(12\,x\,23)} = >[I,P]_{(12\,x\,23)} = T$$

the transmission order and value of the code word bits can be obtained by matrix multiplication (modulo 2 addition without carry) as follows:

$$\left[\text{Ib}_1 \;\; \text{INFO BITS} \;\; \text{Ib}_{12} \right] \cdot \left[\text{I,P} \right] = \left[\text{INFO BITS,CHECK BITS} \right]$$

(1x12)   (12x23)   (1x23)

↑ FIRST BIT TRANSMITTED   ↑ FIRST BIT TRANSMITTED
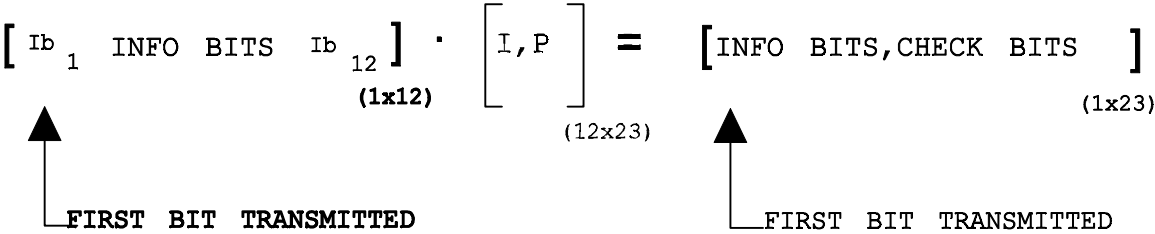
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$$T = \begin{bmatrix}
1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 1 & 0 & 0 & 0 & 1 & 1 & 1 & 0 & 1 & 0 \\
0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 1 & 0 & 0 & 0 & 1 & 1 & 1 & 0 & 1 \\
0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 1 & 1 & 1 & 0 & 1 & 1 & 0 & 1 & 0 & 0 \\
0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 1 & 1 & 1 & 0 & 1 & 1 & 0 & 1 & 0 \\
0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 1 & 1 & 1 & 0 & 1 & 1 & 0 & 1 \\
0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 1 & 0 & 1 & 1 & 0 & 0 & 1 & 1 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 1 & 0 & 1 & 1 & 0 & 0 & 1 & 1 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 1 & 0 & 1 & 1 & 0 & 0 & 1 & 1 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 1 & 1 & 0 & 1 & 1 & 1 & 0 & 0 & 0 & 1 & 1 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 1 & 0 & 1 & 0 & 1 & 0 & 0 & 1 & 0 & 1 & 1 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 1 & 0 & 0 & 1 & 0 & 0 & 1 & 1 & 1 & 1 & 1 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 1 & 0 & 0 & 0 & 1 & 1 & 1 & 0 & 1 & 0 & 1 \\
\end{bmatrix}$$

$$\underbrace{\hspace{4cm}}_{I} \quad \underbrace{\hspace{4cm}}_{P}$$

FIGURE F-4. <u>Matrix T.</u>

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APPENDIX G

PACKET CONSTRUCTION AND BIT ORDERING

G.1. General.

G.1.1 Scope. This appendix illustrates the construction of packets starting with the Application Layer Protocol Data Unit (PDU) and VMF Message data buffers and ending with the data link bit order of transmission and physical layer PDU. However this example excludes the S/R protocol. The focus of this example is to show correct formatting of the 188-220 subnetwork.

G.1.2 Application. This appendix is a mandatory part of this document. The bit ordering defined herein shall be utilized by all implementers.

G.2. Applicable Documents.

      a. RFC 768: User Datagram Protocol

      b. RFC 791: Internet Protocol -- DARPA Internet Program Protocol Specification

      c. MIL-STD-2045-47001: Interoperability Standard for Connectionless Data Transfer -- Application Standard

      d. Joint Interoperability of Tactical Command and Control Systems, Variable Message Format Technical Interface Design Plan (Test Edition), Reissue 2, Volume III

G.3. PDU construction. This section provides examples illustrating the construction and bit ordering of a VMF message through the Application Layer, the Transport Layer, the Network Layer, Link Layer and Physical Layer. For clarity, each layer will be discussed separately and then combined for actual transmission. The same representations will be utilized for each layer:

    • the MSB (2^n bit) is represented with an italicized font and

    • the LSB (2^0 bit) is shown to the RIGHT in the Value (binary) column.

This representation is carried into the other columns to identify the beginning and end of each of the fields as the bits are moved into individual octets. Note that the bit markings for MSB and LSB are on a field basis, not on an octet basis. Single bit fields are treated as LSB. In addition, since some layers (e.g. transport) are based on commercial standards, the representation from the appropriate RFC will also be included. In all cases, we will start with a figure which illustrates the interaction with upper/lower communication layers, followed by a figure showing the exchange between communication layers. There will be a table showing the construction of the PDU. This will be followed by a table showing the construction of each octet and a figure showing the serial representation of this particular PDU as it would appear at physical layer.

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Each layer typically adds value and its own header to an outgoing message. This process is illustrated in Figure G-1.
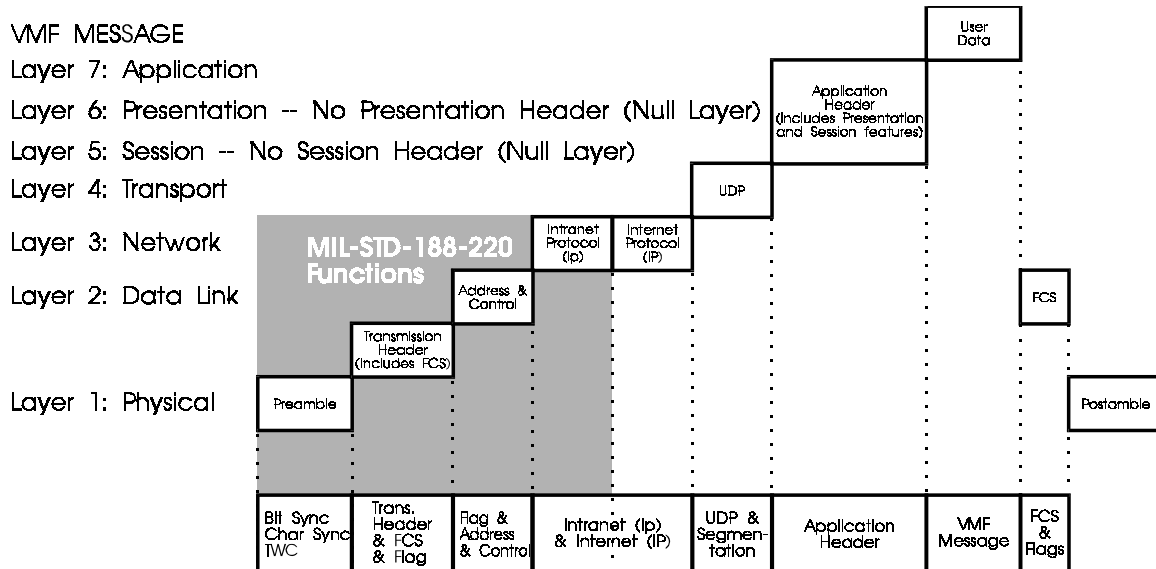
FIGURE G-1. <u>PDU construction</u>.

An application header is added to the VMF message at application layer. For this protocol, layers 5 and 6 are null layers, and no processing or headers are present. The Application Layer handles these functions. The transport layer adds its header. Although the standard calls out TCP, UDP and segmentation/reassembly, only UDP is illustrated in this appendix. Next, the network layer adds the IP header and the Intranet header. The message is now passed to the data link layer which adds both a header and a trailer. Finally, the physical layer adds its header resulting in the final PDU for transmission. Note that this example does not include TCP, segmentation & reassembly, or COMSEC.

G.3.1 <u>VMF message data exchange</u>. The relationship of the VMF Messaging Services to other communication layers is shown in Figure G-2.

A layered communication model is used in this example for consistency with the principles of the ISO OSI reference model. The model discussed here is tailored to focus attention specifically on VMF Messaging Services, and the data it produces. A user of VMF Messaging Services exchanges Message Content with its peer at another node by sending and receiving the Message Content via the VMF Messaging Services. VMF Messaging Services sends and receives the Message Content by converting the Message Content to Message Data and exchanging the Message Data with its peer at another node. The VMF Message Data is sent and received via lower communication layers. The lower communication layers send and receive the VMF Message Data transparently over a variety of communications media. Note that VMF Messaging Services would ordinarily use Application Layer services from the lower communication layers to

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send and receive Message Data. The Message Data would then appear in the Application Layer PDU's VMF message.
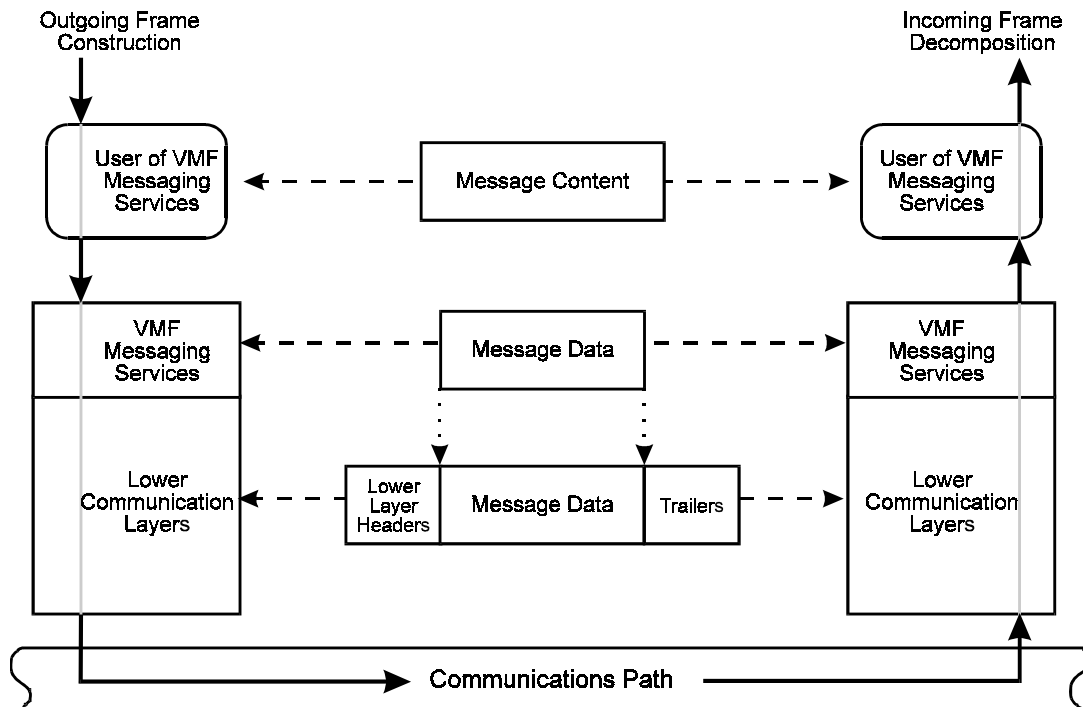
FIGURE G-2. VMF message services interaction with other communication layers.

The format of the Message Data is defined in terms of the actual data buffer or data stream used to exchange the Message Data between the VMF Messaging Services and the lower communication layers. The rationale for using the Message Data's data buffer/stream to define the format is: 1) for consistency with industry standard commercial communications hardware and software (e.g., UNIX implementations of TCP/IP), which exchange data with other software when sending or receiving as a buffer or stream of octets; 2) to provide a definition independent of the specifics of any other communication layer, consistent with the OSI ISO model principle of making communication layers independent; and 3) to avoid differences in the bit representations used to implement communications on different media. For example, on Ethernet LAN media each octet is sent least significant bit first, but on FDDI media each octet is sent most significant bit first. To achieve a universal definition of the Message Data format, its representation is defined independent of the other communication layers. The relationship of the Message Data's data buffer/stream to the VMF Messaging Services is depicted in Figure G-3. The Message Data is defined as a buffer or stream of octets. The rational for treating the Message Data as a series of octets is for consistency with the way communications data is handled by industry standard commercial communications hardware and software and for independence from platform-dependent byte ordering issues.

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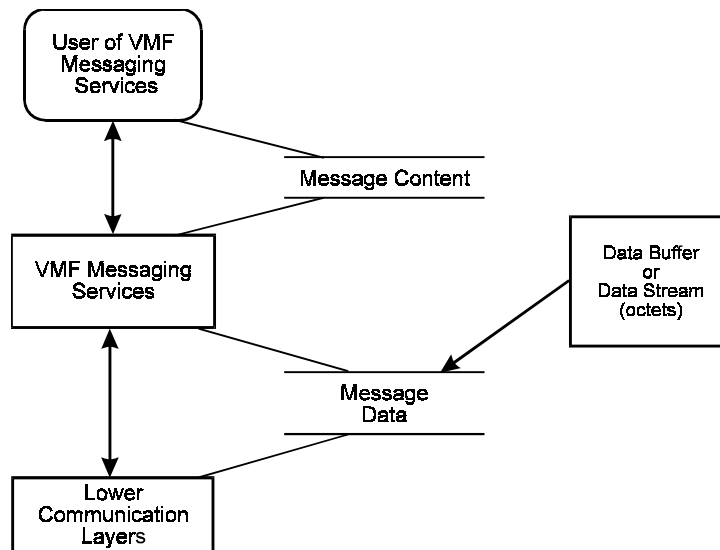
FIGURE G-3. Exchange of message data between communication layers.

G.3.1.1 Example of VMF message data construction. The construction of VMF Message Data is illustrated by the example in Table G-1. The first four columns of the table provide a description of each field in the example, the field length in bits, and the value of the field in both decimal and binary representations. The last three columns show the physical encoding of the VMF Message Data. In the fifth column, Field Fragments, the bits of each field are placed in octets. The bit(s) of each field are positioned in an octet such that the LSB of the field is positioned in the least significant unencoded bit of the octet, the next LSB of the field is placed in the next least significant unencoded bit of the octet, and repeated until all of the bits of the field have been encoded. When an octet is filled before all the bits of a field are encoded, the process is continued encoding the next octet with the remaining bits of the field. This field/octet encoding procedure is performed starting with the first field and octet, and repeated for each successive field and individual octet, in order, until the encoding is completed. When a field has groups, the field encoding procedure is performed starting with the first group, and repeated for each successive group and individual octet, in order, until the encoding of the field is completed. The Target Number field illustrates the encoding of a field with groups. Note the LSB of a field or octet is defined as the bit having the weight of 2^0 when the field or octet is represented as a numeric value. X's are used to identify bits that are not associated with the field being encoded. The sixth column, Octet Value - Binary, assembles the bits contributed by successive fields into complete octets, represented in binary. The seventh column, Octet Value – Hexadecimal, represents the octet value in hexadecimal. The last column, Octet Number, numbers the octets from first to last starting with 0.

When all fields have been encoded, any remaining unencoded bits in the last octet are filled with zeroes (zero padded). Each VMF Message is individually encoded and zero padded.

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TABLE G-1. Example of VMF message data construction.

Field Name	Length (bits)	Value (Dec)	Value (Bin)	Field Fragments	Octet Value (Bin)	Octet Value (Hex)	Octet Number
			MSB 2^n LSB 2^0	MSB 2^7 LSB 2^0	MSB 2^7 LSB 2^0		
Check Fire Type	3	0	*0*00	xxxxx*000*			
Check Fire/Cancel Check fire command	3	1	*0*01	xx*001*xxx			
FPI	1	1	1	x1xxxxxx			
Target Number (Group 1)	7	65 (A)	*1*000001	1xxxxxxx xx*1*00000	11*001000*	C8	0
(Group 2)	7	66 (B)	*1*000010	10xxxxxx xxx*1*0000	10*1*00000	A0	1
(Group 3)	14	1543	*0*0011000000111	111xxxxx 11000000 xxxxx*000*	111*1*0000 11000000	F0 C0	2 3
FPI (Observer URN)	1	0	0	xxxx0xxx			
FPI (First Unit URN)	1	0	0	xxx0xxxx			
GPI DTG	1	0	0	xx0xxxxx			
FPI (launcher message)	1	0	0	x0xxxxxx			
(Zero Padding)	1	0	0	0xxxxxxx	00000*000*	00	4

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Figure G-4 illustrates the octets arranged in a serial format as they would appear at the physical layer, with LSB first.

Octet 0	Octet 1	Octet 2	Octet 3	Octet 4
$2^0 \qquad 2^7$	$2^0 \qquad 2^7$	$2^0 \qquad 2^7$	$2^0 \qquad 2^7$	$2^0 \qquad 2^7$
00*0*10*0*11	00000*1*01	0000*1*111	00000011	00*0*00000

FIGURE G-4. Serial representation of PDU.

G.3.2 Application Layer Data Exchange. The relationship of the Application Layer to other communication layers is shown in Figure G-5. A layered communication model is used in this example for consistency with the principles of the ISO OSI reference model. The model discussed here is tailored to focus attention specifically on the Application Layer, and the data it produces. A user of the Application Layer exchanges a VMF message with its peer at another node by sending and receiving the VMF message via the Application Layer. The Application Layer sends and receives the VMF message transparently by producing and exchanging an Application Layer Protocol Data Unit (PDU) with its peer at another node. The Application Layer PDU consists of the Application Header concatenated with the VMF message, and is sent and received via lower communication layers. The lower communication layers send and receive the VMF message transparently over a variety of communications media.

The format of the Application Layer PDU is defined in terms of the actual data buffer or data stream used to exchange the PDU between the Application Layer and the lower communication layers. The rationale for using the PDU's data buffer/stream to define the format is 1) for consistency with industry standard commercial communications hardware and software (e.g., UNIX implementations of TCP/IP), which exchange data with other software when sending or receiving as a buffer or stream of octets; 2) to provide a definition independent of the specifics of any other communication layer, consistent with the OSI ISO model principle of making communication layers independent; and 3) to avoid differences in the bit representations used to implement communications on different media. For example, on Ethernet LAN media each octet is sent least significant bit first, but on FDDI media each octet is sent most significant bit first. To achieve a universal definition of the PDU format, its representation is defined independent of the other communication layers.

The relationship of the Application Layer PDU's data buffer/stream to the Application Layer is depicted in Figure G-6. The Application Layer PDU is defined as a buffer or stream of octets. The rational for treating the PDU as a series of octets is for consistency with the way communications data is handled by industry standard commercial communications hardware and software and for independence from platform-dependent byte ordering issues. The Application Header and the VMF message are each individually defined as a series of octets for the same reasons.

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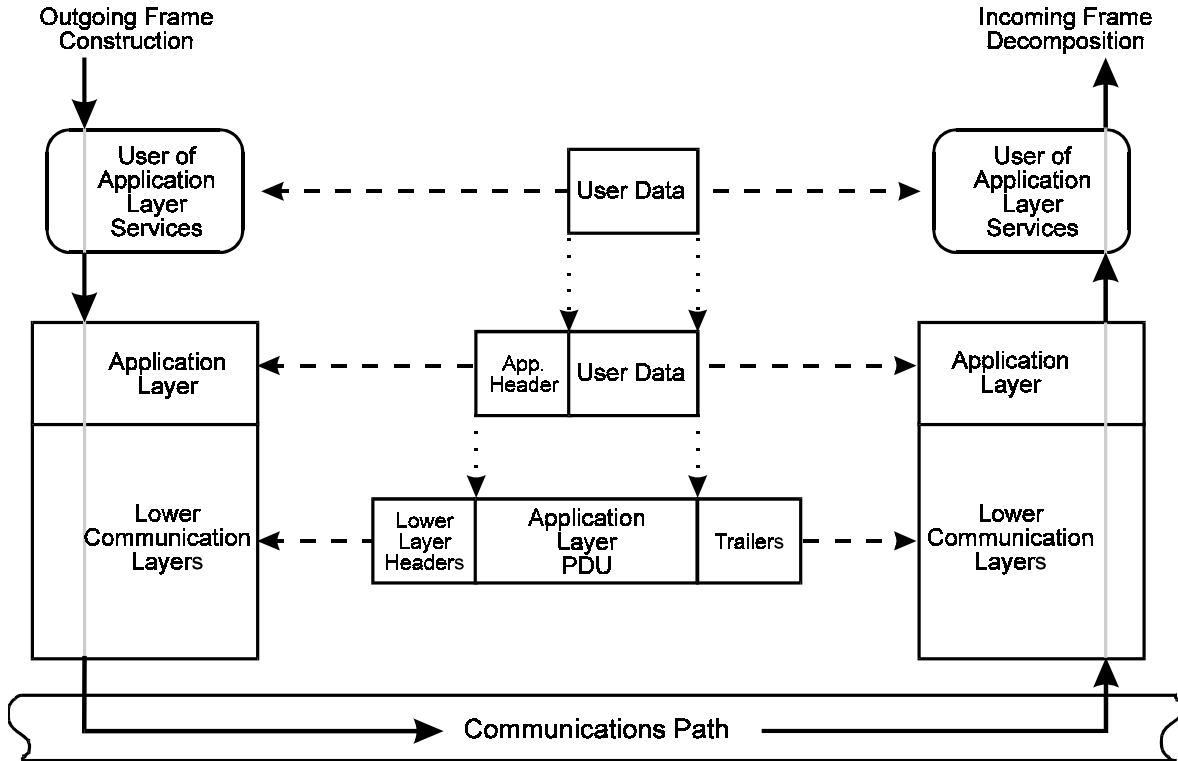
FIGURE G-5. Application layer interaction with other communication layers.
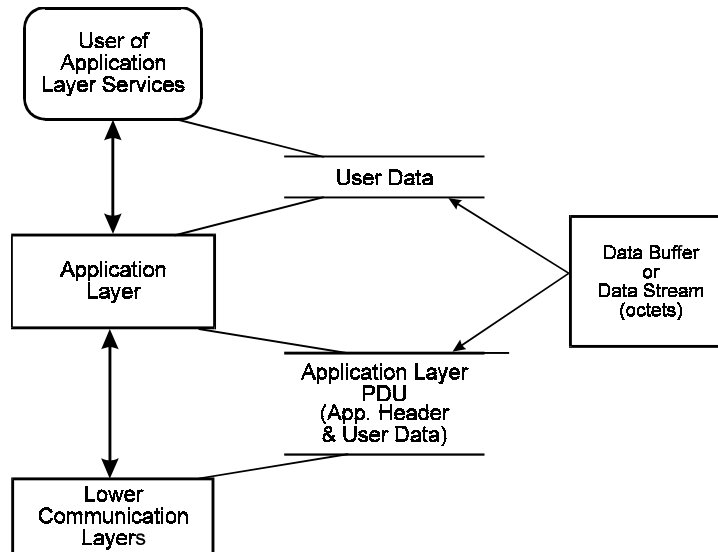
FIGURE G-6. Exchange of application layer PDU between communication layers.

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G.3.2.1 <u>Example of application layer PDU</u>. The construction of an Application Layer PDU is illustrated by the example in Table G-2. The first four columns of the table provide a description of each field in the example, the field length in bits, and the value of the field in both decimal and binary representations. The last four columns show the physical encoding of the Application Layer PDU. In the fifth column, Field Fragments, the bits of each field are placed in octets. The bit(s) of each field are positioned in an octet such that the LSB of the field is positioned in the least significant unencoded bit of the octet, the next LSB of the field is placed in the next least significant unencoded bit of the octet, and repeated until all of the bits of the field have been encoded. When an octet is filled before all the bits of a field are encoded, the process is continued encoding the next octet with the remaining bits of the field. This field/octet encoding procedure is performed starting with the first field and octet, and repeated for each successive field and individual octet, in order, until the encoding is completed. When a field has groups, the field encoding procedure is performed starting with the first group, and repeated for each successive group and individual octet, in order, until the encoding of the field is completed. The Unit Reference Number field illustrates the encoding of a field with groups. Note the LSB of a field or octet is defined as the bit having the weight of 2^0 when the field or octet is represented as a numeric value. X's are used to identify bits that are not associated with the field being encoded. The sixth column, Octet Value - Binary, assembles the bits contributed by successive fields into complete octets, represented in binary. The seventh column, Octet Value, represents the octet value in binary that should be submitted to the Transport layer. The last column, Octet Number, numbers the octets from first to last starting with 0.

When all fields have been encoded, any remaining unencoded bits in the last octet are filled with zeroes (zero padded). The Application Header is individually encoded and zero padded. The VMF message is individually encoded and zero padded before it is passed to the Application Layer to have the Application Header added.

Any of the ASCII fields (e.g. Unit Name) in the application header can be terminated by either an end of text marker, or by using the maximum number of bits. Table G-3 shows how to format the Unit Name when the Unit Name is used as part of the originator address group. The Unit Name and Unit Reference Number are mutually exclusive inside the address group – never send both, Unit Name and Unit Reference Number, in an address group. However if the address group has a Group Repeat Indicator (GRI) each of the repeatable address groups can be different address types (e.g. Unit Name or Unit Reference Number).

The Application Header is followed by the VMF message. The VMF message is shown as a single 10-octet message to complete the Application Layer PDU.

Figure G-7 provides an illustration of the Application Header as it would appear in serial form at the lower layers.

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TABLE G-2. Example construction of the application header.

Syntax	Field Description	Length (bits)	Value (Dec)	Value (Bin)		Field Fragments		Octet Value (Bin)		Octet Number
				MSB 2^n	LSB 2^0	MSB 2^n	LSB 2^0	MSB 2^n	LSB 2^0	
	Version	4	1		*0*001	xxxx*0*001				
FPI	Compression Type	1	0		0	xxx0xxxx				
GPI	Presence Indicator (Originator)	1	1		1	xx1xxxxx				
FPI	Presence Indicator (URN)	1	1		1	x1xxxxxx				
	Unit Reference Number (Originator)	24	23	*0*000000000000000000010111		1xxxxxxx 00001011 00000000 x*0*000000		1110*0*001 00001011 00000000		0 1 2
FPI	Presence Indicator (Unit Name)	1	0		0	0xxxxxxx		0*0*000000		3
GPI	Presence Indicator (Recipient)	1	1		1	xxxxxxx1				
GRI	Group Repeat Indicator (Recipient)	1	0		0	xxxxxx0x				
FPI	Presence Indicator (URN)	1	1		1	xxxxx1xx				
	Unit Reference Number (Recipient URN)	24	124	*0*000000000000000001111100		11100xxx 00000011 00000000 xxxxx*0*00		11100101 00000011 00000000		4 5 6
FPI	Presence Indicator (Unit Name)	1	0		0	xxxx0xxx				
GPI	Group Presence Indicator (Information)	1	0		0	xxx0xxxx				
GRI	Group Repeat Indicator (Message)	1	0		0	xx0xxxxx				
	User Message Format	4	2		*0*010	10x*xxxx* xxxxxx*0*0		10000*0*00		7
GPI	Group Presence Indicator	1	1		1	xxxxx1xx				

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TABLE G-2. Example construction of the application header.

Syntax	Field Description	Length (bits)	Value (Dec)	Value (Bin)		Field Fragments		Octet Value (Bin)		Octet Number
				MSB 2ⁿ	*LSB 2⁰*	MSB 2ⁿ	LSB 2⁰	MSB 2ⁿ	LSB 2⁰	
	(Message Identification)									
	Functional Area Designator	4	2		*0*010	x*0*010xxx				
	Message Number	7	1		*0*000001	1xxxxxxx xx*0*00000		10*0*101*0*0		8
FPI	Presence Indicator (Message Subtype #)	1	0		0	x0xxxxxx				
FPI	Presence Indicator (File Name)	1	0		0	0xxxxxxx		00*0*00000		9
FPI	Presence Indicator (Message Size)	1	0		0	xxxxxxx0				
	Operation Indicator	2	0		00	*x*xxxx*0*0x				
	Retransmit Indicator	1	0		0	xxxx0xxx				
	Message Precedence Code	3	7		*1*11	x*1*11xxxx				
	Security Classification	2	0		00	0xxxxxxx xxxxxxx*0*		0*1*110*0*00		10
FPI	FPI for Control/Release Marking	1	0		0	xxxxxx0x				
GPI	GPI for Originator DTG	1	1		1	xxxxx1xx				
	Year	7	96		*1*100000	00000xxx xxxxx*x*11		00000100*0*		11
	Month	4	7		*0*111	xx*0*111xx				
	Day	5	1		*0*0001	01xxxxxx xxxxx*0*00		01*0*111*1*1		12
	Hour	5	8		*0*1000	*0*1000xxx		*0*1000*0*00		13
	Minute	6	32		*1*00000	xx*1*00000				
	Second	6	16		*0*10000	00xxxxxx xxxx*0*100		00*1*00000		14
FPI	DTG Extension	1	0		0	xxx0xxxx				
GPI	GPI for Perishability	1	0		0	xx0xxxxx				

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TABLE G-2. <u>Example construction of the application header.</u>

Syntax	Field Description	Length (bits)	Value (Dec)	Value (Bin)		Field Fragments	Octet Value (Bin)	Octet Number
				MSB *2ⁿ*	LSB 2⁰	MSB 2ⁿ LSB 2⁰	MSB 2ⁿ LSB 2⁰	
	DTG							
GPI	GPI for ACK Request Group	1	0		0	x0xxxxxx		
GPI	GPI for Response Data Group	1	0		0	0xxxxxxx	0000*0*100	15
GPI	GPI for Reference Message Data	1	0		0	xxxxxxx0		
	(Zero Padding)	7	0	*0000000*	*0000000x*	*00000000*	16

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TABLE G-3. Example of a unit name as originator.

Syntax	Field Description	Length (bits)	Value (Dec)	Value (Bin)		Field Fragments		Octet Value (Bin)		Octet Number
				MSB 2^n	LSB 2^0	MSB 2^n	LSB 2^0	MSB 2^n	LSB 2^0	
	Version	4	1		*0*001	xxxx*0*001				
FPI	Compression Type	1	0		0	xxx0xxxx				
GPI	Presence Indicator (Originator)	1	1		1	xx1xxxxx				
FPI	Presence Indicator (URN)	1	0		0	x0xxxxxx				
FPI	Presence Indicator (Unit Name)	1	1		1	1xxxxxxx		10000000		0
	Unit Name (Originator)	448 Max	"UNITA"							
	"U"	7	85		*1*010101	x*1*010101				
	"N"	7	78		*1*001110	0xxxxxxx xx*1*00111		0*1*010101		1
	"I"	7	73		*1*001001	01xxxxxx xxx*1*0010		01*1*00111		2
	"T"	7	84		*1*010100	100xxxxx xxxx*1*010		100*1*0010		3
	"A"	7	65		*1*000001	0001xxxx xxxxx*1*00		0001*1*010		4
	End of text marker (ANSI ASCII DEL)	7	127		*1*111111	11111xxx xxxxxx*1*1		11111*1*00		
GPI	Presence Indicator (Recipient)	1	1		1	xxxxx1xx				
	encode rest of the message as in Figure G-3									

Octet 0		Octet 1		Octet 2				Octet 11		Octet 12		Octet 13		Octet 14		Octet 15		Octet 16	
2^0	2^7	2^0	2^7	2^0	2^7			2^0	2^7	2^0	2^7	2^0	2^7	2^0	2^7	2^0	2^7	2^0	2^7
100*0*0111		11010000		00000000				*0*0100000		1*1*111*0*10		00*0*0001*0*		00000*1*00		001*0*0000		0000000*0*	

FIGURE G-7. Application header (octets).

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G.3.3 <u>Transport layer data exchange</u>. The relationship of the Transport Layer to other communication layers is shown in Figure G-8. A user of the Transport Layer exchanges data with its peer at another node by sending and receiving the Application Layer PDU via the Transport Layer. The Transport Layer sends and receives the Application Layer PDU transparently by producing and exchanging a Transport Layer Protocol Data Unit (PDU) with its peer at another node. The Transport Layer PDU consists of the Transport Header concatenated with the Application Layer PDU, and is sent and received via lower layer communication layers. The lower communication layers send and receive the Transport PDU transparently over a variety of communications media.
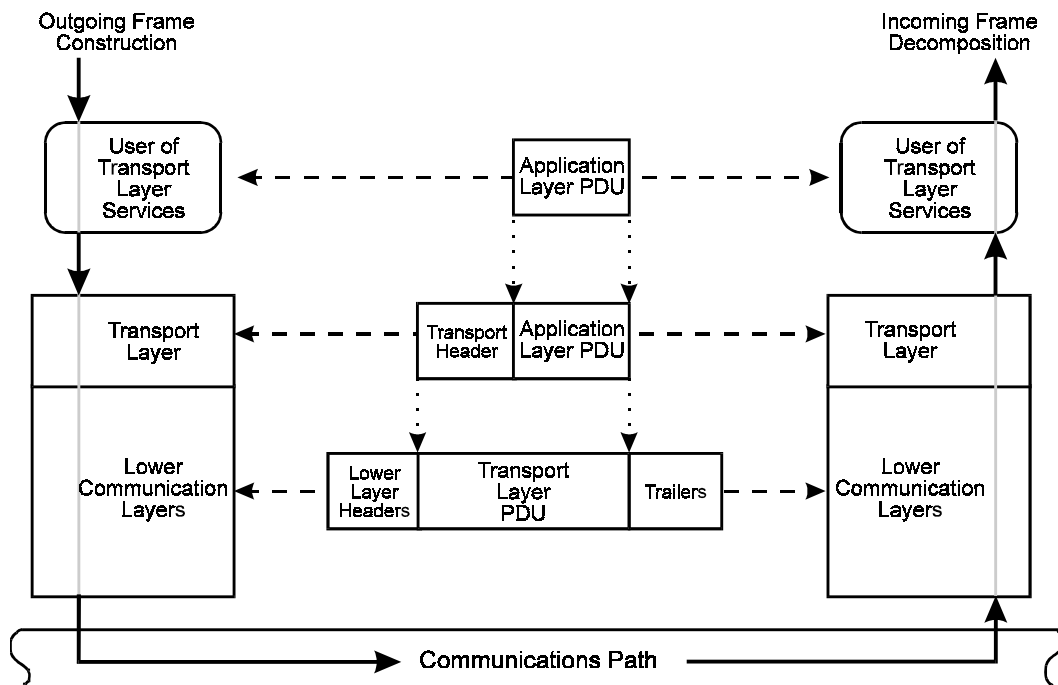
FIGURE G-8. <u>Transport layer interaction with other communication layers</u>.

The relationship of the Transport Layer PDU's data buffer/stream to the Application Layer is depicted in Figure G-9. The Transport Layer PDU is defined as a buffer or stream of octets consisting of the VMF message, Application Header and Transport Header.

G.3.3.1 <u>An example of UDP header construction</u>. UDP is described by RFC 768. The UDP header from RFC 768 consists of 8 octets as shown in Figure G-10 with the example values to be used for this appendix. Since the RFC treats bit 0 as most significant bit (MSB), Figures G-10 and G-11 show B_0 as MSB. For this example, the source has a value of 1581, destination of 1581, length of 30 and the checksum equals 3491. MIL-STD-188-220 typically treats the least significant bit as bit 0.

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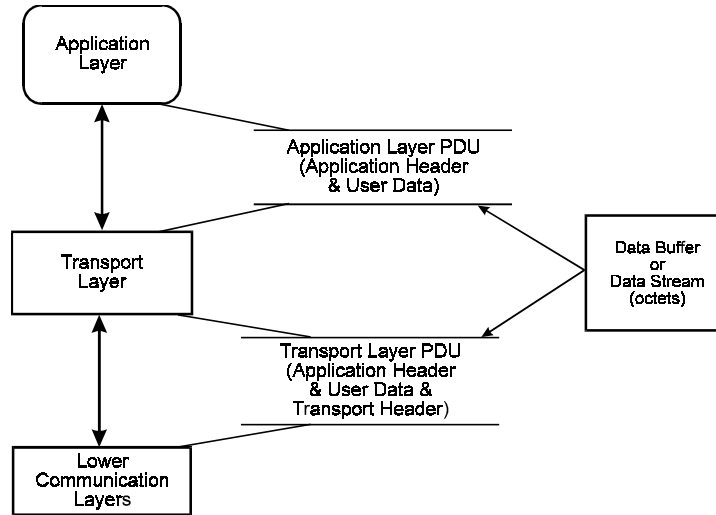
FIGURE G-9. Exchange of transport layer PDU between communication layers.

0　　　　　7	8　　　　15	16　　　23	24　　　31
UDP Source (1581)		UDP Destination (1581)	
UDP Length (30)		UDP Checksum (3491)	

Bit 0 is most significant bit (MSB)

FIGURE G-10. UDP header.

Figure G-11 illustrates the eight octets comprising UDP with the binary bit patterns. Each octet is marked to show both the MSB and LSB of each octet. It demonstrates how each of the octets are arranged and passed in order to next layer.

Octet 0		Octet 1		Octet 2		Octet 3	
B_0	B_7	B_8	B_{15}	B_{16}	B_{23}	B_{24}	B_{31}
2^7	2^0	2^7	2^0	2^7	2^0	2^7	2^0
*0*0000110		00101101		*0*0000110		00101101	
UDP Source (1581)				**UDP Destination (1581)**			

Octet 4		Octet 5		Octet 6		Octet 7	
B_0	B_7	B_8	B_{15}	B_{16}	B_{23}	B_{24}	B_{31}
2^7	2^0	2^7	2^0	2^7	2^0	2^7	2^0
*0*0000000		00011110		*0*0001101		10100011	
UDP Length (30)				**UDP Checksum (3491)**			

FIGURE G-11 Octet representation of UDP header.

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The construction of a Transport Layer Header is illustrated by the example in Table G-4. The first four columns of the table provide a description of each field in both decimal and binary representations. The last two columns show the physical encoding of the Transport Layer PDU. In the fifth column, Field Fragments, the bits of each field are placed in octets. The bits(s) of each field are positioned in an octet such that the LSB of the field is positioned in the least significant unencoded bit of the octet, the next LSB of the field is placed in the Next last significant unencoded bit of the octet, and repeated until all of the bits of the field have been encoded. When an octet is filled before all the bits of a field are encoded, the process is continued encoding the next octet with the remaining bits of the field. This field/octet encoding procedure is performed starting with the first field and octet, and repeated for each successive field and individual octet, in order, until the encoding is completed. The sixth column, Octet Value - Binary, assembles the bits contributed by successive fields into complete octets, represented in binary. The last column, Octet Number, numbers the octets from first to last starting with 0.

TABLE G-4. Example construction of UDP header.

Field Name	Length (bits)	Value (Dec)	Value (Bin)		Field Fragments		Octet Value (Bin)		Octet Number
			MSB 2^{15}	LSB 2^0	MSB 2^7	LSB 2^0	MSB 2^7	LSB 2^0	
UDP Source	16	1581	$0$000011000101101		0 0 0 0 0 1 1 0		0 0 0 0 0 1 1 0		0
					0 0 1 0 1 1 0 1		0 0 1 0 1 1 0 1		1
UDP Destination	16	1581	$0$000011000101101		0 0 0 0 0 1 1 0		0 0 0 0 0 1 1 0		2
					0 0 1 0 1 1 0 1		0 0 1 0 1 1 0 1		3
UDP Length	16	30	$0$000000000011110		0 0 0 0 0 0 0 0		0 0 0 0 0 0 0 0		4
					0 0 0 1 1 1 1 0		0 0 0 1 1 1 1 0		5
UDP Checksum	16	3491	$0$000000010100011		0 0 0 0 1 1 0 1		0 0 0 0 1 1 0 1		6
					1 0 1 0 0 0 1 1		1 0 1 0 0 0 1 1		7

Table G-5 illustrates the eight octets of the Transport Header showing the binary value of the octet, the octet number (0-7) and the field represented by each octet. Note that the bit with the bold italicized font identifies the MSB (2^n) of the field, not the octet.

Figure G-12 provides a serial representation of the UDP header as it would appear at the physical layer.

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TABLE G-5. Octet representation of UDP header.

Octet Value (Binary) 2^7 2^0		Octet Number	Field Name
0 0 0 0 0 1 1 0		0	**Source**
0 0 1 0 1 1 0 1		1	**Source**
0 0 0 0 0 1 1 0		2	**Destination**
0 0 1 0 1 1 0 1		3	**Destination**
0 0 0 0 0 0 0 0		4	**Length**
0 0 0 1 1 1 1 0		5	**Length**
0 0 0 0 1 1 0 1		6	**Checksum**
1 0 1 0 0 0 1 1		7	**Checksum**

Octet 0 2^0 2^7	Octet 1 2^0 2^7	Octet 2 2^0 2^7	Octet 3 2^0 2^7	Octet 4 2^0 2^7	Octet 5 2^0 2^7	Octet 6 2^0 2^7	Octet 7 2^0 2^7
0 1 1 0 0 0 0 *0*	1 0 1 1 0 1 0 0	0 1 1 0 0 0 0 *0*	1 0 1 1 0 1 0 0	0 0 0 0 0 0 0 *0*	0 1 1 1 1 0 0 0	1 0 1 1 0 0 0 *0*	1 1 0 0 0 1 0 1

FIGURE G-12. Serial representation of UDP header.

G.3.4 Network layer data exchange. The relationship of the Network Layer to other communication layers is shown in Figure G-13. A user of the Network Layer exchanges data with its peer at another node by sending and receiving the Transport Layer PDUs via the Network Layer. The Network Layer sends and receives the Transport Layer PDUs transparently by producing and exchanging a Network Layer PDU. The Network Layer PDU consists of the Network Headers concatenated with the Transport Layer PDU, and is sent and received via lower layer communication layers. The lower communication layers send and receive the Network Layer PDU transparently over a variety of communications media.

The relationship of the Network Layer PDU's data buffer/stream to the Transport Layer is depicted in Figure G-14. The Network Layer PDU is defined as a buffer or stream of octets consisting of the VMF message, Application Header, Transport Header and Network Headers. There are two Network Headers in the Network Layer PDU when using MIL-STD-188-220.

The Internet Protocol (IP) is described by RFC 791. The IP header from RFC 791 is shown in Figure G-15 with the example values to be used for this appendix.

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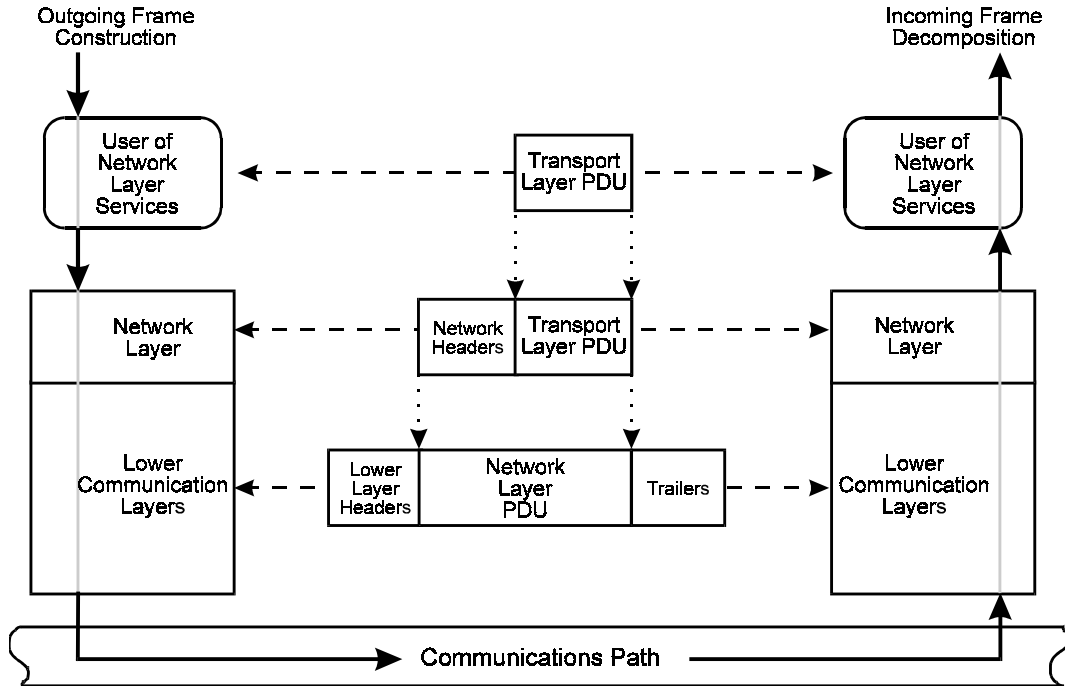
FIGURE G-13. Network layer interaction with other communication layers.
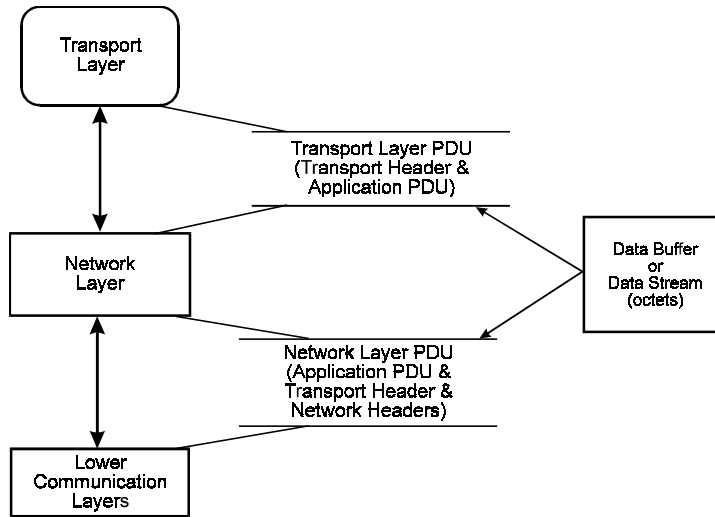
FIGURE G-14. Exchange of network layer PDU between communication layers.

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0			1		2		3
0 1 2 3 4 5 6 7	8 9 0 1 2 3 4 5	6 7 8 9 0 1 2 3	4 5 6 7 8 9 0 1
Ver (4)	IHL (5)	Type of Service (0)	Total Length (50)				
Identification (1)		Flag (0)	Fragment Offset (0)				
Time to Live (50)	Protocol (17)	Header Checksum (4093)					
Source Address (192.31.124.65)							
Destination Address (192.31.124.61)							

FIGURE G-15. IP header.

G.3.4.1 Example of internet layer header. The construction of an Internet Layer Header is illustrated by the example in Table G-6. The first four columns of the table provide a description of each field in the example, the field length in bits, and the value of the field in both decimal and binary representations. The last three columns show the physical encoding of the Internet Layer Header. In the fifth column, Field Fragments, the bits of each field are placed in octets. The bit(s) of each field are positioned in an octet such that the LSB of the field is positioned in the least significant unencoded bit of the octet, the next LSB of the field is placed in the next least significant unencoded bit of the octet, and repeated until all of the bits of the field have been encoded. When an octet is filled before all the bits of a field are encoded, the process is continued encoding the next octet with the remaining bits of the field. This field/octet encoding procedure is performed starting with the first field and octet, and repeated for each successive field and individual octet, in order, until the encoding is completed. X's are used to identify bits that are not associated with the field being encoded. The sixth column, Octet Value - Binary, assembles the bits contributed by successive fields into complete octets, represented in binary. The last column, Octet Number, numbers the octets from first to last starting with 0.

Figure G-16 illustrates the Internet Header demonstrating the relationship between the individual bits (B^0 - B^7), the bit weighting (2^7 - 2^0), the individual fields and the example bit patterns associated with each field.

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TABLE G-6. Example construction of IP header.

Field Name	Length (bits)	Value (Dec)	Value (Bin) 2^n 2^0	Field Fragments 2^n 2^0	Octet Value (Bin) 2^n 2^0	Octet Number
Version	4	4	0100	0100xxxx		
Internet Header Length	4	5	0101	xxxx0101	01000101	0
Type of Service	8	0	00000000	00000000	00000000	1
Length	16	50	0000000000110010	00000000 00110010	00000000 00110010	2 3
Identification	16	111	0000000000000001	00000000 00000001	00000000 00000001	4 5
Flags	3	0	000	000xxxxx		
Fragmentation Offset	13	0	0000000000000	xxx00000 00000000	00000000 00000000	6 7
Time to Live	8	50	00110010	00110010	00110010	8
Protocol	8	17	00010001	00010001	00010001	9
Header Checksum	16	4093	0000111111111101	00001111 11111101	00001111 11111101	10 11
Source Address	32	192.31.124.65	1100000000011111 0111110001000001	11000000 00011111 01111100 01000001	11000000 00011111 01111100 01000001	12 13 14 15
Destination Address	32	192.31.124.61	1100000000011111 0111110000111101	11000000 00011111 01111100 00111101	11000000 00011111 01111100 00111101	16 17 18 19

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Octet 0		Octet 1	Octet 2	Octet 3
B$_0$ B$_7$		B$_0$ B$_7$	B$_0$ B$_7$	B$_0$ B$_7$
2^7 2^0		2^7 2^0	2^7 2^0	2^7 2^0
0 1 0 0 *0* 1 0 1		*0 0* 0 0 0 0 0 0	*0 0* 0 0 0 0 0 0	0 0 1 1 0 0 1 0
Ver (4)	**IHL (5)**	**Type of Service (0)**	**Total Length (50)**	

Octet 4	Octet 5	Octet 6		Octet 7
B$_0$ B$_7$	B$_0$ B$_7$	B$_0$ B$_7$		B$_0$ B$_7$
2^7 2^0	2^7 2^0	2^7 2^0		2^7 2^0
0 0 0 0 0 0 0 0	0 0 0 0 0 0 1	0 0 0	*0* 0 0 0 0	0 0 0 0 0 0 0 0
Identification (1)		**Flag (0)**	**Fragment Offset (0)**	

Octet 8	Octet 9	Octet 10	Octet 11
B$_0$ B$_7$	B$_0$ B$_7$	B$_0$ B$_7$	B$_0$ B$_7$
2^7 2^0	2^7 2^0	2^7 2^0	2^7 2^0
0 0 1 1 0 0 1 0	*0* 0 0 1 0 0 0 1	*0* 0 0 0 1 1 1 1	1 1 1 1 1 1 0 1
Time (50)	**Protocol (17)**	**Header Checksum (4093)**	

Octet 12	Octet 13	Octet 14	Octet 15
B$_0$ B$_7$	B$_0$ B$_7$	B$_0$ B$_7$	B$_0$ B$_7$
2^7 2^0	2^7 2^0	2^7 2^0	2^7 2^0
1 1 0 0 0 0 0 0	0 0 0 1 1 1 1 1	0 1 1 1 1 1 0 0	0 1 0 0 0 0 0 1
Source Address (192.31.124.65)			

Octet 16	Octet 17	Octet 18	Octet 19
B$_0$ B$_7$	B$_0$ B$_7$	B$_0$ B$_7$	B$_0$ B$_7$
2^7 2^0	2^7 2^0	2^7 2^0	2^7 2^0
1 1 0 0 0 0 0 0	0 0 0 1 1 1 1 1	0 1 1 1 1 1 0 0	0 0 1 1 1 1 0 1
Destination Address (192.31.124.61)			

FIGURE G-16. Octet representation of IP header.

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G.3.4.2 <u>Example of intranet layer header</u>. The construction of an Intranet Layer Header is illustrated by the example in Table G-7. The first four columns of the table provide a description of each field in the example, the field length in bits, and the value of the field in both decimal and binary representations. The last three columns show the physical encoding of the Intranet Layer Header. In the fifth column, Field Fragments, the bits of each field are placed in octets. The bit(s) of each field are positioned in an octet such that the LSB of the field is positioned in the least significant unencoded bit of the octet, the next LSB of the field is placed in the next least significant unencoded bit of the octet, and repeated until all of the bits of the field have been encoded. When an octet is filled before all the bits of a field are encoded, the process is continued encoding the next octet with the remaining bits of the field. This field/octet encoding procedure is performed starting with the first field and octet, and repeated for each successive field and individual octet, in order, until the encoding is completed. X's are used to identify bits that are not associated with the field being encoded. The sixth column, Octet Value - Binary, assembles the bits contributed by successive fields into complete octets, represented in binary. The last column, Octet Number, numbers the octets from first to last starting with 0. This example only illustrates the Intranet Header fields that must be transmitted as a minimum.

TABLE G-7. <u>Example construction of Intranet header (minimum)</u>.

Field Name	Length (bits)	Value (Dec)	Value & Byte Representation (Bin) 2^n 2^0	Field Fragments 2^7 2^0	Octet Value (Bin) 2^7 2^0	Octet Number
Version Number	4	0	*0*000	xxxx*0*000		
Message Type	4	4	*0*100	*0*100xxxx	*0*100*0*000	0
Intranet Header Length	8	3	00000011	00000011	00000011	1
Type of Service	8	0	00000000	00000000	00000000	2

The Intranet layer is defined in MIL-STD-188-220 and is shown in Figure G-17 with the example values used in this appendix.

Octet 0		Octet 1	Octet 2
2^0 2^7		2^0 2^7	2^0 2^7
0 0 0 *0*	0 0 1 *0*	1 1 0 0 0 0 0 *0*	0 0 0 0 0 0 0 *0*
Version (0)	**Message Type (4)**	**Intranet Header Length (3)**	**Type of Service (0)**

FIGURE G-17. <u>Intranet header.</u>

Figure G-18 provides a serial representation of the Network Layer PDU as it would appear at the physical layer.

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Intranet header			IP header				
Octet 0	**Octet 1**	**Octet 2**	**Octet 3**	**Octet 4**	**Octet 5**	**Octet 6**	**Octet 7**
2^0 2^7	2^0 2^7	2^0 2^7	2^0 2^7	2^0 2^7	2^0 2^7	2^0 2^7	2^0 2^7
0000001*0*	1100000*0*	0000000*0*	101*000*1*0*	0000000*0*	0000000*0*	01001100	0000000*0*

IP header (continued)							
Octet 8	**Octet 9**	**Octet 10**	**Octet 11**	**Octet 12**	**Octet 13**	**Octet 14**	**Octet 15**
2^0 2^7	2^0 2^7	2^0 2^7	2^0 2^7	2^0 2^7	2^0 2^7	2^0 2^7	2^0 2^7
10000000	0000000*0*	00000000	0100110*0*	1000100*0*	1111000*0*	10111111	0000001*1*

IP header (continued)						IP header (end)
Octet 16	**Octet 17**	**Octet 18**	**Octet 19**	**Octet 20**	**Octet 21**	**Octet 22**
2^0 2^7	2^0 2^7	2^0 2^7	2^0 2^7	2^0 2^7	2^0 2^7	2^0 2^7
11111000	00111110	10000010	0000001*1*	11111000	00111110	10111100

FIGURE G-18. Serial representation of network layer PDU.

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G.3.6 <u>Data link layer data exchange</u>. The relationship of the Data Link Layer to other communication layers is shown in Figure G-19. A user of the Data Link Layer exchanges the Network Layer PDU with its peer at another node by sending and receiving the Network PDU via the Data Link Layer. The Data Link Layer sends and receives the VMF message transparently by producing and exchanging a Data Link Layer PDU with its peer at another node. The Data Link Layer PDU consists of the Transmission Header, and Data Link Frame Header, Network PDU, and the Data Link Frame Trailer, and is sent and received via the Physical layer. The Physical layer sends and receives the VMF message transparently over a variety of communications media.
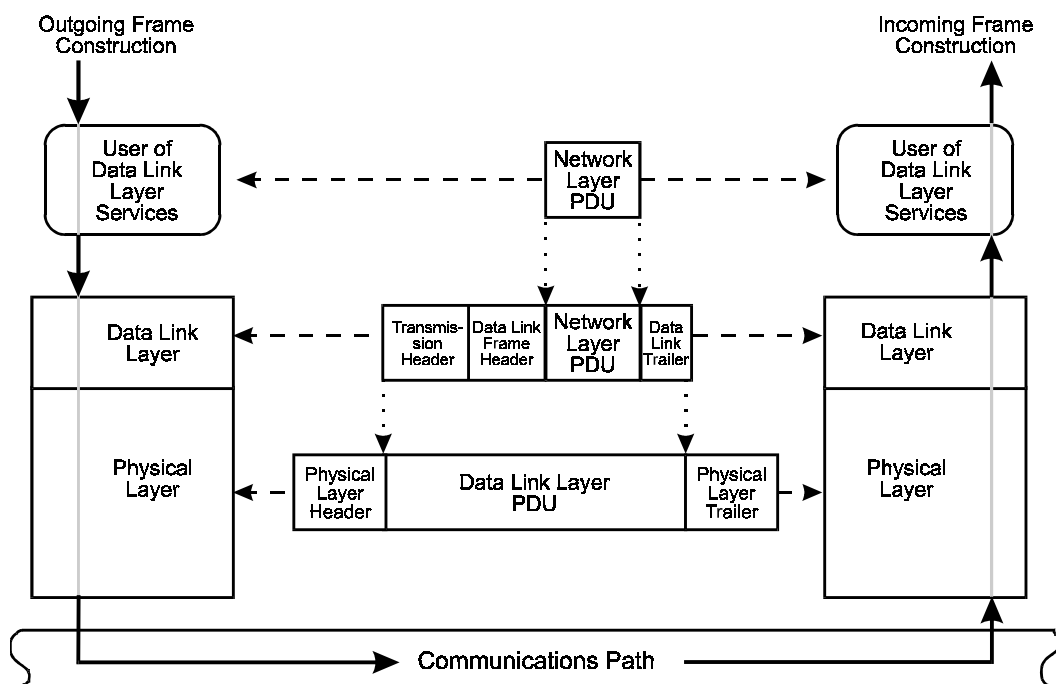
Figure G-19. <u>Data link layer interaction with other communication layers</u>.

The format of the Data Link Layer PDU is defined in terms of the actual data buffer or data stream used to exchange the PDU between the Network Layer and the Physical Layer. The relationship of the Data Link Layer PDU's data buffer/stream to the Intranet Layer is depicted in Figure G-20. The Data Link Layer PDU is defined as a buffer or stream of octets consisting of the Transmission Header, Data Link Frame Header, Network PDU and Data Link Layer trailer.

G.3.6.1 <u>Example of data link layer PDU</u>. The Data Link Layer PDU consists of the Transmission Header, Data Link Frame Header, followed by the information field and Data Link Frame Trailer as shown in Figure G-21. The information field consists of the Network PDU described previously (VMF message, Application Header, Transport Header, IP Header and Intranet Header).

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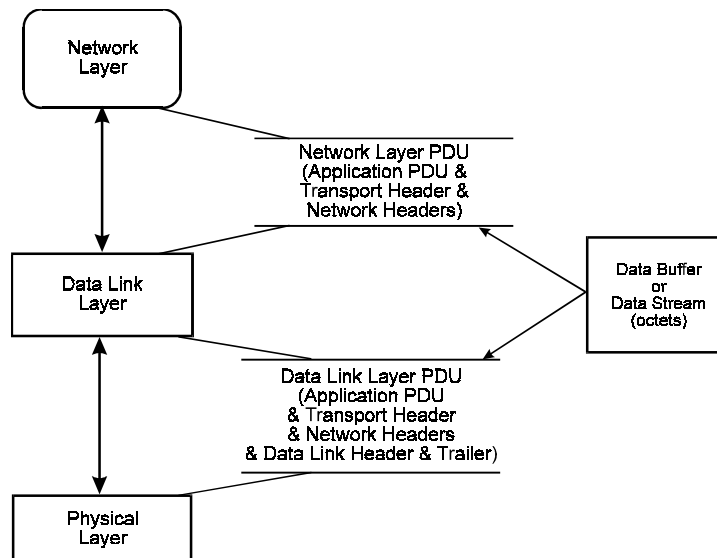
FIGURE G-20. Exchange of data link layer PDU between communication layers.

Trans-mission Header	Data Link Frame Header	Information Field	Data Link Frame Trailer

FIGURE G-21. Data link layer PDU.

Table G-8 illustrates the Data Link Frame Header, and Table G-9 illustrates the Data Link Frame Trailer. The first four columns of the tables provide a description of each field in the example, the field length in bits, and the value of the field in both decimal and binary representations. The last three columns show the physical encoding of the Data Link Frame. In the fifth column, Field Fragments, the bits of each field are placed in octets. The bit(s) of each field are positioned in an octet such that the LSB of the field is positioned in the least significant unencoded bit of the octet, the next LSB of the field is placed in the next least significant unencoded bit of the octet, and repeated until all of the bits of the field have been encoded. When an octet is filled before all the bits of a field are encoded, the process is continued encoding the next octet with the remaining bits of the field. This field/octet encoding procedure is performed starting with the first field and octet, and repeated for each successive field and individual octet, in order, until the encoding is completed. The sixth column, Octet Value - Binary, assembles the bits contributed by successive fields into complete octets, represented in binary. The last column, Octet Number, numbers the octets from first to last starting with 0.

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TABLE G-8. Example construction of data link frame header.

Field Name	Length (bits)	Value (Dec)	Value (Bin)		Field Fragments		Octet Value (Bin)		Octet Number
			2^n	2^0	2^7	2^0	2^7	2^0	
Flag	8	126		01111110		01111110		01111110	0
Command/Response Bit	1	0		0		xxxxxxx0			
Source Address	7	7		0000111		0000111x		00001110	1
Extension Bit	1	1		1		xxxxxxx1			
Destination Address	7	4		0000100		0000100x		00001001	2
Control Field	8	19		00010011		00010011		00010011	3

TABLE G-9. Example construction of data link frame trailer.

Frame Check Sequence (transmitted MSB first)	32	162159487	0000100110101010 0101110101111111		00001001 10101010 01011101 01111111		00001001 10101010 01011101 01111111		0 1 2 3
Flag	8	126	01111110		01111110		01111110		4

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Table G-10 illustrates the octets comprising the Data Link Frame showing the actual bit patterns from the previous examples for each layer, the octet number based on each individual layer, and the octet number based on entire Data Link Frame. This data is shown in serial representation as it would be transmitted in Figure G-22.

TABLE G-10. Octets comprising data link frame.

2^7 2^0	Nomenclature	Octet Number (Individual Layer)	Octet Number (Entire Transaction)
01111110	**Flag**	0	0
00001110	**Source Address**	1	1
00001001	**Destination Address**	2	2
00010011	**Control Field**	3	3
01000000		0	4
00000011	*INTRANET HEADER*	1	5
00000000		2	6
01000101		0	7
00000000		1	8
00000000		2	9
00110010		3	10
00000000		4	11
00000001		5	12
00000000		6	13
•	*IP HEADER*	•	•
•		•	•
01111100		18	25
00111101		19	26
00000110		0	27
00101101		1	28
00000110		2	29
•	*UDP HEADER*	•	•
•		•	•
10100011		7	34

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TABLE G-10. <u>Octets comprising data link frame</u>.

2^7 2^0	Nomenclature	Octet Number (Individual Layer)	Octet Number (Entire Transaction)
1110*0*001		0	35
00001011		1	36
●		●	●
●		●	●
0*1*110000		10	45
0000010*0*		11	46
01*0*1111*1*	*APPLICATION HEADER*	12	47
01000*0*00		13	48
●		●	●
●		●	●
0000*0*100		15	50
*0*0000000		16	51
11*00*1*0*00		0	52
10*1*00000		1	53
111*1*0000		2	54
11000000		3	55
●	*CHECKFIRE MESSAGE*	●	●
●		●	●
00000*0*00		4	56
*0*0001001	**Note: FCS transmitted MSB First**	0	57
10101010	**FCS**	1	58
01011101		2	59
01111111		3	60
*0*1111110	**Flag**	0	61

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DATA LINK FRAME HEADER				INTRANET HEADER			IP	
0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	
2^0　　　2^7	2^0　　　2^7	2^0　　　2^7	2^0　　　2^7	2^0　2^7	2^0　　2^7	2^0　　2^7	2^0　2^7	
FLAG	SRC	DST	CNTL	V	T	LEN	TOS	L	V
01111110	01110000	10010000	11001000	0000	0010	11000000	00000000	1010	0010

IP (cont.)							
8	**9**	**10**	**11**	**12**	**13**	**14**	
2^0　　2^7	2^0　　2^7	2^0　　2^7	2^0　　2^7	2^0　　2^7	2^0　2^7	2^0　2^7	
TOS	Total Length		Identification		Offset	Flag	Offset
00000000	00000000	01001100	00000000	10000000	00000	000	00000000

IP (cont.)		UDP			
25	**26**	**27**	**28**	**29**	**30**
2^0　　2^7	2^0　　2^7	2^0　　2^7	2^0　　2^7	2^0　　2^7	2^0　　2^7
DESTINATION		SOURCE		DESTINATION	
00111110	10111100	01100000	10110100	01100000	10110100

APP. HEADER		
34	**35**	**36**
2^0　　2^7	2^0　　2^7	2^0　　2^7
CHKSM	GPI-FPI-ORIG	
11000101	10000111	11010000

APP. HEADER			
45	**46**	**47**	**48**
2^0　　2^7	2^0　　2^7	2^0　　2^7	2^0　　2^7
Message Size- etc.			GPI-YR
00001110	00100000	11111010	00000010

APP. HEADER		VMF MESSAGE			
50	**51**	**52**	**53**	**54**	**55**
2^0　　2^7	2^0　　2^7	2^0　　2^7	2^0　　2^7	2^0　　2^7	2^0　　2^7
Min/Sec-etc.		CF-etc.	GROUP-etc		
00100000	00000000	00010011	00000101	00001111	00000011

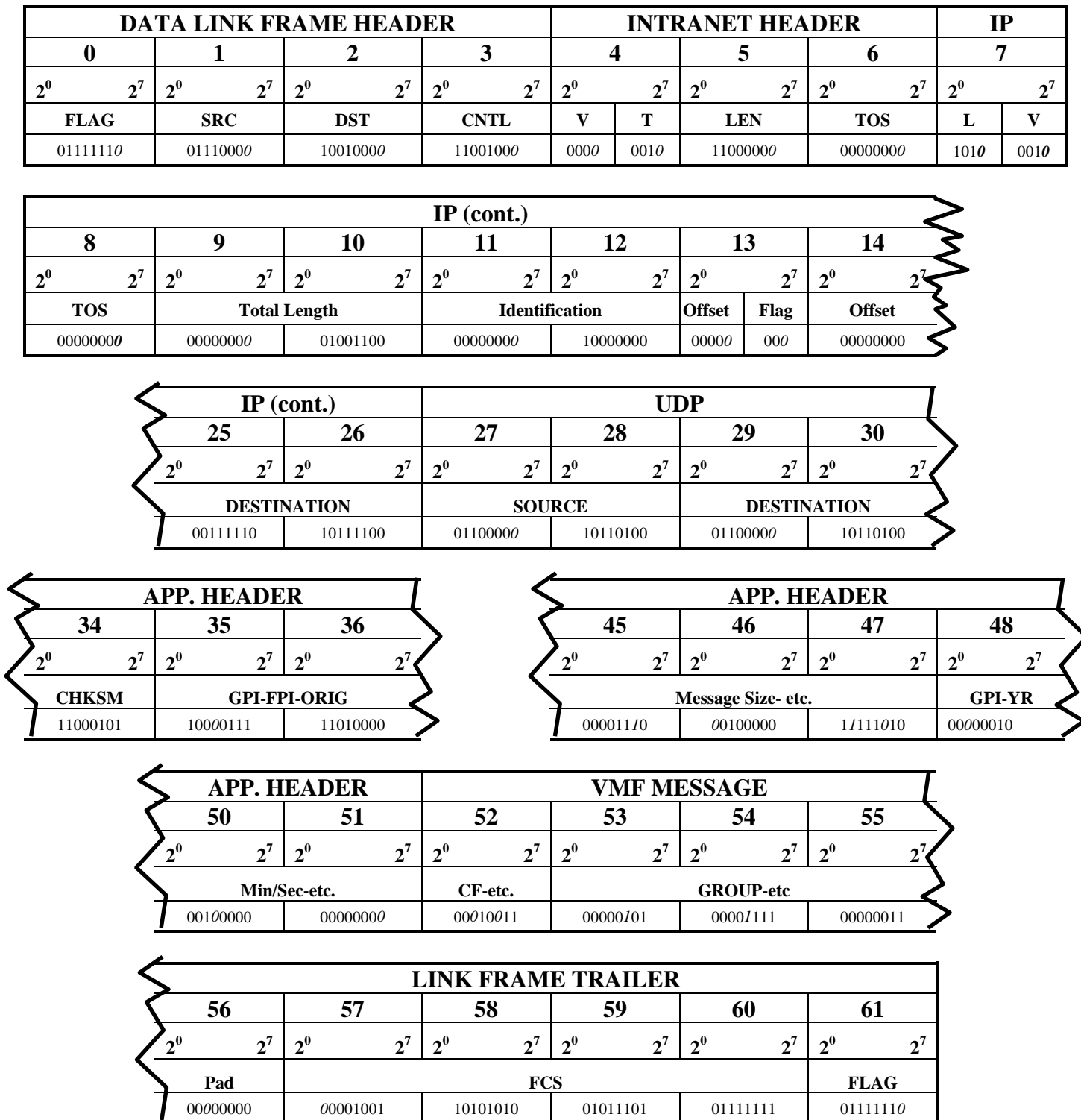| LINK FRAME TRAILER					
56	**57**	**58**	**59**	**60**	**61**
2^0　　2^7	2^0　　2^7	2^0　　2^7	2^0　　2^7	2^0　　2^7	2^0　　2^7
Pad	FCS				FLAG
00000000	00001001	10101010	01011101	01111111	01111110

FIGURE G-22. Serial representation of data link layer PDU.

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G.3.6.1.1 Zero bit insert/v36 scramble/FEC/TDC of the data link frame. The Data Link Frame must be zero inserted to prevent any part of the data accidentally being interpreted as a Frame Flag. Also in our example scrambling, FEC and TDC are being used. Figure G-23 shows some of the example data before applying zero-bit insertion, scrambling, FEC or TDC. After zero-bit insertion, scrambling, FEC and TDC, the fields are not easy to identify; therefore field names are not shown.

1 word				2 word				3 word			
2^0	2^7	2^0	2^7	2^0	2^7	2^0	2^7	2^0	2^7	2^0	2^7
0x7e70				0x90c8				0x02c0			

30 word				31 word				32 word			
2^0	2^7	2^0	2^7	2^0	2^7	2^0	2^7	2^0	2^7	2^0	2^7
0x09aa				0x5d7f				0x7e00			

FIGURE G-23. Data before zero bit insertion in transmission order.

The following is a Hex dump of the data link frame in the different stages: (a) zero-bit inserted, (b) scrambled, (c) FEC, and (d) TDC:

Note: In the following dumps the 16 bit values are in transmission order. The TWC in the physical layer is defined in words and fields are no longer easily distinguishable.

    a. Data after zero bit insertion (505 bits plus 7 padding bits)
        0x7e70 0x90c8 0x02c0 0x00a2 0x0000 0x4c00 0x8000 0x004c 0x88f0 0xbe81 0xf60f
        0x9040 0x7d83 0xe5e3 0x05a3 0x05a0 0x03c5 0x862c 0x3e40 0x0002 0x9f00 0x0002
        0x5200 0x1c41 0xf202 0x0420 0x0013 0x050f 0x0300 0x09aa 0x5d7d 0xbf00

    b. Data after V.36 scrambling (512 bits)
        0x8f80 0x872a 0xa161 0x7a0a 0xbfaa 0x524c 0x50c3 0x50aa 0x024c 0x6cc2 0x9ca9
        0x6b17 0xe9f3 0x0403 0xbda9 0xfe4c 0xfc54 0x3014 0x02e2 0xe3a7 0xb9fa 0xdf90
        0x0006 0x2754 0xf1bf 0x5f20 0x0b70 0xe695 0x59a2 0xfc47 0x616b 0x5d41

    c. Data after FEC(Golay 24,12) (data size in bits: 0x0408 plus 8 padding bits)
        Golay (24,12) is derived from Golay (23,12): See paragraph F 4.1 for details.
        0x8f8a 0x5a08 0x7898 0x2aae 0x8616 0x140a 0x7a0b 0xf0ab 0xf3e8 0xaa54 0x7624
        0xc5a0 0x50c6 0xde35 0x0622 0xaa06 0x0a24 0xc5a0 0x6cc0 0x4029 0xc884 0xa960
        0x08b1 0x7c8c 0xe9f3 0x1e30 0x424a 0x03b9 0xb8da 0x9dc0 0xfe40 0x8acf 0xc6f6
        0x543d 0xc201 0x49f0 0x02e8 0xa22e 0x3632 0xa7b7 0x3c9f 0xa4d0 0xdf93 0x3e00
        0x0000 0x0622 0x6a75 0x4a8e 0xf1bd 0xe6f5 0xfae8 0x200f 0x68b7 0x0c9a 0xe69b
        0x5e55 0x9a5c 0xa2f3 0x54c4 0x7c94 0x6169 0x9cb5 0xd5ec 0x4105 0x5c00

d. Data after TDC(16,24) (data size in bits: 0x0480)
    0x8623 0x0888 0x2f7f 0x18c1 0xee2e 0x9158 0xbe20 0x8447 0xa59c 0x479f 0x6403
    0x5601 0xe805 0x33f1 0xace0 0x0d10 0x6d95 0x8e88 0x0f50 0xca80 0xd4a3 0x2285
    0xb2e0 0x0000 0x9c38 0x9e09 0xc861 0x5a19 0x9c58 0x0e7b 0x3cfa 0xa539 0xb4b8
    0xcd81 0xa2f2 0xb268 0x3381 0x1670 0xc46b 0xb328 0x3f91 0x5712 0x25ea 0xa578
    0xe82b 0x8429 0xcecb 0x0000 0xdb40 0xcda0 0xfac0 0xd440 0x0000 0x5d40 0x1a00
    0xd4e0 0xce40 0x43c0 0xc380 0xcf40 0xfd80 0xb160 0x6e00 0xaae0 0xd1c0 0xee60
    0xe040 0x1fa0 0x7ce0 0x8fe0 0x9800 0x0000

G.3.6.1.2 Construction of the transmission header. The Transmission Header precedes the data link frame and formatted as defined in Table G-11.

G.3.6.1.3 Zero bit insert/v36 scramble/FEC of the transmission header. The Transmission Header must be zero inserted to prevent any part of the data accidentally being interpreted as a Frame Flag. After zero-bit insertion, the fields are not easy to identify; therefore field names are not shown. The following is a Hex dump of the Transmission Header of zero-bit inserted:

  Transmission Header after zero bit insertion (Size In Bits 0x0040)
  0x7ee0 0x001c 0x2119 0x707e

G.3.6.1.4 Completed data link layer PDU to be passed to the physical layer. The data link layer passes the Data Link Layer PDU to the physical layer. The elements of a Data Link Layer PDU include one transmission header and one or more PDUs. The following complete data link PDU (consisting of transmission header and data link frame) will be passed to the physical layer:

Complete Data Link Layer PDU

a. Transmission Header:
    0x7ee0 0x001c 0x2119 0x707e

b. Data Link Layer Frame (72 16 bit words):
    0x8623 0x0888 0x2f7f 0x18c1 0xee2e 0x9158 0xbe20 0x8447 0xa59c 0x479f 0x6403
    0x5601 0xe805 0x33f1 0xace0 0x0d10 0x6d95 0x8e88 0x0f50 0xca80 0xd4a3 0x2285
    0xb2e0 0x0000 0x9c38 0x9e09 0xc861 0x5a19 0x9c58 0x0e7b 0x3cfa 0xa539 0xb4b8
    0xcd81 0xa2f2 0xb268 0x3381 0x1670 0xc46b 0xb328 0x3f91 0x5712 0x25ea 0xa578
    0xe82b 0x8429 0xcecb 0x0000 0xdb40 0xcda0 0xfac0 0xd440 0x0000 0x5d40 0x1a00
    0xd4e0 0xce40 0x43c0 0xc380 0xcf40 0xfd80 0xb160 0x6e00 0xaae0 0xd1c0 0xee60
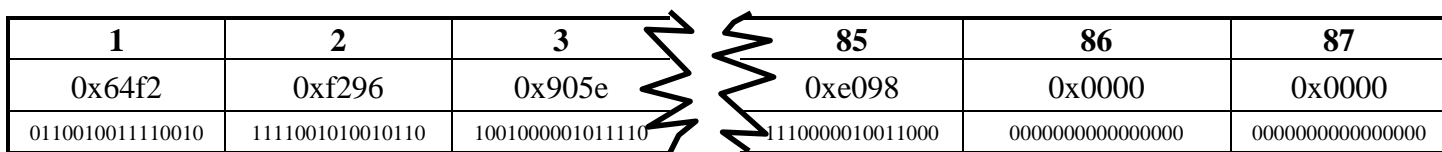   0xe040 0x1fa0 0x7ce0 0x8fe0 0x9800 0x0000

G.3.7 Physical layer data exchange. The relationship of the Physical Layer to other communication layers is shown in Figure G-24. A user of the Physical Layer exchanges the Data Link Layer PDU with its peer at another node by sending and receiving the Data Link PDU via the Physical Layer.

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TABLE G-11. Example construction of data link transmission header.

Field Name	Length (bits)	Value (Dec)	Value (Bin) 2^n $\qquad$ 2^0	Field Fragments 2^7 $\quad$ 2^0	Octet Value (Bin) 2^7 $\quad$ 2^0	Octet Number
Flag	8	126	01111110	01111110	01111110	0
FEC	1	0	1	xxxxxxx1		
TDC	1	0	1	xxxxxx1x		
Scramble	1	0	1	xxxxx1xx		
Topology Update Id	3	0	000	xx000xxx		
Transmit Queue	10	0	0000000000	00xxxxxx	00000111	1
				00000000	00000000	2
FCS	32	471931248	0001110000100001	00011100	00011100	3
			0001100101110000	00100001	00100001	4
				00011001	00011001	5
				01110000	01110000	6
Flag	8	126	01111110	01111110	01111110	7

1	2	3	85	86	87
0x64f2	0xf296	0x905e	0xe098	0x0000	0x0000
0110010011110010	1111001010010110	1001000001011110	1110000010011000	0000000000000000	0000000000000000

FIGURE G-24. Serial representation of physical layer transmission unit.

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G.3.7.1 Physical layer processing example. The Physical layer encodes data submitted by the data link layer in a format to meet the physical media's requirements. This example does not address the electrical or mechanical functions normally associated with the physical layer protocols. At the physical layer the transmission header is extracted and the TWC is calculated, the Transmission header is FEC & TDC encoded. Note the other physical layer functions (COMSEC, DMTD, etc) are not shown in this example.

TWC	*Transmission Header*	*Data Link Frame*

G.3.7.1.1 Transmit word count (TWC). TWC is calculated across the data link frame plus the size of the encoded Transmission Header & TWC size (encoded Transmission Header & TWC [10.5 16 bit words]). Therefore this Physical layer PDU's TWC would be calculated as follows:

> TWC = encoded data link frame + encoded Transmission Header and TWC
> TWC = 72 words + 10.5 words (rounded up to nearest word)
> TWC = 83 words

TWC (83)	*Transmission Header*	*Data Link Frame*

> Transmission header including TWC (size in bits: 0x004C)
> 0xca07 0xee00 0x01c2 0x1197 0x07e0

G.3.7.1.2 FEC & TDC of transmission header. The Transmission Header must have FEC & TDC encoding applied. Below is the Transmission Header in the different stages of FEC & TDC:

a. Transmission header/with TWC after FEC (Golay 24,12) (size in bits: 0x00a8)
    Golay (24,12) is derived form Golay (23,12): See paragraph F 4.1 for details.
    0xca0f 0x587e 0xe806 0x0000 0x001c 0x20c8 0x1191 0xfe70 0x75a4 0xe005 0x2600

b. Transmission header/with TWC after TDC (7,24) (size in bits: 0x00a8)
    0x838d 0x1aed 0x0a30 0x0448 0x8950 0x6c10 0xe047 0x1d30 0x3c49 0x89d2 0x8000

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G.3.7.1.3 <u>The Physical layer PDU</u>. Complete message including 64-bit frame synchronization, TWC, transmission header, and data link frame. (size in bits: 0x0568):

```
0x64f2 0xf296 0x905e 0xadd9 0x838d 0x1aed 0x0a30 0x0448
0x8950 0x6c10 0xe047 0x1d30 0x3c49 0x89d2 0x8086 0x2308
0x882f 0x7f18 0xc1ee 0x2e91 0x58be 0x2084 0x47a5 0x9c47
0x9f64 0x0356 0x01e8 0x0533 0xf1ac 0xe00d 0x106d 0x958e
0x880f 0x50ca 0x80d4 0xa322 0x85b2 0xe000 0x009c 0x389e
0x09c8 0x615a 0x199c 0x580e 0x7b3c 0xfaa5 0x39b4 0xb8cd
0x81a2 0xf2b2 0x6833 0x8116 0x70c4 0x6bb3 0x283f 0x9157
0x1225 0xeaa5 0x78e8 0x2b84 0x29ce 0xcb00 0x00db 0x40cd
0xa0fa 0xc0d4 0x4000 0x005d 0x401a 0x00d4 0xe0ce 0x4043
0xc0c3 0x80cf 0x40fd 0x80b1 0x606e 0x00aa 0xe0d1 0xc0ee
0x60e0 0x401f 0xa07c 0xe08f 0xe098 0x0000 0x0000
```

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APPENDIX H

INTRANET TOPOLOGY UPDATE

H.1. General.

H.1.1. Scope. This appendix describes a procedure for active intranet topology updates. The intranet is defined as all processors and CNRs within a single transmission channel.

H.1.2. Application. This appendix is a mandatory part of MIL-STD-188-220. The information contained herein is intended for compliance.

H.2. Applicable Documents. This section is not applicable to this appendix.

H.3. Problem overview. Figure H-1 shows a sample extended CNR network. Each node labeled A through H is considered to be a radio with an associated communication processor. The dotted ovals indicate subsets of connectivity. Figure H-2 is a link diagram of the sample network. Assuming the nodes know nothing about neighbor nodes that are more than 1 hop away, they need to exchange connectivity information. The topology update packet is used to exchange topology information to build up a more complete view of the intranet's topology at every node.
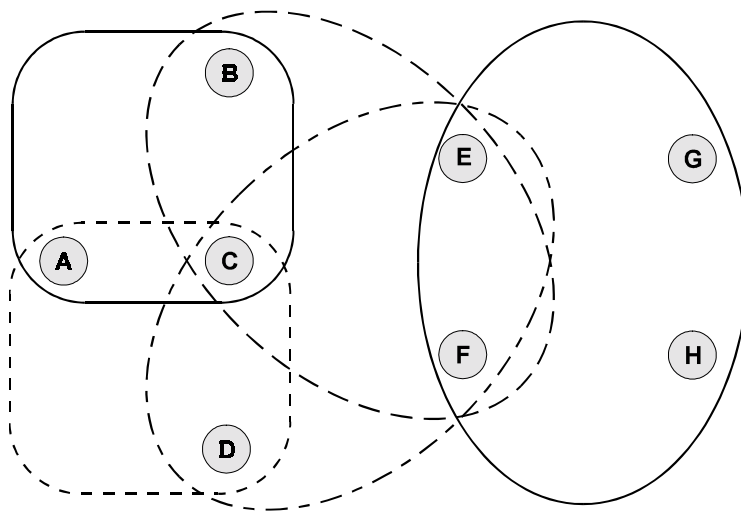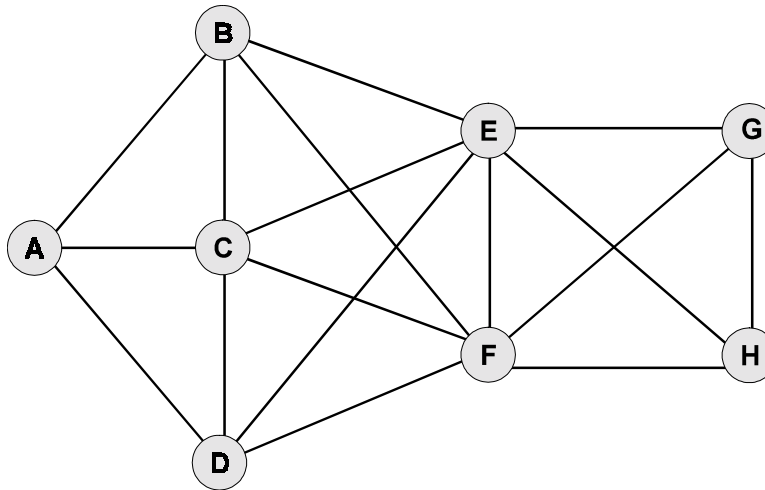
FIGURE H-1. Sample intranet.

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FIGURE H-2. Link diagram of sample network.

H.3.1. Routing trees. Each node should store topology information as a routing tree graph. Considering the network in Figure H-2, Figure H-3 shows the routing tree for nodes A and C prior to the exchange of any topology information. The routing trees for A and C contain only their nearest neighbors - those nodes which they can talk to directly. Similar graphs would exist for all other nodes.
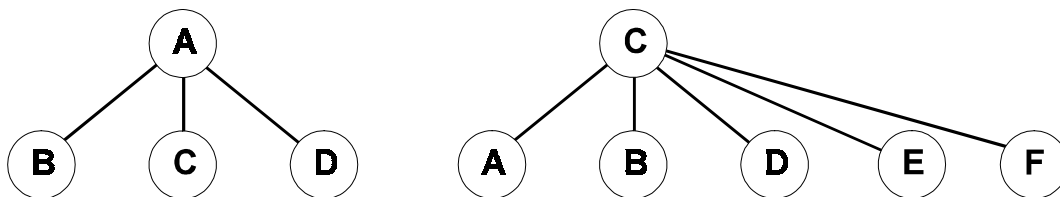
FIGURE H-3. Routing tree for nodes A and C.

H.4. Topology updates.

H.4.1. Exchanging routing trees. Nodes in the network gain more topology information by multicasting their individual routing trees to their nearest neighbor nodes. This exchange of routing trees will percolate more complete topology information through the network. For example, assume the routing trees for all nodes in Figure H-2 initially contain only nearest neighbors (nodes who are in direct communication with the given node). If node C multicasts its topology information to all nodes one hop away (those which are nearest neighbors), all neighbor nodes integrate C's routing tree into their own. Node A would integrate the graph for Node C into its routing tree as shown in Figure H-4.

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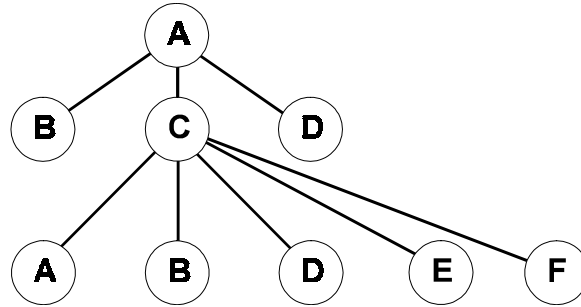
FIGURE H-4. Concatenated routing tree for node A.

Before the routing tree is saved, Node A prunes any successive instances of itself. For instance, in Figure H-4, the link from A to C is the same as the link from C to A; therefore, the link from C to A is removed. All redundant identical links are also pruned. These are links with the order of the end points reversed.

H.4.2. Topology tables. The topology table for A is shown in Table H-1. It assumes no nodes are in quiet mode, all nodes can participate in relay, and all links have a cost of 1. The actual link layer addresses for the nodes would be placed into the table in place of the symbols A, B, C, etc. The extension bit in the address octet would always be set to 0 for topology updates.

TABLE H-1. Topology table for node A.

Node Address	Node Predecessor	Hops	Cost	NR	Quiet
B	A	1	1	0	0
C	A	1	1	0	0
D	A	1	1	0	0
B	C	2	1	0	0
D	C	2	1	0	0
E	C	2	1	0	0
F	C	2	1	0	0

There are two entries for node B indicating that there are two paths from A to B. This table could be immediately copied to the respective fields of a topology update packet. The predecessor address is not included in the topology update packet for nearest neighbor nodes because the predecessor is, by definition, the originator node.

H.4.3. Sparse routing trees. Exchanging full routing tree tables provides full topology information; however, the amount of data in the routing tree gets very large, especially for fully connected nets. The number of links in a fully connected net with n nodes is n(n-1)/2. Although

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full routing trees should be stored by a node, exchanging these routing trees may consume too much bandwidth. A smaller copy of the full routing tree (called a sparse routing tree) should be prepared for transmission to neighbor nodes. To reduce the number of branches in the routing tree, some of the paths to duplicate nodes on the tree are pruned according to following rules:

      a.   Only the shortest paths from the root node to another node are retained.

      b.   For redundant paths from a root node to another node which are the same length (same number of links in the routing tree), at most 2 are retained. Some redundancy in paths is necessary for volatile networks.

For the previous example, the path from C to B and C to D would be pruned, since there are already shorter paths from A to C and A to D. The pruning yields the sparse routing tree in Figure H-5 and Table H-2.
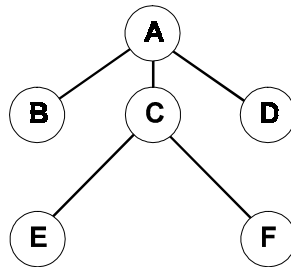

FIGURE H-5. Sparse routing tree for node A.

TABLE H-2. Sparse routing tree for node A.

Node Address	Node Predecessor	Hops	Cost	NR	Quiet
B	A	1	1	0	0
C	A	1	1	0	0
D	A	1	1	0	0
E	C	2	1	0	0
F	C	2	1	0	0

The final routing tree for Node A, after all the nodes exchange their sparse routing trees, is shown in Figure H-6 and Table H-3. Note that figure H-6 shows more than 2 paths between nodes G and A and H and A; however, the sparse routing tree table, which is the information actually transmitted, shows only two entries for nodes G and H. The pruning rules stated above have not been violated. They have been applied to the entries in the sparse routing table. The sparse routing graph is deduced from the table. Thus, quite a few redundant paths can be derived from the structure of the sparse routing table.
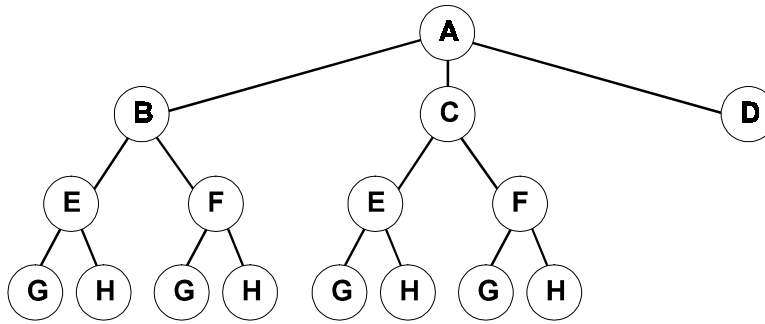
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FIGURE H-6. Final routing tree for node A.

TABLE H-3. Final routing tree for node A.

Node Address	Node Predecessor	Hops	Cost	NR	Quiet
B	A	1	1	0	0
C	A	1	1	0	0
D	A	1	1	0	0
E	B	2	1	0	0
F	B	2	1	0	0
E	C	2	1	0	0
F	C	2	1	0	0
G	E	3	1	0	0
H	E	3	1	0	0
G	F	3	1	0	0
H	F	3	1	0	0

H.4.4. Rules for exchanging topology updates. Topology update packets are transmitted exclusively using a global multicast address.

H.4.4.1. Topology update triggers. Topology updates are triggered for node I by the following:

a. Node I detects a failed link and the link is to a node that is not a static node (link quality =7)

b. Node I detects a new or recovered link and the link is to a node that is not a static node (link quality =7)

c. Node I detects a change in the quality of a link - applicable only if link costs are used.

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d.   Node I receives a topology update from another node which modifies its sparse routing tree.

e.   Node I changes its Quiet Mode status and wishes to announce this change.

f.   Node I changes its relay capability status.

g.   Node I receives a topology update request.

H.4.4.2. <u>Sending topology update messages</u>. Optimally, topology updates should be concatenated with other traffic for queuing by the link layer. Topology Update Messages are sent to the global multicast address using Type 1 Unnumbered Information Frames which are not acknowledged. The precedence of the Topology Update Message is user configurable.

The updates should be transmitted no more often than once every MIN_UPDATE_PER. MIN_UPDATE_PER is measured in minutes and is set by the network administrator when the nodes are configured. The network administrator can disable topology update transmission by setting MIN_UPDATE_PER to zero. Update packets are superseded by newer packets if they have not been queued at the link layer.

H.4.5. <u>Non-relayers</u>. In the Topology Update broadcast by non-relayers, the non-relayer indicates its status by setting the NR bit to one in its entry of the Topology Update message. Additionally, the non-relayer includes all one-hop, and only one-hop, neighbors (because relaying by this node is not permitted). Non-relayer nodes remain in the sparse routing trees; however, they must not have any subsequent branches. Their entries in the routing table must have the NR bit set to 1.

H.4.6. <u>Quiet nodes</u>. Nodes in the quiet state may appear in the sparse routing tables and in update packets with the QUIET bit set to 1; however, they must not have any subsequent branches in the routing tree. Nodes wishing to announce that they are entering quiet mode must add a separate entry into the sparse routing table and update packets with NODE ADDRESS and NODE PREDECESSOR set to their own address and the QUIET bit set to 1.

H.4.7. <u>Topology update request messages.</u> The Topology Update Request Message is triggered whenever there is a mismatch between the topology update ID received from a station and the value that had been stored previously. The Topology Update Request message may also be sent whenever a data link transmission is detected from a previously unknown neighbor. The Topology Update Request message uses a Type 1 Unnumbered Information frame which is not acknowledged and is addressed according to paragraphs 5.4.1.1.7, 5.4.1.1.9, and 5.4.1.3. The Topology Update Request message is addressed to specific stations at the Intranet layer and may be sent to the global multicast address at the data link layer. The precedence of the Topology Update Request Message is user-configurable. The Topology Update Request Message may be sent no more often than MIN_UPDATE_PER/2. This constant allows up to two requests to be sent to a node while the node is waiting for the MIN_UPDATE_PER timer to expire.

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APPENDIX I

SOURCE DIRECTED RELAY

I.1. General.

I.1.1 Scope. This appendix describes a procedure for relaying packets across a CNR intranet using source directed routes. The intranet is defined as all processors and CNRs within a single transmission channel.

I.1.2 Application. This appendix is a mandatory part of MIL-STD-188-220. The information contained herein is intended for compliance.

I.2. Applicable Documents. None.

I.3. Problem overview. Intranet relaying is required when nodes in an intranet need to communicate, but are not nearest neighbors capable of hearing one another's radio transmissions.

I.4. Procedure.

I.4.1 Forward routing. Source Directed Relay provides a simple non-dynamic procedure for relaying a packet from an originator to one or more destinations. The source must calculate the path through the intranet network to reach each destination. These paths are based on the topology and connectivity table. The specific source directed route for each destination must be encoded into the intranet header. If the routes for two or more destinations share common links along the paths, the two paths should be merged together. As a result of this, the resulting paths should not have any common nodes.

The address of successive relayers, destinations, and their associated status bytes are placed in the intranet header in order of progressing through the routing tree. Nodes which are one hop away and destinations only are placed into the Intranet Header first with their DES bit set to 1. The next entries into the Intranet Header are the relay paths which may include nodes which are relayers and destinations. Each relay path starting at the source is completed before another relay path with its origin at the source is begun. Within the status byte for each relayer the REL bit is set to 1 and S/D is set to 0. If the relayer is also a destination in addition to being a relayer, the DES bit is set to 1. If there are multiple destinations that are not relayers following a relayer, each of these destination addresses and their status bytes should be listed in the header after the relay node sequentially in the order of their appearance in the path. Within this group the extension bit within the destination/relay address field is not used. The last address can be determined from the Intranet header length. The last address in a group can be determined from the DIS field of the Destination/Relay Status Byte defined in 5.4.1.1.7.

All destinations in the relay path that are required to provide end-to-end intranet acknowledgments have set the ACK bit in their status bytes to 1. For all destinations, the

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DISTANCE field is set to the number of hops between the originator and the ultimate destination host for the relay.

I.4.2 <u>End-to-end acknowledgments</u>. End-to-end Acknowledgments are formed by the *i*th final destination nodes upon receipt of an intranet header with **ACK** bit set in **DESTINATION STATUS BYTE** for the *i*th destination. The **MESSAGE ID** for the packet to be acknowledged is retained. The message type is set to 1. The path between the originator node and the *i*th destination is reversed. All intermediate destinations are removed. The path will contain one originator, one destination, and the relayers. The **DES** bit in the status bytes for all relayers is set to 0, indicating they perform relay only. No data is carried with an end-to-end acknowledgment packet; just the intranet header.

I.5. <u>Examples</u>. To illustrate Source Directed Relay procedures consider the sample network link diagram in Figure I-1 and final routing tree in Figure I-2. Table I-1 gives specific addresses for the nodes labeled A, B, C, D, E, F, G and H. To maintain consistency with other sections of MIL-STD-188-220, the least significant bit (LSB) is presented to the left of the figures in this appendix.
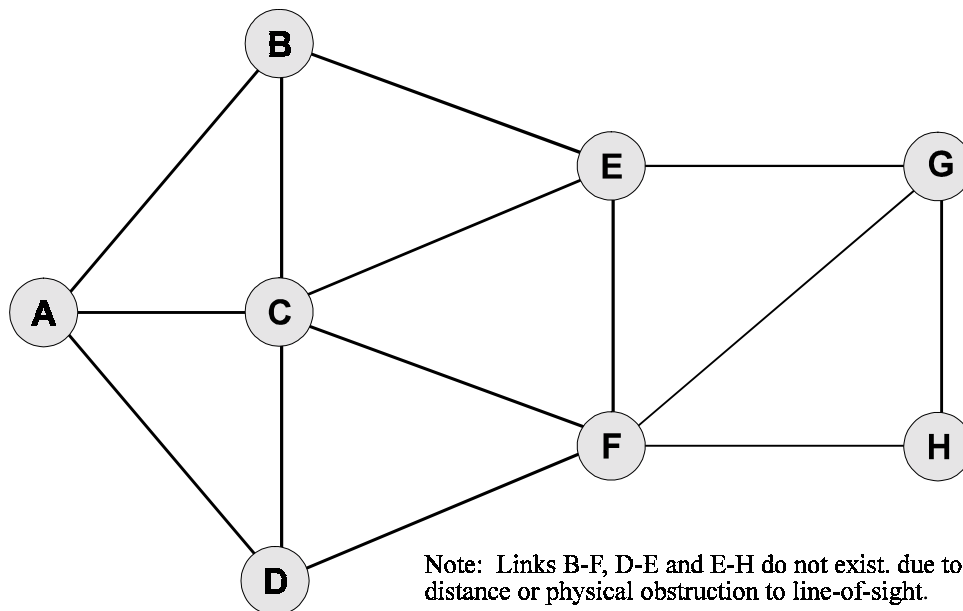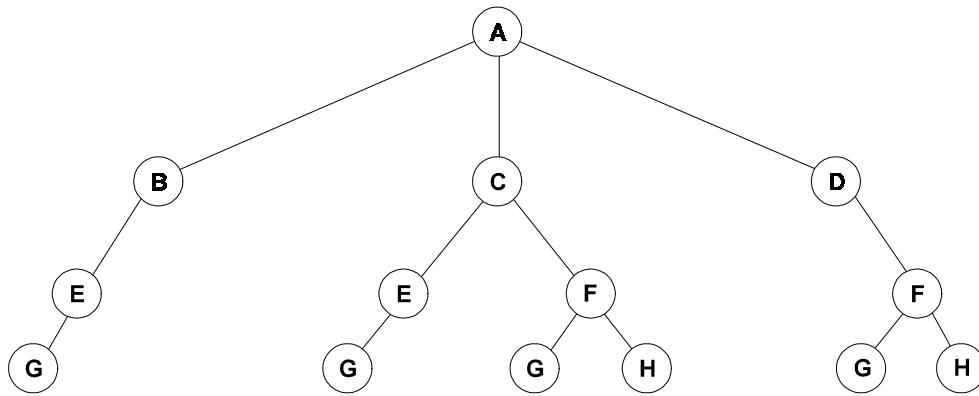

Note: Links B-F, D-E and E-H do not exist. due to distance or physical obstruction to line-of-sight.

FIGURE I-1. <u>Link diagram of a sample network</u>.

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FIGURE I-2. Final routing tree for node A.

TABLE I-1. Sample node addresses

Node	LSB							MSB	Address
A	x	1	1	1	1	0	0	0	15
B	x	0	0	1	0	0	0	0	4
C	x	1	0	1	0	0	0	0	5
D	x	0	1	1	0	0	0	0	6
E	x	1	1	1	0	0	0	0	7
F	x	0	0	0	1	0	0	0	8
G	x	1	0	0	1	0	0	0	9
H	x	0	1	0	1	0	0	0	10

I.5.1. Example 1. Assume that node A has a packet bound for node G alone. Node A's Sparse Routing Tree provides the following potential paths to Node G: A-B-E-G, A-C-E-G, A-C-F-G and A-D-F-G. Assuming that all paths have the same quality and cost, any path may be selected by Node A. In this example, path A-B-E-G is selected.

The following values are assigned to the Intranet Header in example 1:

    MESSAGE TYPE = 4 (IP Packet)
    TYPE_OF_SERVICE = 00000000
    MESSAGE ID = 1
    MAX_HOP_COUNT = 3 (Distance from node A to node G)
    ORIGINATOR ADDRESS = 15 (node A)
    STATUS BYTE 1 = 10010000 (DIS=1, REL=Yes, DES=No, ACK=No)
    DESTINATION 1 = 4 (node B)
    STATUS BYTE 2 = 01010000 (DIS=2, REL=Yes, DES=No, ACK=No)
    DESTINATION 2 = 7 (node E)

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STATUS BYTE 3 = 11000010 (DIS=3, REL=No, DES=Yes, ACK=No)
DESTINATION 3 = 9 (node G)
HEADER LENGTH = 12 octets

Figure I-3 shows the complete Intranet Header for example 1. Note that the LSB in all destination addresses is 0 except for the last destination address (node G).

LSB	1	2	3	4	5	6	7 MSB
VERSION NUMBER				MESSAGE TYPE			
0	0	0	0	0	0	1	0
INTRANET HEADER LENGTH							
0	0	1	1	0	0	0	0
TYPE OF SERVICE							
0	0	0	0	0	0	0	0
MESSAGE IDENTIFICATION NUMBER							
1	0	0	0	0	0	0	0
MAX HOP COUNT				SPARE			
1	1	0	0	0	0	0	0
ORIGINATOR ADDRESS							
0	1	1	1	1	0	0	0
DESTINATION/RELAY STATUS BYTE 1							
1	0	0	1	0	0	0	0
DESTINATION/RELAY ADDRESS 1							
0	0	0	1	0	0	0	0
DESTINATION/RELAY STATUS BYTE 2							
0	1	0	1	0	0	0	0
DESTINATION/RELAY ADDRESS 2							
0	1	1	1	0	0	0	0
DESTINATION/RELAY STATUS BYTE 3							
1	1	0	0	0	0	1	0
DESTINATION/RELAY ADDRESS 3							
1	1	0	0	1	0	0	0

FIGURE I-3. Example 1 Intranet header.

I.5.2. Example 2. Assume that node A has a packet bound for nodes G and H. Node A's Sparse Routing Tree provides the following potential paths to nodes G and H: A-B-E-G, A-C-E-G, A-C-F-G, A-C-F-H, A-D-F-G, and A-D-F-H. Of these potential paths, the most economical choices are those that use node F for relaying: A-C-F-G, A-D-F-G, A-C-F-H, and A-D-F-H. Although paths A-B-E-G and A-C-E-G are viable paths to node G, they would unnecessarily increase processing at nodes B and E, and would increase the size of the Intranet Header in this example. In this example the selected paths are A-C-F-G and A-C-F-H.

The following values are assigned to the Intranet Header in example 2:

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MESSAGE TYPE = 4 (IP Packet)
TYPE_OF_SERVICE = 00000000
MESSAGE ID = 2
MAX_HOP_COUNT = 3 (Distance from node A to nodes G and H)
ORIGINATOR ADDRESS = 15 (node A)
STATUS BYTE 1 = 10010000 (DIS=1, REL=Yes, DES=No, ACK=No)
DESTINATION 1 = 4 (node C)
STATUS BYTE 2 = 01010000 (DIS=2, REL=Yes, DES=No, ACK=No)
DESTINATION 2 = 8 (node F)
STATUS BYTE 3 = 11000010 (DIS=3, REL=No, DES=Yes, ACK=No)
DESTINATION 3 = 9 (node G)
STATUS BYTE 4 = 11000010 (DIS=3, REL=No, DES=Yes, ACK=No)
DESTINATION 4 = 10 (node H)
HEADER LENGTH = 14 octets

Figure I-4 shows the complete Intranet Header for example 2. Note that the LSB in all destination addresses is 0 except for the last destination address (node H).

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0 *LSB*	*1*	*2*	*3*	*4*	*5*	*6*	*7* *MSB*
VERSION NUMBER				MESSAGE TYPE			
0	0	0	0	0	0	1	0
INTRANET HEADER LENGTH							
0	1	1	1	0	0	0	0
TYPE OF SERVICE							
0	0	0	0	0	0	0	0
MESSAGE IDENTIFICATION NUMBER							
0	1	0	0	0	0	0	0
MAX HOP COUNT				SPARE			
1	1	0	0	0	0	0	0
ORIGINATOR ADDRESS							
0	1	1	1	1	0	0	0
DESTINATION/RELAY STATUS BYTE 1							
1	0	0	1	0	0	0	0
DESTINATION/RELAY ADDRESS 1							
0	0	0	1	0	0	0	0
DESTINATION/RELAY STATUS BYTE 2							
0	1	0	1	0	0	0	0
DESTINATION/RELAY ADDRESS 2							
0	0	0	0	1	0	0	0
DESTINATION/RELAY STATUS BYTE 3							
1	1	0	0	0	0	1	0
DESTINATION/RELAY ADDRESS 3							
0	1	0	0	1	0	0	0
DESTINATION/RELAY STATUS BYTE 4							
1	1	0	0	0	0	1	0
DESTINATION/RELAY ADDRESS 4							
1	0	1	0	1	0	0	0

FIGURE I-4. Example 2 Intranet header.

I.5.3. Example 3. In the third example, node A wishes to deliver a packet to nodes D, E, F, G and H. In this case node A again would select the most economical path to each destination, taking into consideration the impacts on network traffic and Intranet header size. Table I-2 lists the potential and selected paths from node A to each of the intended destinations.

A similar process would be used to select economical paths to relay nodes, such as node C. The shortest path to the most distant nodes G and H are reviewed to determine whether the relay nodes C and F are also destinations. Note that node F is both a destination and a relay while node C is a relay node only.

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Destination Node	Potential Paths	Selected Path
D	A-D	A-D
E	A-B-E A-C-E	A-C-E
F	A-C-F A-D-F	A-C-F
G	A-B-E-G A-C-E-G A-C-F-G A-D-F-G	A-C-F-G
H	A-C-F-H A-D-F-H	A-C-F-H

TABLE I-2. Paths used in example 3.

The following values are assigned to the Intranet Header in example 3:

      MESSAGE TYPE = 4 (IP Packet)
      TYPE_OF_SERVICE = 00000000
      MESSAGE ID = 3
      MAX_HOP_COUNT = 3 (Distance from node A to nodes G and H)
      ORIGINATOR ADDRESS = 15 (node A)
      STATUS BYTE 1 = 10000010 (DIS=1, REL=No, DES=Yes, ACK=No)
      DESTINATION 1 = 6 (node D)
      STATUS BYTE 2 = 10010000 (DIS=1, REL=Yes, DES=No, ACK=No)
      DESTINATION 2 = 5 (node C)
      STATUS BYTE 3 = 01000010 (DIS=2, REL=No, DES=Yes, ACK=No)
      DESTINATION 3 = 7 (node E)
      STATUS BYTE 4 = 01010010 (DIS=2, REL=Yes, DES=Yes, ACK=No)
      DESTINATION 4 = 8 (node F)
      STATUS BYTE 5 = 11000010 (DIS=3, REL=No, DES=Yes, ACK=No)
      DESTINATION 5 = 9 (node G)
      STATUS BYTE 6 = 11000010 (DIS=3, REL=No, DES=Yes, ACK=No)
      DESTINATION 6 = 10 (node H)
      HEADER LENGTH = 18 octets

Figure I-5 shows the complete Intranet Header for example 3. Note that the LSB in all destination addresses is 0 except for the last destination address (node H).

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0 LSB	1	2	3	4	5	6	7 MSB
VERSION NUMBER				MESSAGE TYPE			
0	0	0	0	0	0	1	0
INTRANET HEADER LENGTH							
0	1	0	0	1	0	0	0
TYPE OF SERVICE							
0	0	0	0	0	0	0	0
MESSAGE IDENTIFICATION NUMBER							
1	1	0	0	0	0	0	0
MAX HOP COUNT				SPARE			
1	1	0	0	0	0	0	0
ORIGINATOR ADDRESS							
0	1	1	1	1	0	0	0
DESTINATION/RELAY STATUS BYTE 1							
1	0	0	0	0	0	1	0
DESTINATION/RELAY ADDRESS 1							
0	0	1	1	0	0	0	0
DESTINATION/RELAY STATUS BYTE 2							
1	0	0	1	0	0	0	0
DESTINATION/RELAY ADDRESS 2							
0	1	0	1	0	0	0	0
DESTINATION/RELAY STATUS BYTE 3							
0	1	0	0	0	0	1	0
DESTINATION/RELAY ADDRESS 3							
0	1	1	1	0	0	0	0
DESTINATION/RELAY STATUS BYTE 4							
0	1	0	1	0	0	1	0
DESTINATION/RELAY ADDRESS 4							
0	0	0	0	1	0	0	0
DESTINATION/RELAY STATUS BYTE 5							
1	1	0	0	0	0	1	0
DESTINATION/RELAY ADDRESS 5							
0	1	0	0	1	0	0	0
DESTINATION/RELAY STATUS BYTE 6							
1	1	0	0	0	0	1	0
DESTINATION/RELAY ADDRESS 6							
1	0	1	0	1	0	0	0

FIGURE I-5. Example 3 intranet header created by node A (originator).

I.5.4. Relay processing. Although the separate examples 1,2,3 all have diverse paths, they would all require the same number data link information frames for delivery (one). The UI, I, or DIA frame would be transmitted to each destination simultaneously. Addressed destinations would perform the required data link layer processing described in 5.3 and pass the information field of the frame to the Intranet layer for further processing.

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The Intranet header is scanned for the node's data link layer address. When found, the previous octet - the Destination/Relay Status byte - is inspected. If the Relay bit is not set and the destination bit is set, the data portion following the Intranet header is passed to the next higher protocol layer for further processing. If the Relay bit is set, Relay processing is required. If both the Relay bit and the Destination bit are set, Relay processing is performed before the passing data portion of the frame to the next higher protocol layer for further processing. Relay processing involves the following steps:

a.   Scan forward until the relayer node sees its own address.

b.   Scan toward the end of the header looking for all nodes whose DES bit is set and whose distance is one hop greater than your own. Terminate the scan when a distance less than or equal to your own or the end of the header is found. Save the addresses.

c.   While scanning forward until a hop distance less than or equal to your own is found, find all relay addresses that are one hop away from your address and save these addresses.

d.   Remove all duplicate saved addresses and pass the remaining addresses to the data link layer to form a multi-addressed information frame containing the Intranet header and data.

The following sections discuss the relay processing at each of the downstream relayers in Example 3. There are two options when filling out the Intranet Header Address Field at the relay nodes. The relay nodes may copy the Address Field and place it into the relay packet intact or they may delete the addresses which have no impact on forwarding or return of a network layer acknowledgment. If the implementor chooses to leave the address field intact, the address field in Figure I-5 is used at every relayer. If the implementor chooses to compress the address field to save transmitted bytes, the following paragraphs dictate the method for compression. There is no interoperability problem regardless of which of these two methods are implemented.

I.5.4.1 Relay processing at node C. Node C is a relay node, but not a destination node. Node C is responsible for relaying the information to nodes E, F, G and H. Node C assigns the following values to the Intranet Header in example 3:

        MESSAGE TYPE = 4 (IP Packet)
        TYPE_OF_SERVICE = 00000000
        MESSAGE ID = 3
        MAX_HOP_COUNT = 2 (Original MAX_HOP_COUNT - 1)
        ORIGINATOR ADDRESS = 15 (node A)
        STATUS BYTE 1 = 10010000 (DIS=1, REL=Yes, Des=No, ACK=No)
        DESTINATION 1 = 5 (node C)
        STATUS BYTE 2 = 01000010 (DIS=2, REL=No, DES=Yes, ACK=No)
        DESTINATION 2 = 7 (node E)

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STATUS BYTE 3 = 01010010 (DIS=2, REL=Yes, DES=Yes, ACK=No)
DESTINATION 3 = 8 (node F)
STATUS BYTE 4 = 11000010 (DIS=3, REL=No, DES=Yes, ACK=No)
DESTINATION 4 = 9 (node G)
STATUS BYTE 5 = 11000010 (DIS=3, REL=No, DES=Yes, ACK=No)
DESTINATION 5 = 10 (node H)
HEADER LENGTH = 16 octets

Figure I-6 shows the complete Intranet Header created by Node C.

I.5.4.2. Relay processing at node F. Node F is both a destination and a relayer with relay
responsibilities to nodes G and H. Node F assigns the following values to the Intranet Header in
example 3:

MESSAGE TYPE = 4 (IP Packet)
TYPE_OF_SERVICE = 00000000
MESSAGE ID = 3
MAX_HOP_COUNT = 1 (Received MAX_HOP_COUNT - 1)
ORIGINATOR ADDRESS = 15 (node A)
STATUS BYTE 1 = 10010000 (DIS=1, REL=Yes, DES=No, ACK=No)
DESTINATION 1 = 5 (node C)
STATUS BYTE 2 = 01010010 (DIS=2, REL=Yes, DES=Yes, ACK=No)
STATUS BYTE 2 = 8 (node F)
STATUS BYTE 3 = 11000010 (DIS=3, REL=No, DES=Yes, ACK=No)
DESTINATION 3 = 9 (node G)
STATUS BYTE 4 = 11000010 (DIS=3, REL=No, DES=Yes, ACK=No)
DESTINATION 4 = 10 (node H)
HEADER LENGTH = 14 octets

Figure I-7 shows the complete Intranet Header created by Node F.

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	1	2	3	4	5	6	7
LSB							*MSB*
VERSION NUMBER				MESSAGE TYPE			
0	0	0	0	0	0	1	0
INTRANET HEADER LENGTH							
0	0	0	0	1	0	0	0
TYPE OF SERVICE							
0	0	0	0	0	0	0	0
MESSAGE IDENTIFICATION NUMBER							
1	1	0	0	0	0	0	0
MAX HOP COUNT				SPARE			
0	1	0	0	0	0	0	0
ORIGINATOR ADDRESS							
0	1	1	1	1	0	0	0
DESTINATION/RELAY STATUS BYTE 1							
1	0	0	1	0	0	0	0
DESTINATION/RELAY ADDRESS 1							
0	1	0	1	0	0	0	0
DESTINATION/RELAY STATUS BYTE 2							
0	1	0	0	0	0	1	0
DESTINATION/RELAY ADDRESS 2							
0	1	1	1	0	0	0	0
DESTINATION/RELAY STATUS BYTE 3							
0	1	0	1	0	0	1	0
DESTINATION/RELAY ADDRESS 3							
0	0	0	0	1	0	0	0
DESTINATION/RELAY STATUS BYTE 4							
1	1	0	0	0	0	1	0
DESTINATION/RELAY ADDRESS 4							
0	1	0	0	1	0	0	0
DESTINATION/RELAY STATUS BYTE 5							
1	1	0	0	0	0	1	0
DESTINATION/RELAY ADDRESS 5							
1	0	1	0	1	0	0	0

FIGURE I-6. Example 3 Intranet header for node C (relay node).

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0 *LSB*	*1*	*2*	*3*	*4*	*5*	*6*	*7* *MSB*
VERSION NUMBER				MESSAGE TYPE			
0	0	0	0	0	0	1	0
INTRANET HEADER LENGTH							
0	1	0	1	0	0	0	0
TYPE OF SERVICE							
0	0	0	0	0	0	0	0
MESSAGE IDENTIFICATION NUMBER							
1	1	0	0	0	0	0	0
MAX HOP COUNT				SPARE			
1	0	0	0	0	0	0	0
ORIGINATOR ADDRESS							
0	1	1	1	1	0	0	0
DESTINATION/RELAY STATUS BYTE 1							
1	0	0	1	0	0	0	0
DESTINATION/RELAY ADDRESS 1							
0	1	0	1	0	0	0	0
DESTINATION/RELAY STATUS BYTE 2							
0	1	0	1	0	0	1	0
DESTINATION/RELAY ADDRESS 2							
0	0	0	0	1	0	0	0
DESTINATION/RELAY STATUS BYTE 3							
1	1	0	0	0	0	1	0
DESTINATION/RELAY ADDRESS 3							
0	1	0	0	1	0	0	0
DESTINATION/RELAY STATUS BYTE 4							
1	1	0	0	0	0	1	0
DESTINATION/RELAY ADDRESS 4							
1	0	1	0	1	0	0	0

FIGURE I-7. Example 3 intranet header created by node F (relay and destination nodes).

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APPENDIX J

ROBUST COMMUNICATIONS PROTOCOL

J.1. General.

J.1.1. Scope. This Appendix describes the interoperability and technical requirements for the robust communications protocol for DMTD and interfacing C4I systems (DTEs). This Appendix applies only to HAVEQUICK II compatible systems that require interoperability with radios that do not have data buffering or synchronization capability.

J.1.2 Application. This Appendix is a mandatory part of MIL-STD-188-220. The information contained herein is intended for compliance.

J.2. Applicable Documents. This section is not applicable to this Appendix.

J.3. Introduction. This physical layer protocol provides the additional processing to aid the transfer of secure and non-secure digital data when concatenated with the link processing of the MIL-STD-188-220 protocol. The additional processing of this protocol allows for a higher level protocol with an error correcting capability equal to rate 1/2 Golay to transfer a burst of data containing up to 67,200 data symbols with better than 90% probability of success in a single transmission, this being over an active HAVEQUICK II compatible link with a random bit error rate of 0.1 or less. The second goal of this physical protocol is for the required performance to be achieved entirely in software using current systems with modest processing capability.

J.3.1 Physical protocol components. Three individually selectable processes are used to meet the performance requirement. The first is the application of rate 1/3 convolutional coding to combat high random bit error rates. The second is a provision for data scrambling. Scrambling at the physical layer is implemented simply as the multiplication of the transmit data with a pseudo random bit pattern. The third is a packetizing scheme that allows for the re-transmission of the data that was lost due to an HAVEQUICK II compatible frequency hop. The re-transmission is performed, and data recovered within the data burst and the data interruption is transparent to the higher level protocol. This packetizing scheme has been dubbed the Multi-Dwell protocol because it was formulated to allow a message to be transmitted over multiple HAVEQUICK II compatible hop dwells.

J.3.2 Optional rate 1/3 convolutional coding. The transmitting convolutional encoder generates three output bits for each input information bit. Figure J-1 shows an example of the encoding process for a constraint length (K) of 3. The encoder consists of a shift register equal in length to the constraint length. The data to encode is shifted from left to right one bit at a time. After each shift, three output bits are generated using the G1, G2, and G3 polynomials. The three encoded output bits are generated in the G1, G2, and G3 order. The G2 output shall be inverted to provide some data scrambling capability. The convolutional encoding shift register is initialized to a state of zero when a transmission is requested. The first output bits are generated when the shift register contains the first upper layer bit to transmit, followed by all zeros. Upon detection of the

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robust synchronization pattern, the Viterbi decoder is initialized to make use of the knowledge of the initial encoder shift register state.
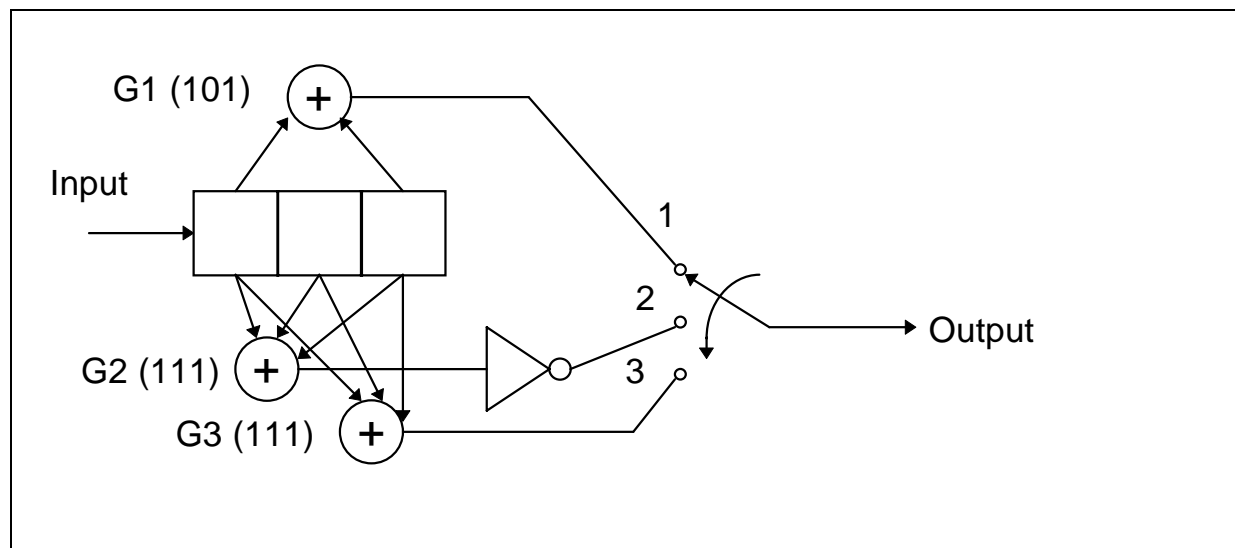

FIGURE J-1. Convolutional encoder with inverted G2 K=3.

Table J-1 lists the generator polynomials used for the three specified constraint lengths. The most significant bits of the octal representation of each polynomial are used for each polynomial.

TABLE J-1. Convolutional coding generator polynomials (octal).

Constraint Length	G1	G2	G3
3	5	7	7
5	52	66	76
7	554	624	764

Figure J-2 shows the relative error correcting capability of rate 1/3 convolutional coding in a random error environment using the Viterbi decoding algorithm with hard decisions. The performance was achieved using a trace back buffer length of 16, 32, and 64 for constraint lengths 3, 5, and 7 respectively. If the demodulator and decoder are components of the same subsystem, soft decision information from the demodulator can be used to further enhance the performance.
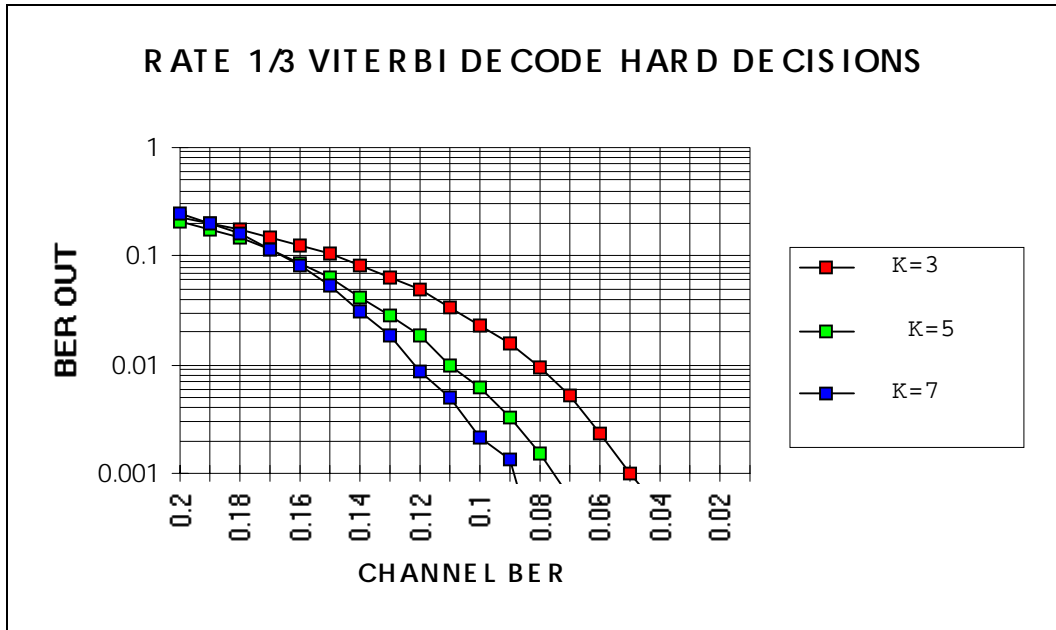
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FIGURE J-2. Rate 1/3 convolutional coding performance for constraint lengths 3, 5, and 7.

J.3.3 Optional data scrambling. Physical layer data scrambling shall use the pseudo random bit generator specified in CCITT V.33 Annex A. The shift register shall be initialized to all zeros before the first bit of data is scrambled on transmission. On data reception, the descrambler shift register shall be initialized to zero before the first received data bit is descrambled. Figure J-3 shows the structure of the data scrambler and descrambler.
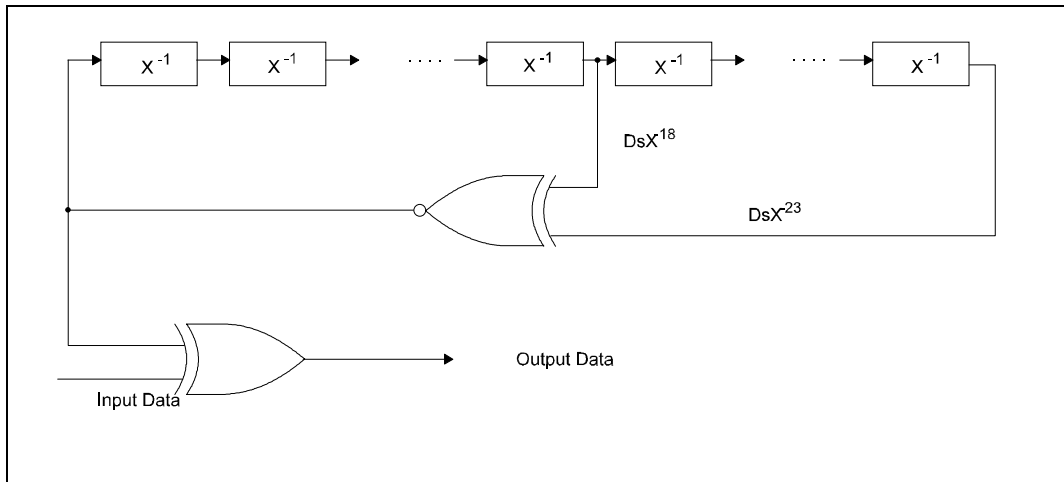
FIGURE J-3. Data scrambler structure.

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J.3.4 Optional robust multi-dwell.

J.3.4.1 Multi-dwell packet format. When the HAVEQUICK II compatible radio is in active mode, multi-dwell packetizing shall be enabled. The multi-dwell packetizing described in this appendix assumes a physical level bit rate of 16 kbps. The format of each multi-dwell packet is shown in Figure J-4. Each packet consists of a start of packet (SOP) pattern and a segment counter followed by 6, 11 or 13 64-bit data segments.

J.3.4.2 Multi-dwell SOP field. The SOP pattern is a 32-bit (Figure J-5) or 64-bit (Figure J-6) pattern used for multi-dwell packet detection. The maximum number of bits in error should be set to match the bit error rate environment. For normal operation, it is recommended that the maximum number of bits in error be set to 13 for a 64-bit pattern, and to 3 for a 32-bit pattern. The length of the SOP pattern shall be determined by bits two, three and four of the robust frame format.
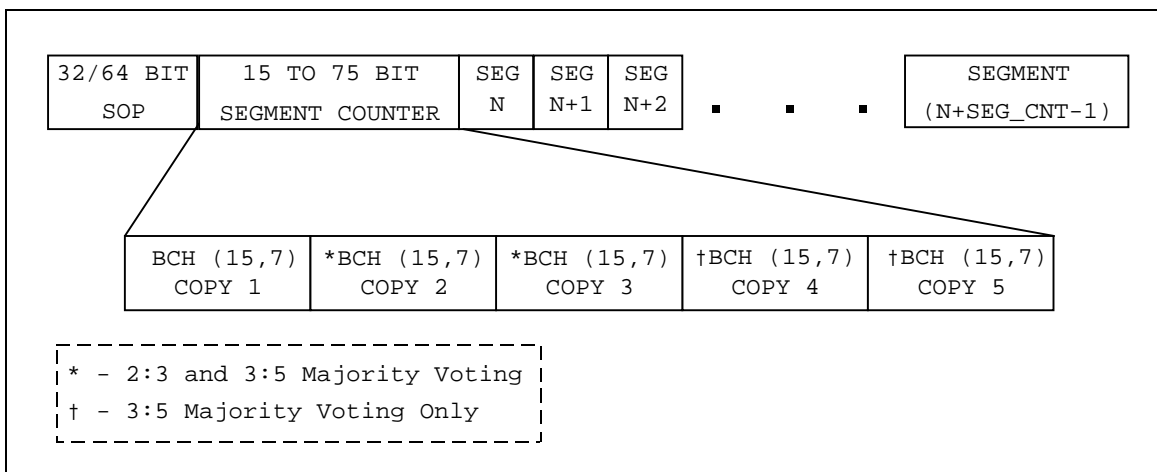

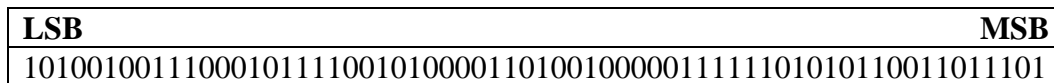FIGURE J-4. Multi-dwell packet.

LSB	MSB
1010010011100010111100101000011010010000011111101010110011011101	

FIGURE J-5. Multi-dwell 64-bit SOP pattern.

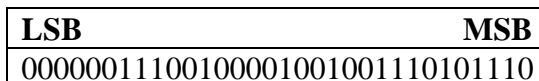| LSB	MSB
00000011100100001001001110101110	

FIGURE J-6. Multi-dwell 32-bit SOP pattern.

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J.3.4.3 <u>Multi-dwell segment count field</u>. The segment counter is a modulo 64 count of the first segment in the packet. The six required bits shall be encoded as 1, 3, or 5 BCH (15,7) codewords depending on bits 2, 3 and 4 of the robust frame format. The six-bit segment counter shall occupy the 6 least significant bits of the seven-bit BCH data field. The most significant bit of the data field shall be used as an end of frame flag which, when set, indicates that data transmission is complete. A multi-dwell packet marked with an end of frame flag shall contain only the SOP pattern and the segment count field used to make the segment number of the last non-fill data segment transmitted.

J.3.4.4 <u>Multi-dwell data segments</u>. Each multi-dwell packet shall contain 6, 11 or 13 consecutive 64-bit data segments. Unless a channel interruption is detected during the transmission of the packet, each data segment shall contain the next 64 bits supplied by the data link layer for transmission. The last multi-dwell packet shall contain pad bits and segments as necessary to complete the packet. The transmitted pad data shall be an alternating one, zero sequence.

J.3.4.5 <u>Multi-dwell hop detection</u>. The physical layer shall have the means of detecting or predicting communications link outages.

J.3.4.6 <u>Multi-dwell transmit processing</u>. Data received from the data link layer for transmission shall be broken into 64 bit segments for transmission. The data shall be packetized as stated in J.3.4.1. Packets shall be transmitted consecutively with the packet count subfield containing the count, modulo 64, of the first segment in the packet until a communications link outage is detected, at which time, the remainder of the data segments in the currently transmitted packet shall be filled with an alternating one/zero pattern. If the configurable hop recovery time (HRT) is greater than the time remaining to complete the transmission of the current packet, the alternating one/zero sequence shall be extended to the end of the HRT period. If a hop is detected during the multi-dwell packet synchronization field, or during the transmission of the first two segments, the entire packet shall be retransmitted. The first multi-dwell packet transmitted in a frame shall not contain the multi-dwell synchronization field. It is assumed that the segment count of the first packet is zero.

J.3.4.6.1 <u>Hop data recovery time period</u>. A configurable variable called the hop recovery time (HRT) shall be used to determine if the fill data transmitted following a hop must be extended to ensure that the following multi-dwell synchronization field can be received. The HRT is defined as the time period from the beginning of the transmitting radio frequency synthesizer frequency hop to the time that the bit synchronizer connected to the receiving radio can reliably demodulate data. Because different hop detection/ prediction methods flag the hop at different times relative to the beginning of the transmitting radio frequency synthesizer frequency slew, the configured HRT shall be internally adjusted to insure that different DTEs in a network can all use the same configurable HRT.

J.3.4.6.2 <u>Data transmitted after a hop</u>. The multi-dwell packet transmitted directly following a communications link outage shall retransmit data starting with the 64-bit segment preceding the segment that was being transmitted when the hop was detected.

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J.3.4.6.3 Termination of transmission. After the final packet of the frame is transmitted, without a hop detected during a data segment containing actual data (not fill data), data transmission shall be terminated. To prevent receive delays caused by the receiver not being able to determine that the last data segment has been received, an optional truncated multi-dwell packet shall be sent with the end of frame flag set. The segment count associated with the end-of-frame flag shall mark the first non-fill data segment transmitted.

J.3.4.7 Multi-dwell receive processing. If the multi-dwell flag was set in the robust synchronization field, the receiver shall buffer the multi-dwell data packet. The segment count for the first multi-dwell packet in a frame shall be assumed to be 0. After the last packet bit is received, the receiver shall open the SOP correlator window. When the SOP pattern is recognized, the segment count is decoded using the combination of majority and BCH decoding specified in the robust synchronization field. After each new segment count is decoded, the buffered data for data segments lower in count than the new segment count are passed on to the next higher layer as received bits. The segments of the newly received packet are then buffered and held until it is verified that the buffered segments will not be re-transmitted.

J.3.4.7.1 Receive end-of-frame detection. The data remaining in the multi-dwell receive data buffer shall be provided to the higher level protocol when an end-of-frame condition is detected. The end-of-frame condition may be determined by the data demodulator, the optional multi-dwell end-of-frame flag, or by a message from the higher level protocol indicating that message reception is complete.

J.3.4.7.2 Optional soft decision information. When there is a very high link BER, a SOP pattern may not be recognized or the segment count may not be correctable. If fewer than three consecutive segment counts cannot be corrected the correct number of bits shall be supplied to the upper level protocol as to not cause a bit slip, and consequently, the loss of the remaining data in the frame. If convolutional coding is used with multi-dwell, it is suggested that soft decision information is supplied indicating the low quality of the received data resulting from a missed SOP pattern or an unrecoverable segment count.

J.3.4.8 Multi-dwell majority logic overhead choice. The choice of the amount of multi-dwell majority voting (MV) overhead is dependent on the expected link BER. Table J-2 gives an estimate of the maximum random BER supported for a 90% probability of passing a single frame of length 1536 bits, 7680 bits, and 67,200 bits with no errors introduced due to multi-dwell processing.

TABLE J-2. Maximum supported BER.

Segment Count MV	1536	7680	67,200
1 out of 1	0.055	0.03	0.016
2 out of 3	0.14	0.11	0.07
3 out of 5	0.2	0.14	0.12

J.3.4.9 Multi-dwell overhead. The multi-dwell protocol introduces an overhead that shall be considered in the network timing calculations. The overhead is a function of the radio hop rate, the multi-dwell segment count majority voting choice, and the message length. Table J-3 gives the equation to calculate the actual worst case realized data rate for each hop rate and majority logic combination. The numbers in table J-3 were run with a hop recovery time of 15.625 ms, a maximum radio timing drift over a 1/2 hour period, an instantaneous data rate of 16000 bits/second. The actual efficiency will depend upon the exact implementation, therefore the numbers in Table J-3 should be used as a guide only. The six-segment multi-dwell packet shall be used for protocol acknowledgments and other single TDC block messages. The calculated realized data rate shall be used for the bit rate of all data encapsulated by the multi-dwell protocol.

TABLE J-3. Multi-dwell overhead.

HOP RATE	Multi-dwell overhead calculation			
	MV 1:1, 11 segments	**MV 2:3, 13 segments**	**MV 3:5, 13 segments**	**MV 3:5, 6 segments**
0	$R/((0.3*10^{(-L*.00003)})+1.06)$	$R/((0.3*10^{(-L*.00003)})+1.16)$	$R/((0.2*10^{(-L*.00003)})+1.17)$	$R/((0.1*10^{(-L*.00003)})+1.36)$
1	$R/((0.6*10^{(-L*.00003)})+1.10)$	$R/((0.6*10^{(-L*.00003)})+1.21)$	$R/((.55*10^{(-L*.00003)})+1.23)$	$R/((0.3*10^{(-L*.00003)})+1.40)$
2	$R/((0.5*10^{(-L*.00003)})+1.15)$	$R/((0.5*10^{(-L*.00003)})+1.27)$	$R/((0.7*10^{(-L*.00003)})+1.30)$	$R/((0.4*10^{(-L*.00005)})+1.48)$
3	$R/((0.5*10^{(-L*.00003)})+1.20)$	$R/((0.4*10^{(-L*.00002)})+1.36)$	$R/((0.8*10^{(-L*.00003)})+1.29)$	$R/((0.2*10^{(-L*.00003)})+1.56)$
4	$R/(1.45)$	$R/(1.51)$	$R/((0.7*10^{(-L*.00002)})+1.46)$	$R/((.07*10^{(-L*.00002)})+1.85)$
ALL	$R/(1.72)$	$R/(1.72)$	$R/(1.96)$	$R/(2.27)$

R = the instantaneous data rate
L = the number of bits to be transmitted

J.3.4.9.1 Terminals lacking hop detection. The ALL case in Table J-3 is to show the efficiency of the multi-dwell protocol in systems where the hop cannot be detected due to hardware or software limitations. Since there is no hop timing information available, the DTE shall assume that the radio will hop at every possible time slot. In these systems, it is assumed that timing synchronization with the radio will be made by the detection of the falling edge of the radio delayed push to talk (DPTT) signal provided by the HAVEQUICK II compatible radio.

J.3.5 Robust communications protocol network timing. The use of the robust communications protocol requires modification to some of the Appendix C type 1 network timing equations. The bit rate, transmit delays, and receive processing delays are modified by the robust protocol. For purposes of robust network timing, two system bit rates are defined. The first is the channel bit rate which is represented as n_c. The second is the data link bit rate which is represented as n_l. As an example, if rate 1/3 convolutional coding is applied at the physical layer and the channel bit

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rate is 16 kbps, the link bit rate would be 5.33 kbps. In this example, an external cryptographic device would transmit the MI field at n_c Hz and an internal cryptographic device would transmit the MI field at n_l Hz. The multi-dwell reduction of n_l is not deterministic but is bounded. The average multi-dwell n_l is a function of the multi-dwell packet format, the timing of the DTE transmit request in relation to the radio TRANSEC timing, and the number of bits to be transmitted. The following Type 1 network access control subfunctions are specified in Appendix C:

        a.   network busy sensing

        b.   response hold delay (RHD)

        c.   timeout period (TP)

        d.   network access delay (NAD)

The following subparagraphs address required modifications to network timing equations associated with these subfunctions as a result of using the robust communications protocol.

J.3.5.1 <u>Net busy sensing</u>. Because net busy sensing is performed at the physical level, there are no modifications to the net busy sensing timing or methods when using the robust communications protocol.

J.3.5.2 <u>Response hold delay</u>. The additional transmission time required for the robust synchronization field and n_l bit rate reductions impact the response transmission time parameter, (S), contained in the response hold delay timing equation, RHD_0. Also additional receive processing delays impact the internal DTE timing calculations. The RHD_0 is calculated as follows:

$$RHD_O = EPRE + PHASING + S + ELAG + TURN + TOL$$

J.3.5.2.1 <u>Response transmission time (S)</u>. The response transmission time is changed by the robust protocol. A Type 1 Response PDU from the data link layer consists of the 64-bit message synchronization field, the 75-bit robust frame format, an optional embedded COMSEC MI field, the 168-bit word count and Transmission Header TDC block, and 384, 168, or 80 bits of acknowledgment data depending on the selectable use of EDC and TDC. The 64-bit message synchronization field and the 75-bit robust frame format are transmitted at the channel bit rate (n_c). The remaining components are transmitted at the link data rate (n_l).

J.3.5.2.1.1 <u>Multi-dwell response</u>. Where multi-dwell is used to send the original message at a channel bit rate, n_c, of 16 Kbps, all responses, i.e. Type 1 acknowledgments, except for a secure external crypto transmission, are short enough that a multi-dwell transmission is not required. A multi-dwell transmission is required when using an external crypto because the data may be interrupted by a frequency hop. Table J-4 gives the maximum number of bits that will be transmitted at the channel bit rate (n_c) for the link data sizes and multi-dwell SOP majority logic

choices. These numbers are for the HOP ALL case, which is the worst case, and for the highest operational hop rate, hop rate 3. The 139 robust protocol header bits are included in Table J-4. The numbers in Table J-4 do not include the "wasted time" shown in Figure J-7.

TABLE J-4. Multi-dwell external crypto response transmission time
HRT= 15.6 ms, mode 3, (MV3:5, 6 segments/packet)

LINK BITS	FEC 1/3 Hop Rate 3	FEC 1/3 Hop All	No FEC Hop Rate 3	No FEC Hop All
312	$2139/n_c$	$3139/n_c$	$662/n_c$	$662/n_c$
392	$2139/n_c$	$4143/n_c$	$1185/n_c$	$1185/n_c$
616	$3139/n_c$	$5189/n_c$	$1185/n_c$	$1708/n_c$

NOTES: Table J-4 is optimized for the AN/ARC-164.
Robust Mode 3 is used for response PDUs. The choices are FEC or no FEC.
LINK BITS = the number of bits sent to the physical layer in a response PDU.
If Delay PTT is not supported by all radios in the network, then only columns marked "Hop All" apply.
Columns marked "Hop All" are required. Columns marked "Hope Rate 3" are optional.

J.3.5.2.1.2 Non multi-dwell response. Where an external crypto device is not used and n_c is 16 Kbps, the long dwell time will contain the entire response. Where an external crypto device is used, convolutional encoding is not used and the n_c is 16 Kbps, the crypto preamble will be contained within the long dwell time and the response will be contained within the first minimum dwell period following the long dwell time.

J.3.5.2.2 Response transmission example. Figure J-7 shows an example of the timing of an acknowledgment when an external cryptographic device is used with the HAVEQUICK II radio. The falling edge of the DPTT signal marks the beginning of a long hop dwell that is long enough to contain the crypto preamble time.

If an external crypto device was not used, this long dwell time would contain the entire acknowledgment. After the crypto has finished transmitting the MI field, the transmitting DTE begins to supply data for transmission. Typically, the COMSEC bit synchronization time is not very accurate and may be long enough to push the MI field to the end of the guaranteed long dwell time. For this reason, the DTE shall wait to start data transmission on the first hop dwell following the long guaranteed dwell. The end of the guaranteed hop dwell is marked by the possible hop label. The first bit of the robust SOM pattern is transmitted after the configured hop recovery time (HRT). During the transmission of the response, one or more hops may occur which will vary the transmission time of the acknowledgment. When the response transmission is complete, the DTE de-asserts the transmit request signal. The radio will de-assert DPTT after a variable delay (ET_1) at a time synchronized with the hop sequence. After DPTT is de-asserted,

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the radio RF output remains active and a radio hop will not occur. This allows for the transmission of the crypto postamble. The radio RF output remains active for longer than is required for the transmission of the crypto postamble, which is shown as the ET_2 time period in Figure J-7. For HAVEQUICK II radios, ET_1, crypto postamble PLUS ET_2 equals the transmitter turnaround time, (TTURN = $ET_1 + ET_2$), as defined in Appendix C.
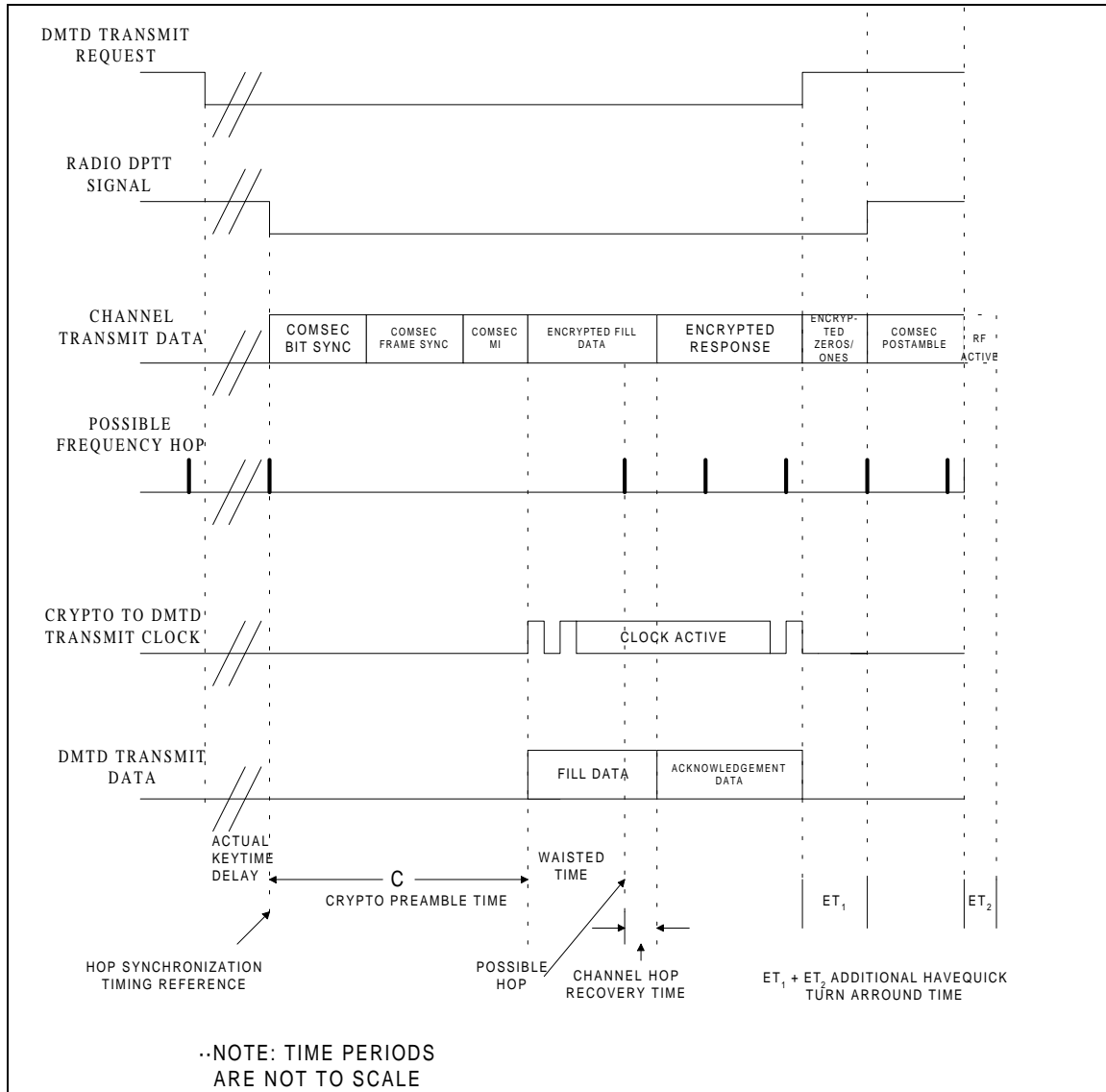

FIGURE J-7. HAVEQUICK II external crypto acknowledgment transmission.

J.3.5.2.3 Estimation of multi-dwell n_l. Figure J-8 shows an example of the n_l data rate for a multi-dwell transmission with a channel data rate of 16 kbps. This is the worst case data rate reduction which would be experienced with rate 1/3 convolutional coding, a 64 bit SOP pattern length, and 3 out of 5 majority logic decoding of the segment count field. The data rate shown

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Figure J-8 is the number of link bits to transmit divided by the number of channel bits transmitted times the n_c. Since rate 1/3 convolutional encoding is used in this example, the maximum link data rate achievable would be 5.33 kbps. For short messages, the radio hop timing at the beginning of the transmission has a significant impact on the transmission efficiency. This example uses 13 segments per packet which is the recommended segment per packet count for long transmissions using 3 out of 5 majority logic. This figure and the equations given in Table J-3 are given as an aid for network throughput estimation and should not be used for network timing. The bit rate estimating equation used in Figure J-3 is:

$$\text{link rate} = \text{nc} / (0.5 * 10^{(-\text{link bits} * .00003)} + 1.301)$$
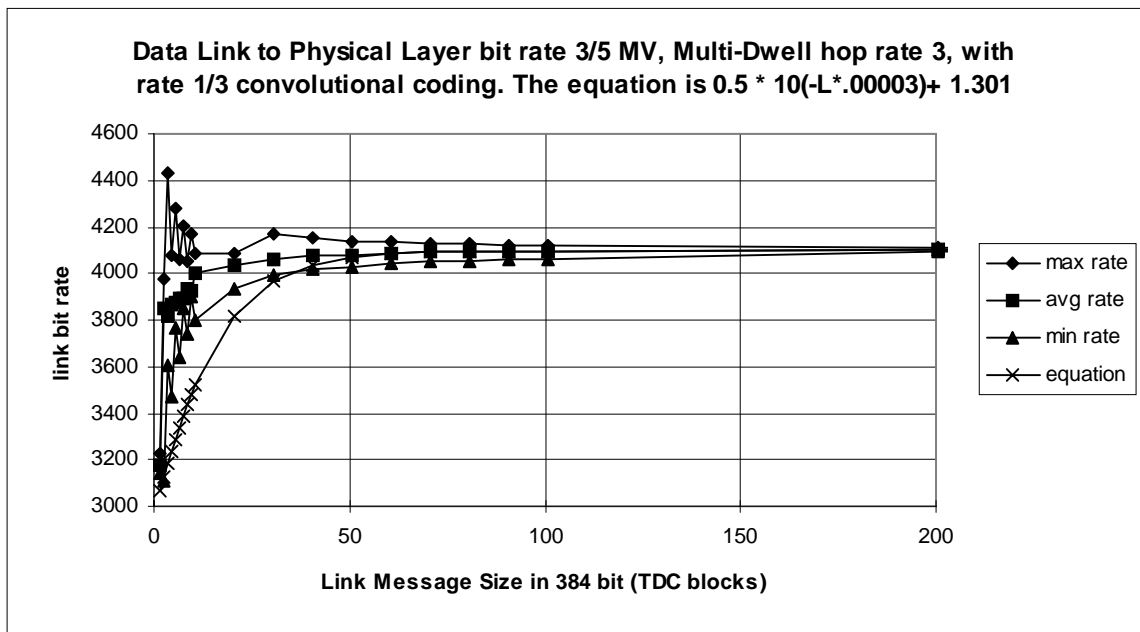

FIGURE J-8. <u>Link data rate as a function of message size</u>.

J.3.5.2.4 <u>Receive processing delays</u>. In order to calculate the reference point for the RHD and TP timers, the receiving DTE must know the time of arrival of the last bit of the transmission. In order to do this, the data link layer normally determines the last bit of the transmission after decoding the word count and tags the arrival of the last data bit from the physical layer. The physical layer receive delays are dependent on the DTE hardware and software implementation. The two delay components are processing delays and data pipeline delays. The processing delays are independent of the received data rate and the pipeline delays are dependent on the data rate. If the receive data rate is known, the data link layer can calculate the time of arrival of the last bit of the message by subtracting off the processing and pipeline delays. If the received data rate is not known, it is impossible to convert a pipeline delay from bits to seconds. The data rate of all non-multi-dwell transmissions is known to be either n_c or $n_c/3$ dependent on the use of rate 1/3 convolutional coding. The received data rate of a multi-dwell transmission is not known. For this

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reason, when a multi-dwell transmission is received, the physical layer must tag the time of arrival of the final multi-dwell bit. The physical layer can determine the time of arrival of the last bit by using the end of frame flag which is the most significant bit in the final multi-dwell segment count field. A logical signal from the physical layer to the data link layer indicating the message completion time is required to insure that the transmitter and receiver(s) use the same reference point for the calculation of RHD and TP.

The trace back buffer length of the Viterbi decoder introduces a known pipeline delay in the received data. The length of the trace back buffer is an implementation choice which is dependent on the Viterbi decoder architecture. Pipeline delay is the time needed to flush the trace back buffer.

J.3.5.3 Timeout period (TP). The timeout period is derived from the following equations as described in Appendix C:

$$TP = (j \ x \ RHD_0) + Maximum(DTEACK, TURN)$$
$$TP = Maximum(DTEPROC, TURN)$$
$$TP = (15 \ x \ RHD_0) + TOL + TURN$$

Modifications to the timeout period are result of changes to RHD_0 and DTE receive processing delays, which have been addressed in paragraph J.3.5.2 and its subparagraphs.

J.3.5.4 Network access delay (NAD). There are no modifications to the network timing equations associated network access delay. The network access delay is always an integer number times the Net_Busy_Detect_Time which, as previously discussed, has not been modified.

J.3.6 Application guidance for the HAVEQUICK II link.

J.3.6.1 Frequency hop synchronization. The HAVEQUICK II TRANSEC timing and the DTE network timing are not synchronized. To avoid the loss of critical data, such as the cryptographic synchronization and/or the protocol SOM patterns, the DTE transmission timing must be synchronized to the frequency hops. The radio should provide a DPTT signal which marks the beginning of a hop dwell with a guaranteed minimum duration. This minimum dwell period is sufficient to carry the synchronization field of an external cryptographic device or the robust frame synchronization field when an internal cryptographic device is used.

J.3.7 Summary. The physical layer robust protocol introduces additional transmit and receive delays due to the robust header and the convolutional decoding pipeline delays. Multi-dwell packetizing introduces a data rate reduction which varies widely for short transmissions. The HAVEQUICK II radio introduces variable delays in the keytime delay and the equipment turn-around time. To maintain network timing using the type 1 timing equations, the net busy sense timing and the response transmission time must be a known constant. In most cases, the response can be transmitted without using the multi-dwell packetizing algorithm. When the multi-dwell packetizing algorithm must be used to transmit a response, the worst case time to complete the transmission is used in the response transmission time component of the term TURN in RHD.

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The message transmission time is variable and is only required to be known at the end of the transmission. Two additional physical to data link signals are required to mark the time of the last transmitted bit for transmission, and the time of the last received bit for a reception.

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APPENDIX K

BOSE - CHAUDHURI - HOCQUENGHEM (15, 7) CODING ALGORITHM

K.1. General.

K.1.1 Scope. This appendix describes a linear block cyclic code capable of correcting any combination of two or fewer errors in a block of 15 bits.

K.1.2 Application. This appendix is a conditionally mandatory part of MIL-STD-188-220. It is mandatory for implementing the Robust Communications Protocol described in Appendix J.

K.2. Applicable documents. This section is not applicable to this appendix.

K.3. BCH (15,7) code. The BCH (15,7) code is a linear, block, cyclic, BCH code capable of correcting any combination of two or fewer errors in a block of 15 bits. The generator polynomial for this code is

$$g(x) = 1 + X^4 + X^6 + X^7 + X^8$$

where g(x) is a factor of $X^{15} + 1$

K.3.1 Hardware encoding. BCH (15, 7) encoding can be performed with an 8 stage feedback shift register with feedback connections selected according to the coefficients of g(x). A shift register corresponding to the coefficients of g(x) is shown in Figure K-1.
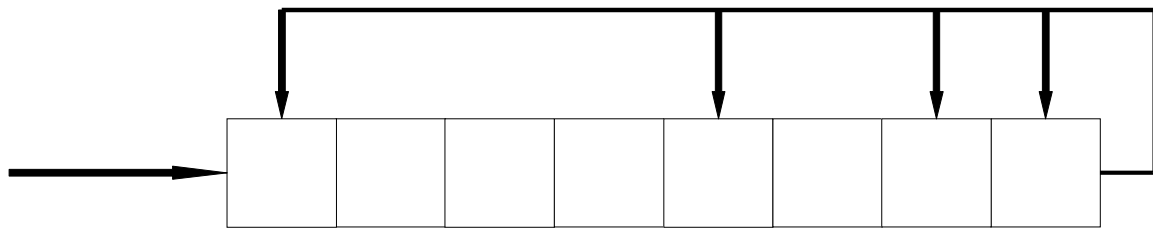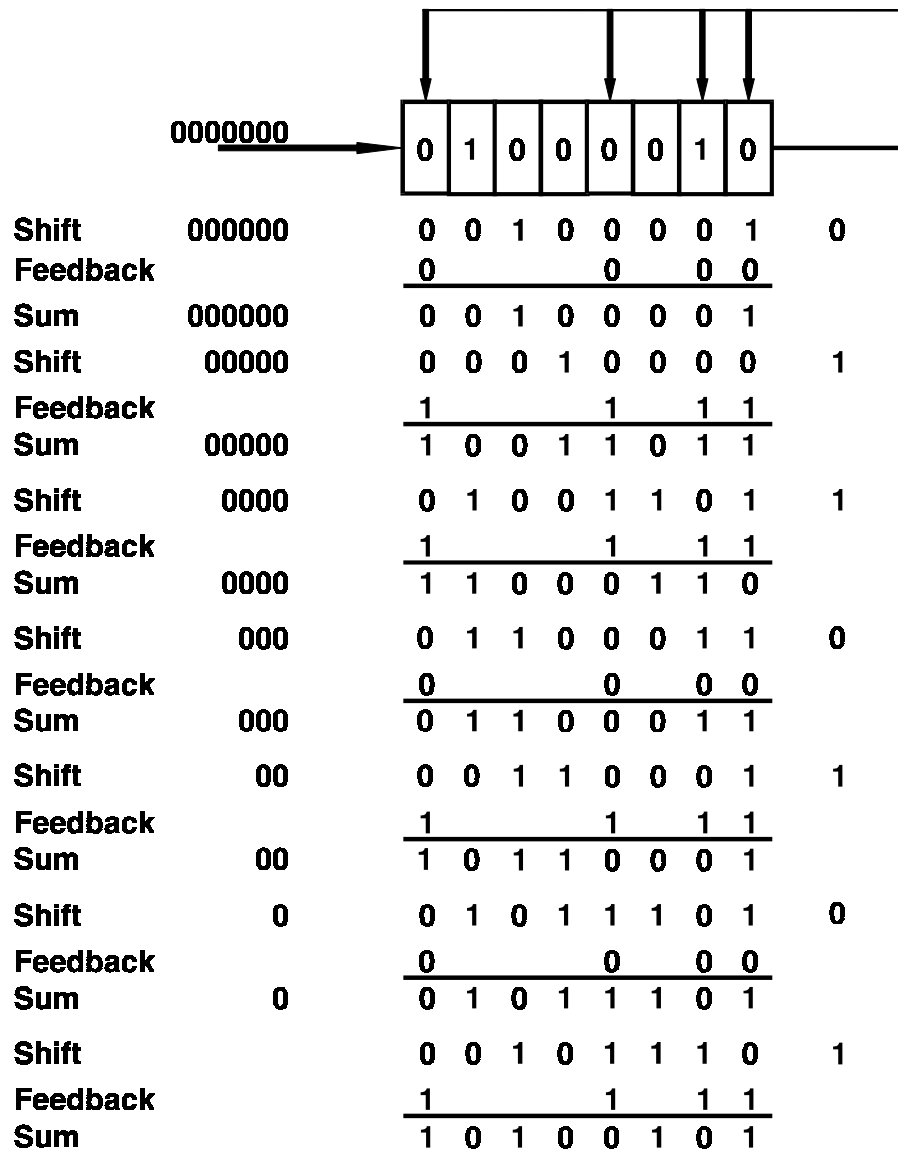

FIGURE K-1. Shift register encoder for the BCH (15, 7) code.

Figure K-2 illustrates its operation by showing the encoding of the information vector (1000010) to form the code vector (10100101 | 01000010), where the parity check sequence is shown before the partition and the information sequence after. The information sequence with eight zeros after it (place holders for the parity bits to be calculated) is shifted into the register initially (it is really a fifteen bit shift register but only the last eight positions correspond to the coefficients of g(x) and contain feedback connections). The operation of the shift register consists of seven rounds of shift, feedback, and sum operations. The parity portion of the code vector can then be read out of the shift register as shown.

0000000 → [0 | 1 | 0 | 0 | 0 | 0 | 1 | 0]

Shift	000000	0	0	1	0	0	0	0	1	0
Feedback		0				0		0	0	
Sum	000000	0	0	1	0	0	0	0	1	
Shift	00000	0	0	0	1	0	0	0	0	1
Feedback		1				1		1	1	
Sum	00000	1	0	0	1	1	0	1	1	
Shift	0000	0	1	0	0	1	1	0	1	1
Feedback		1				1		1	1	
Sum	0000	1	1	0	0	0	1	1	0	
Shift	000	0	1	1	0	0	0	1	1	0
Feedback		0				0		0	0	
Sum	000	0	1	1	0	0	0	1	1	
Shift	00	0	0	1	1	0	0	0	1	1
Feedback		1				1		1	1	
Sum	00	1	0	1	1	0	0	0	1	
Shift	0	0	1	0	1	1	1	0	1	0
Feedback		0				0		0	0	
Sum	0	0	1	0	1	1	1	0	1	
Shift		0	0	1	0	1	1	1	0	1
Feedback		1				1		1	1	
Sum		1	0	1	0	0	1	0	1	

FIGURE K-2. Encoding example.

K.3.2 Hardware/Software decoding. Because of its special structure (it is completely orthogonalizable in one step), the BCH (15,7) code can be decoded very efficiently with a majority logic scheme which can be directly implemented in software or hardware. It is most easily described in terms of the shift register implementation shown in Figure K-3. With gate 2 open and gate 1 closed, the received block is read into the shift register. The output of the four modulo 2 summers is sampled by the majority gate and processed as follows: if a clear majority of the inputs are ones (three or more) then the output is one, otherwise (if two or fewer inputs are ones) the output is zero. This output is used to correct the last bit of the shift register. The

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corrected bit is output to the receiver and feedback through gate 2 as the register is right shifted. The process is now repeated thirteen times until the last bit is corrected.
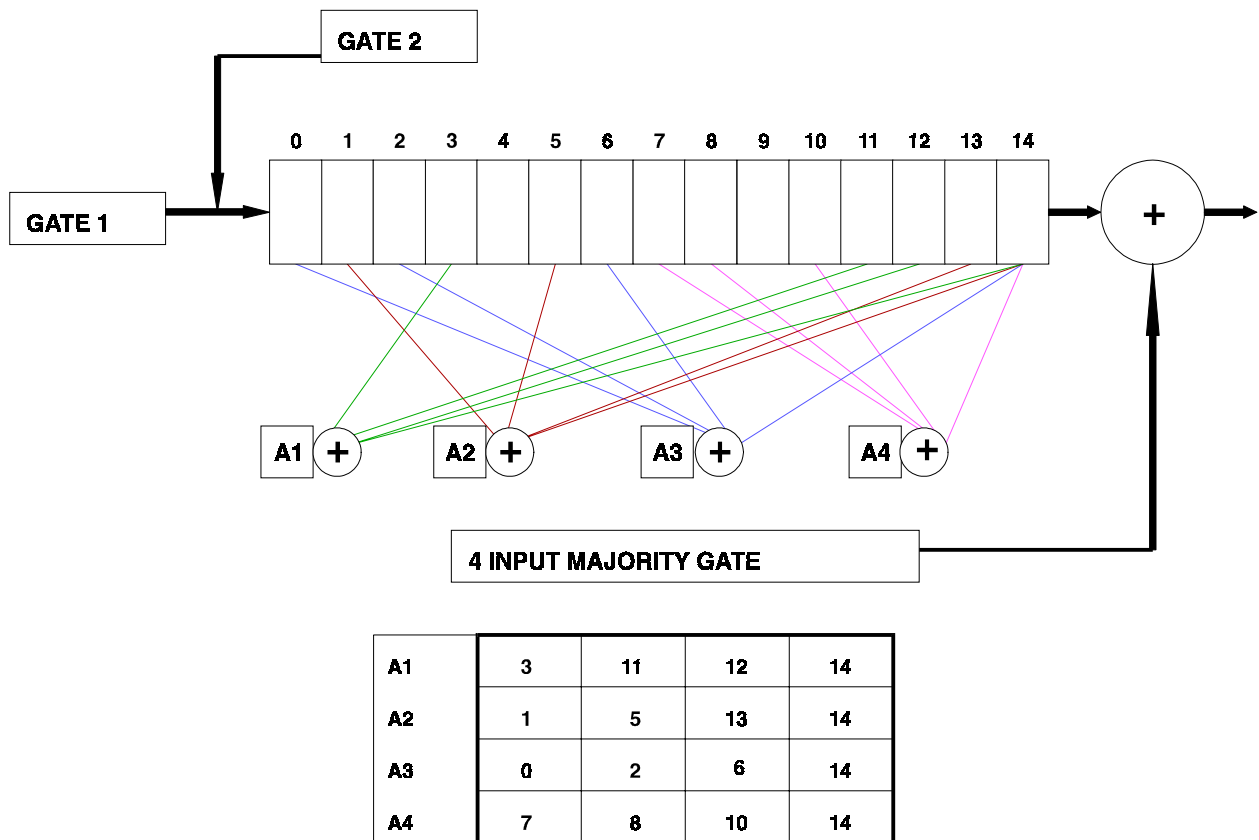

FIGURE K-3. BCH (15, 7) majority logic decoding.

K.3.3 Software encoding. The BCH (15,7) code is most efficiently encoded in systematic form from the generator matrix shown in Figure K-4.

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$$G = \begin{array}{|ccccccccc|} \hline 1 & 0 & 0 & 0 & 1 & 0 & 1 & 1 \\ 1 & 1 & 0 & 0 & 1 & 1 & 1 & 0 \\ 0 & 1 & 1 & 0 & 0 & 1 & 1 & 1 \\ 1 & 0 & 1 & 1 & 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 1 & 1 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 & 1 & 1 & 1 & 0 \\ 0 & 0 & 0 & 1 & 0 & 1 & 1 & 1 \\ \hline \end{array} \quad \begin{array}{|ccccccc|} \hline 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 \\ \hline \end{array}$$

Parity   **Identity**

FIGURE K-4. BCH (15, 7) generator matrix.

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