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Reference Manual for Packet Mode Standards

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PREFACE

This report is submitted as partial completion of a series of studies being conducted for the National Communications System (NCS), Technology and Standards Office, Office of the Manager, Washington, DC, under Reimbursable Order 5-40033 by the National Telecommunication and Information Administration, Institute for Telecommunication Sciences (NTIA/ITS), Boulder, CO.

The views, opinions, and/or findings contained in this report are those of the author and should not be construed as an official NCS or NTIA position or decision unless designated by other official documentation.

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LIST OF ACRONYMS

A	Additional (CCITT Recommendation X.2 facilities)
ABM	Asynchronous Balanced Mode
ADM	Asynchronous Disconnected Mode
ANS	American National Standard
ANSI	American National Standards Institute
ARM	Asynchronous Response Mode
ASC	Accredited Standards Committee
ASCII	American Standard Code for Information Interchange
ASYNC	Asynchronous
BCD	Binary Coded Decimal
CCITT	The International Telegraph and Telephone Consultative Committee
CMD/RES	Command/Response
CRC	Cyclic Redundancy Check
CSPDN	Circuit-Switched Public Data Network
CUG	Closed User Group
D-bit	Delivery confirmation bit
DCE	Data Circuit-terminating Equipment
DISC	Disconnect
DM	Disconnected Mode
DNIC	Data Network Identification Code
DSE	Data Switching Exchange
DTE	Data Terminal Equipment
DXE	DTE or DCE
E	Essential (CCITT Recommendation X.2 facilities)
EIA	Electronic Industries Association
F	Final bit
FCS	Frame Check Sequence
FED STD	Federal Standard
FEP	Front End Processor
FIPS PUB	Federal Information Processing Standards Publication
FRMR	Frame Reject
GFI	General Format Identifier
HDLC	High-level Data Link Control

LIST OF ACRONYMS (cont.)

HDTM	Half-Duplex Transmission Module
I	Information (control field format)
IA5	International Alphabet No. 5 (ISO)
IM	Initialization Mode
IS	International Standard
ISO	International Organization for Standardization
ITS	Institute for Telecommunication Sciences
k	maximum number of unacknowledged I frames
kb/s	kilobits per second
LAP	Link Access Procedure
LAPB	Link Access Procedure, Balanced
LAPX	Link Access Procedure, Half-Duplex (or Extended)
LCGN	Logical Channel Group Number
LCN	Logical Channel Number
LDS	Logically Disconnected State
m	Meter
M-bit	More data bit
MLP	Multilink Procedure
NBS	National Bureau of Standards
NCS	National Communications System
ND	Network Default
NDM	Normally Disconnected Mode
NN	National Number
NRM	Normal Response Mode
N(R)	Receive Sequence Number
N(S)	Send Sequence Number
NTIA	National Telecommunications and Information Administration
NTN	Network Terminal Number
NUI	Network Unit Identifier
OSI	Open Systems Interconnection
P	Poll bit
PAD	Packet Assembly/Disassembly
pf	Picofarad

P/F	Poll/Final bit
PLP	Packet Level Protocol
P(R)	Packet Receive Sequence Number
P(S)	Packet Send Sequence Number
PSN	Public Switched Network
PSPDN	Packet-Switched Public Data Network
PSTN	Public Switched Telephone Network
PVC	Permanent Virtual Circuit
Q-bit	Qualifier bit
REJ	Reject
RNR	Receive Not Ready
RPOA	Recognized Private Operating Agency
RR	Receive Ready
S	Supervisory (control field format)
SABM	Set Asynchronous Balanced Mode
SABME	Set Asynchronous Balanced Mode Extended
SLP	Single Link Procedure
STE	Signal Terminal Equipment
SYN	International Alphabet No. 5 Character
TCC	Telephone Country Code
U	Unnumbered (control field format)
UA	Unnumbered Acknowledgment
v	Volts
VC	Virtual Calls
V(R)	Receive Sequence Variable
V(S)	Send Sequence Variable
W	Window
XID	Exchange Identification

REFERENCE MANUAL FOR PACKET MODE STANDARDS

Donald V. Glen*

American National Standard (ANS) X3.100 will be adopted as Federal Information Processing Standards Publication (FIPS PUB) 100 and Federal Standard (FED STD) 1041. These standards are based on CCITT Recommendation X.25 and ISO Standards 7776 and 8208. CCITT X.25 is an interface that is oriented toward data circuit-terminating equipment (DCE) for packet operation. While ISO 7776 and 8208 are compatible with X.25, they also provide added guidance that allows two pieces of data terminal equipment (DTE) to exchange packets over a dedicated path or circuit-switched network without a packet-switched network in between. Hence, ANS X3.100 and FIPS PUB 100/FED STD 1041 provide for operation that may, or may not, include an intervening packet network.

While X.25 requires a dedicated circuit for access, CCITT Recommendation X.32 essentially modifies X.25 and allows switched access to a packet-switched network. Consequently, X.32 has been called a "dial-in, dial-out X.25" through the use of, for example, a public switched telephone network (PSTN). Although X.32 is not part of FIPS PUB 100/FED STD 1041, it is described in this reference manual.

This reference manual provides a tutorial description of terminals operating in the packet mode and the applicable standards at the physical, link, and packet levels. This should permit the reader to begin understanding an area of data communications that has become popular and is being implemented throughout the United States and other countries.

Key words: DTE/DCE interfaces; Federal Standards; high-level data link control (HDLC); ISO 7776; ISO 8208; link access procedure, balanced (LAPB); link access procedure, half-duplex (LAPX); link level; logical channels; open systems interconnection (OSI); packet level protocol (PLP); packet switching; packet switched public data network (PSPDN); physical level; public switched network (PSN); X.21; X.21 bis; X.25; X.32

1. INTRODUCTION

1.1 Background

The International Telegraph and Telephone Consultative Committee (CCITT) has approved versions of CCITT Recommendation X.25 during 1976, 1980, and 1984. CCITT X.25 (CCITT, 1984a) describes a user-network interface between data

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terminal equipment (DTE) and data circuit-terminating equipment (DCE) for terminals that:

- o operate in the packet mode and
- o are connected to public data networks by a dedicated circuit.

After each adoption of the latest version of X.25 by the CCITT, the American National Standards Institute (ANSI) and the Federal Government have subsequently approved the standard for commercial use in the United States and by government agencies, respectively. During 1984, the ANSI task group, X3S3.7, Public Data Network Access, undertook the task of defining specific requirements for the use of CCITT Recommendation X.25, International Standard (IS) 7776 [high-level data link control (HDLC) procedures] (ISO, 1985a) and IS 8208 [X.25 packet level protocols (PLP)] (ISO, 1985b). The last two standards are from the International Organization for Standardization (ISO). As a result of this work, early in 1987 the Board of Standards Review of ANSI is expected to approve publication of American National Standard X3.100 (ANSI, 1986), "Interface between Data Terminal Equipment (DTE) and Data Circuit-Terminating Equipment (DCE) for Operation with Packet-Switched Data Networks (PSDN), or between two DTEs, by Dedicated Circuit."

ANSI X3.100 will subsequently be adopted as a joint Federal Information Processing Standard (FIPS) and Federal (Telecommunication) Standard (FED STD). The ANSI X3.100 is known then as FIPS PUB (Publication) 100 and FED STD 1041 (Figure 1). Whether any changes will be necessary to ANSI X3.100 (1987) before it is adopted by the Federal Government can only be surmised as of January 1987. The FIPS publications are developed by the National Bureau of Standards (NBS), Institute for Computer Sciences and Technology, Washington, DC, 20899. The Federal Standards in the telecommunications series are developed by the Office of the Manager, National Communications System, Washington, DC, 20305-2010.

A DTE/DCE interface that is not part of FIPS PUB 100/FED STD 1041, CCITT X.32, was initially approved for the 1984 CCITT Red Books. Subsequently, a more inclusive version was developed and then approved for the 1984 CCITT Gray Books. The CCITT X.32 allows the use of a switched access circuit when a dedicated circuit, as required in X.25, is not economical or is unavailable. The CCITT X.32 has not been adopted as an ANSI or Federal standard, but will probably be considered in the future.

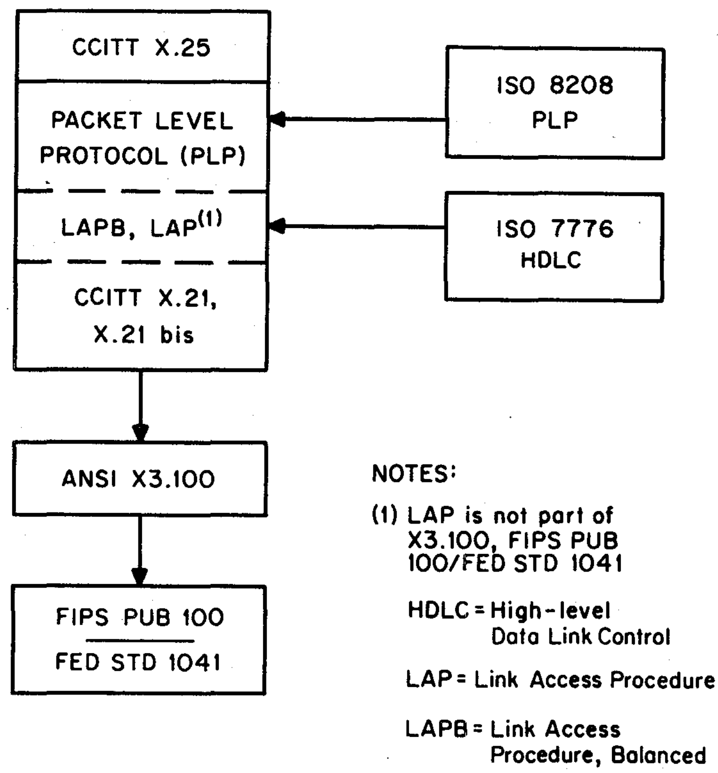


Figure 1. Related packet-switching standards.

1.2 Purpose and Organization

The purpose of this report is to provide some understanding of packet mode switching and guidance to related standards. It is specifically intended as a companion piece to FIPS PUB 100/FED STD 1041 at the suggestion of the National Communications System (NCS).

This reference manual is divided into three major sections. Section 2 contains a description of packet switching starting with three concepts--the DTE/DCE interface, virtual circuit service, and network transparency--all of which are integral to packet operation. The section concludes with a description of the packet network and the physical components (i.e., terminals, modems, and switching exchanges) that make up the network. These physical components are then related to the Open Systems Interconnection (OSI) reference model. With this approach, the practicing engineer can relate the "real world" component implementation to that of the frequently "abstract-appearing" standards world.

Section 3 is a description of the physical, link, and packet-level standards that make up packet-mode operation and serve as the basis for X3.100, which is anticipated to be adopted, perhaps with modifications, as FIPS PUB 100/FED STD 1041.

The levels and standards are as follows:

- o Physical Level — X.21, X.21 bis including EIA-232-D
- o Link Level — X.25 Link Access Procedure, Balanced (LAPB) and HDLC (ISO 7776)
- o Packet Level — X.25 and ISO 8208.

These are extensively described in terms of configurations, operating examples, and frame and packet structures.

Section 4 is devoted specifically to FIPS PUB 100/FED STD 1041 and contains requirements for packet-mode operation in the United States. This section is written to provide added explanations of these requirements that may not be included in Section 3.

Section 5 describes the physical, link, and packet levels in CCITT X.32. This includes descriptions of services, attributes, and identification/authentication procedures.

Section 6 contains a summary and conclusion, Section 7 is an acknowledgment, and Section 8 is a list of references.

Appendix A is a short review of the OSI reference model, Appendix B is a compilation of DTE/DCE interface standards, and Appendix C is a copy of FIPS PUB 100/FED STD 1041.

2. DESCRIPTION OF PACKET SWITCHING

The complete title for CCITT Recommendation X.25 is "Interface Between Data Terminal Equipment (DTE) and Data Circuit-Terminating Equipment (DCE) for Terminals Operating in the Packet Mode and Connected to Public Data Networks by Dedicated Circuit." It is a standard for the connection of computer and terminal equipment to Packet-Switched Public Data Networks (PSPDNs).

2.1 Concepts

Three concepts require introduction for the discussion of X.25 and the other packet standards. The first concept is the traditional view of DTEs and DCEs connected to a communications network as shown in Figure 2. The figure shows the DTE/DCE interface between the computer/terminal equipment (i.e., DTE) and interfacing equipment (i.e., DCE) required to couple with transmission circuits in a communications network. An example of the DCE is the modem that converts digital signals into quasi-analog signals for transmission. It also reconverts the quasi-analog signals into digital signals for acceptance by the DTE.

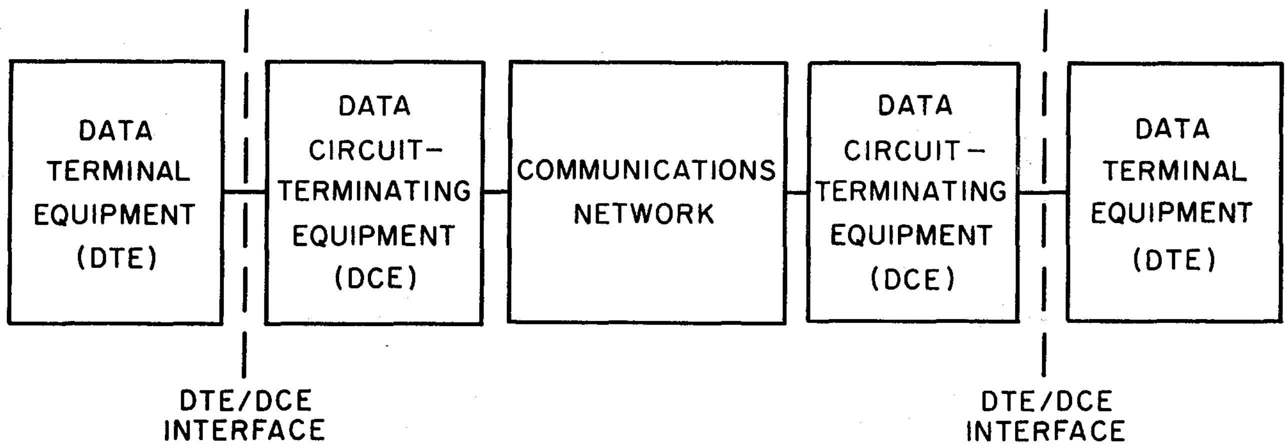


Figure 2. Connection of DTE/DCE equipment to communications network.

This is not quite the way the DCE is considered within a packet network. That will be described in the next section.

The second concept, that of virtual circuits, is not limited to packet operation. A virtual circuit service provides a communication arrangement between users over various real equipment during a period of communication. A virtual circuit service, when related to packet operation, has certain attributes for the transfer of data. A logical channel is established between two user locations before data packet transmission is started. The establishment of logical channels permits the sharing, through multiplexing, of a single physical link by up to 4095 DTE pairs. There can be two types of X.25 virtual circuit services on the same link: virtual calls (VCs) and permanent virtual circuits (PVCs) (Figure 3). The VC is dynamically set up and cleared each time the service is needed. It is analogous to the use of a dial-up telephone call in a circuit-switched service. The PVC does not require call setup or clearing because the circuit is permanently assigned by the network. This is analogous to a dedicated leased line. Each of the services can provide simultaneous multiple communications over the multiplexed link and all packets follow the same route once the path is established. While the logical channel may be dedicated for the duration of the call, as in a VC, or permanently assigned as with a PVC, the link is not--it is shared throughout.

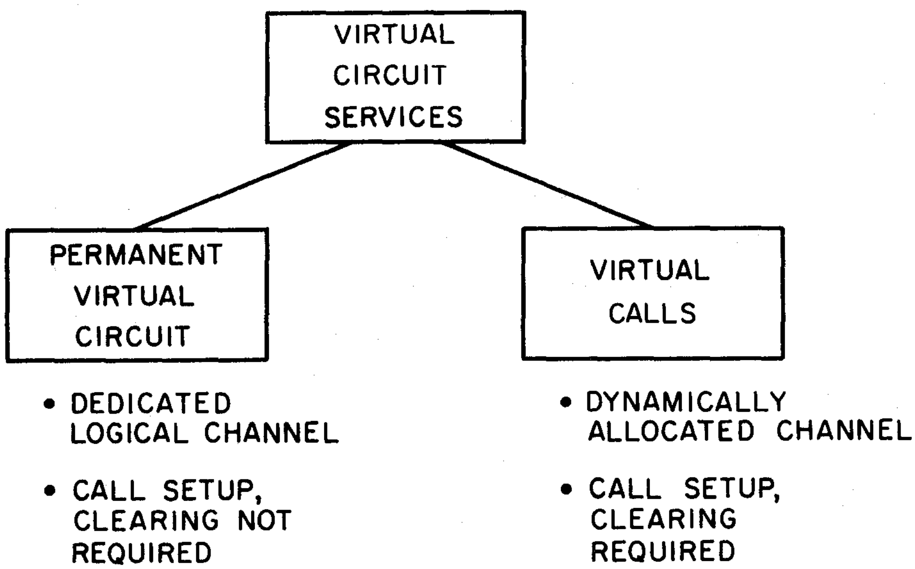


Figure 3. Two types of virtual circuit services.

A third concept that is applicable in considering packet networks is the illusion of transparency between users when communicating through the respective terminals and/or host computers. In reality, the data terminal is communicating with the network which contains nodes that are communicating with each other and then finally with the destination user.

Other concepts exist that could be considered in a discussion of packet-switching networks and X.25. Those just described suffice for introductory purposes.

2.2 Implementation

The three concepts can now be considered relative to the implementation of packet-switched, virtual-circuit services (Figure 4). An example of virtual-circuit service that can provide PVC and VC service (Figure 4a) has a DTE consisting of an intelligent data terminal, with X.25 protocols, and a modem that are located at user A. A host computer and a front-end processor (FEP) with an X.25 interface are located at user B's premises. An X.25 node,

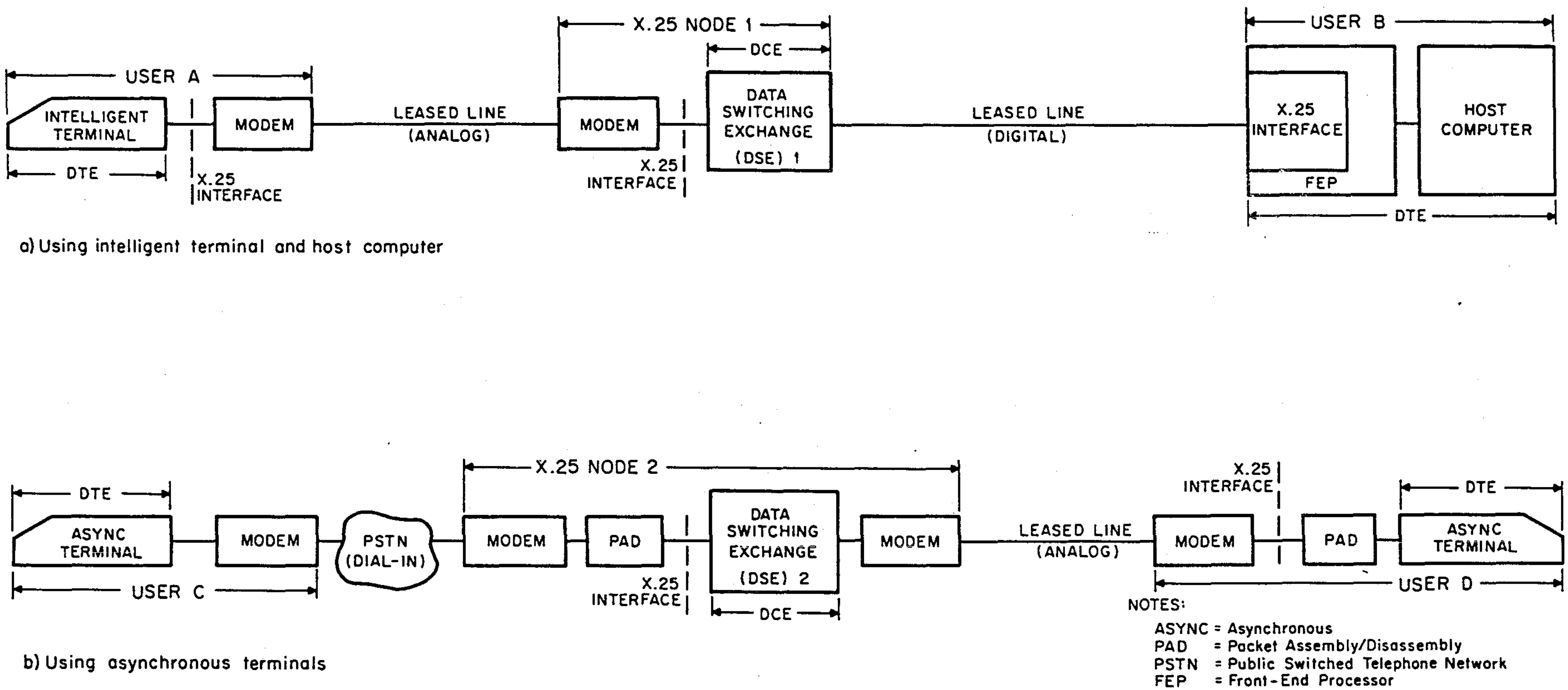


Figure 4. Packet-switched virtual circuit services.

consisting of a modem and data switching exchange (DSE), is located between the two users. The function of a DSE is defined as "Equipment installed at a single location to switch data traffic" (NCS, 1985). In the case of a packet network, the DSE can also be considered the DCE containing embedded X.25 network intelligence. Hence, in this example, the DCE is not located at the user premises as it would be in the usual circuit-switched network.

User A is connected to the X.25 node via an analog line that, for example, has a signaling rate of 4.8 or 9.6 kb/s between modems. An X.25 network interface exists between the terminal and modem according to CCITT Recommendation X.21 or X.21 bis for data rates of less than 20 kb/s. User B is connected via a digital line that could have a signaling rate of 56 kb/s. The X.25 network interface here could be according to CCITT Recommendations V.35, V.28, and V.24, which collectively are for data rates greater than 20 kb/s. The analog and digital lines are both leased for shared use according to logical channel number assignments corresponding to PVC or VC service.

A circuit configuration that is most appropriate for VC service is illustrated in Figure 4b. This circuit configuration consists of an asynchronous (start-stop) terminal and modem at user C. The X.25 node consists of a packet assembly/disassembly (PAD) unit, data switch, and two modems that are used on analog lines to users C and D. User D also has an asynchronous terminal, a modem, and an X.25 PAD. The function of the PAD associated with each user is to allow a simple asynchronous terminal to communicate through a packet network to other devices. The PAD is defined by three CCITT Recommendations (X3, X.28, and X.29). It provides the intelligence that permits the "dumb" terminal to communicate using the X.25 protocol. In this example, user C can initiate a call setup to user D, but user D cannot establish a link to user C. The use of X.3/X.28/X.29 protocols permits simple asynchronous terminals to access an X.25 packet network. On the other hand, intelligent terminals that have more capability become limited due to a lack of flexibility in the PAD approach. A standard to allow "dial-in" or "dial-out" operation between DTEs and packet-switched public data networks (PSPDNs) via a public-switched telephone network (PSTN) or circuit-switched public data networks (CSPDN) is within the realm of CCITT Recommendation X.32 (see Section 5).

An example of interconnected data-switching exchanges and packet networks is shown in Figure 5. The two simple configurations from Figure 4 can now be

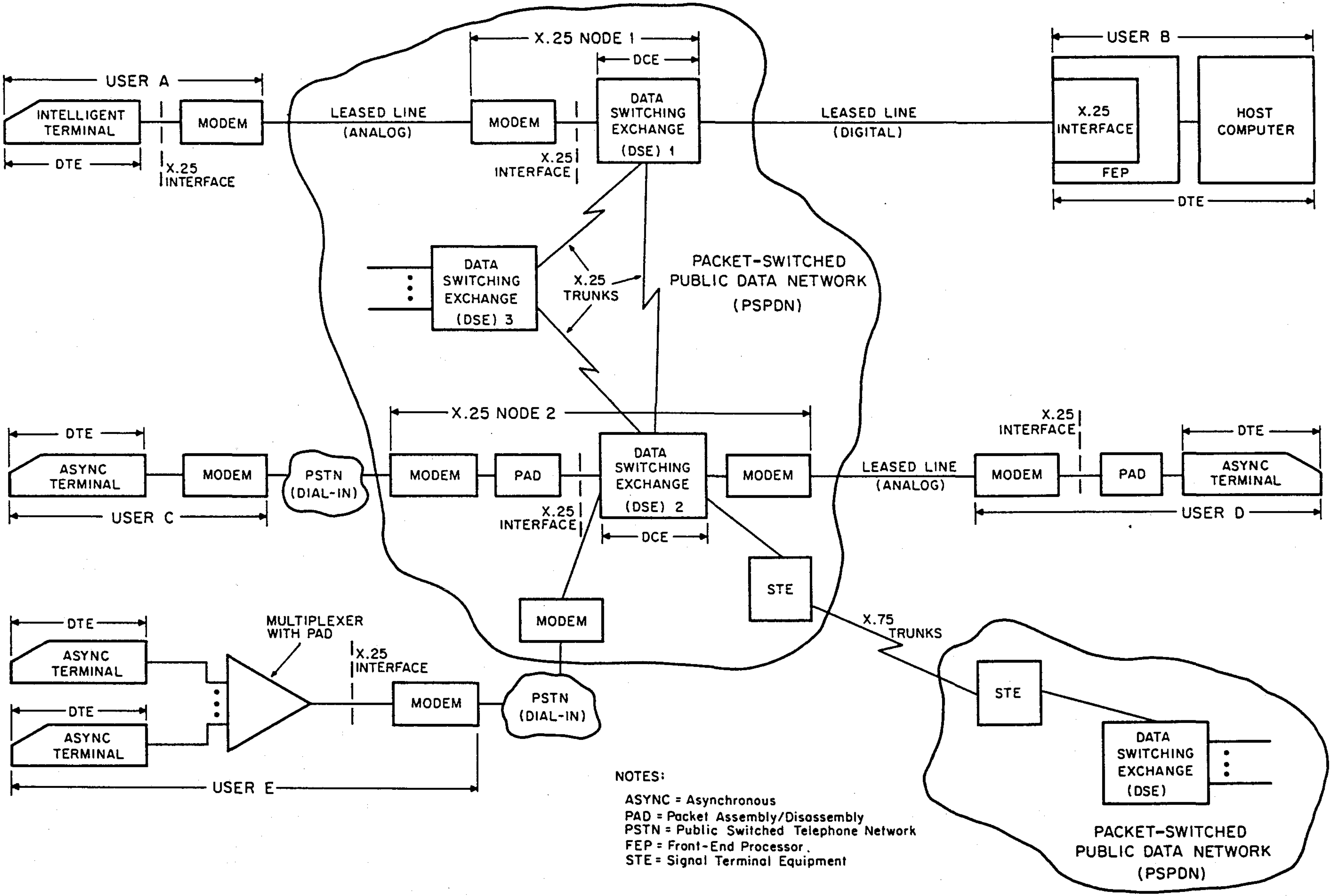


Figure 5. Terminals interconnected through packet-switched network.

connected through the nodes that are part of a PSPDN. User E is connected to the PSPDN via a PSTN and is similar to user C. A PAD with multiple inputs is shown as part of the implementation at the user premises. This is a more common type of PAD than a unit with only one input as shown in Figure 4. A connection to a second PSPDN shows that virtual circuit service can be established through a number of X.25 networks. The CCITT Recommendation X.75 (Terminal and Transit Call Control Procedures and Data Transfer System on International Circuits Between Packet-Switched Data Networks) allocates gateway responsibilities between signal terminal equipment (STE) in different networks for internetworking and between a DCE and STE for intranetworking.

Scenarios for communication between users are now described.

Users A, B, and D have the potential to initiate data packet exchange with each others' data terminals and the host computer. Users C and E can initiate calls to A, B, and D, but not to each other. The others cannot call in to C or E.

In one routing scenario, assume that user D has a message to send to user B, the host computer. The message will have to be distributed among several packets because of its length. A virtual circuit has to be established before the first data packet is sent. First, a connection to user B is requested by sending a Call Request packet to DSE 2. Then DSE 2 has the options of routing to DSE 1 or to DSE 3. For this case it decides to route to DSE 3 because of heavily loaded trunks between DSEs 1 and 2. DSE 3 than sends the request to DSE 1, which then routes the Call Request to the host computer at User B. If the host computer accepts the request, it returns a Call Accepted packet to DSE 1. This packet is than relayed to DSE 3, to DSE 2, and finally to user D's PAD. The asynchronous terminal then gets a "connect indication" from the PAD. The route that was established with the Call Request will be used to exchange all data packets in a duplex mode between users D and B. All routing decisions have been made so that an established route now exists between users. Each packet that is transmitted between the two users contains data and virtual circuit identification. At the end of a data exchange, a Clear Request packet is sent by one of the users when the virtual circuit connection is to be broken. This is an example where the virtual circuit service is a virtual call since a call setup and call clearing phase was performed. A PVC does not require the call setup or subsequent clearing. Any of the users depicted within Figure 5 can have one or more virtual circuits established within the constraints for call establishment between terminals given above.

Users C and E have to initiate call setup to the other users. However, to access an X.25 node they are required to dial(-in) a telephone number, either manually or automatically, along with appropriate identification, passwords, and connection codes.

The concepts of DTE/DCE connections, virtual circuits, and the illusion of network transparency have now been described.

The call setup, data transfer, and call-clearing phases that have been described are depicted in Figure 6 with a time-sequence diagram relative to open systems interconnection (CCITT, 1984b; ISO, 1985c). The last packet shown in the call-clearing state is Clear Confirmation. It is only of "local significance" between the DTE and DCE. These packet types will be described in succeeding sections.

The DTE data exchange between users D and B will now be shown as packets that traverse an OSI configuration that includes relay nodes. Data units from upper OSI layers have header information added at the packet and link levels (Figure 6). (Details of the frame and packet structure are given in Section 3.5.) This X.25 frame structure is presented at the physical level and transmitted through the communication media to the first relay node DSE 2. The header information is removed and subsequently replaced as the data unit moves through DSE 2. The same procedure is followed at DSE 3 and DSE 1. At user B's DTE, header information is removed at each OSI level until applications data is presented as the terminal output. The pertinent X.25 standards for levels 1, 2, and 3, are also shown in Figure 6.

3. CCITT X.25 AND RELATED STANDARDS

Protocols have been defined for CCITT Recommendation X.25 relative to the first three layers of the OSI reference model (Appendix A). Within X.25 the layers are called levels and the network layer is called the packet level. At the physical level, CCITT X.21 (CCITT, 1984c) specifies mechanical, electrical, functional, and procedural characteristics. It is applicable to circuit- and packet-switched operation. CCITT X.21 has not been widely accepted in the United States for two reasons. The first is the wide acceptance of EIA-232-C, which is to be followed by EIA-232-D. Second, X.21 requires more intelligence at the interface since characters are interpreted for call control purposes.

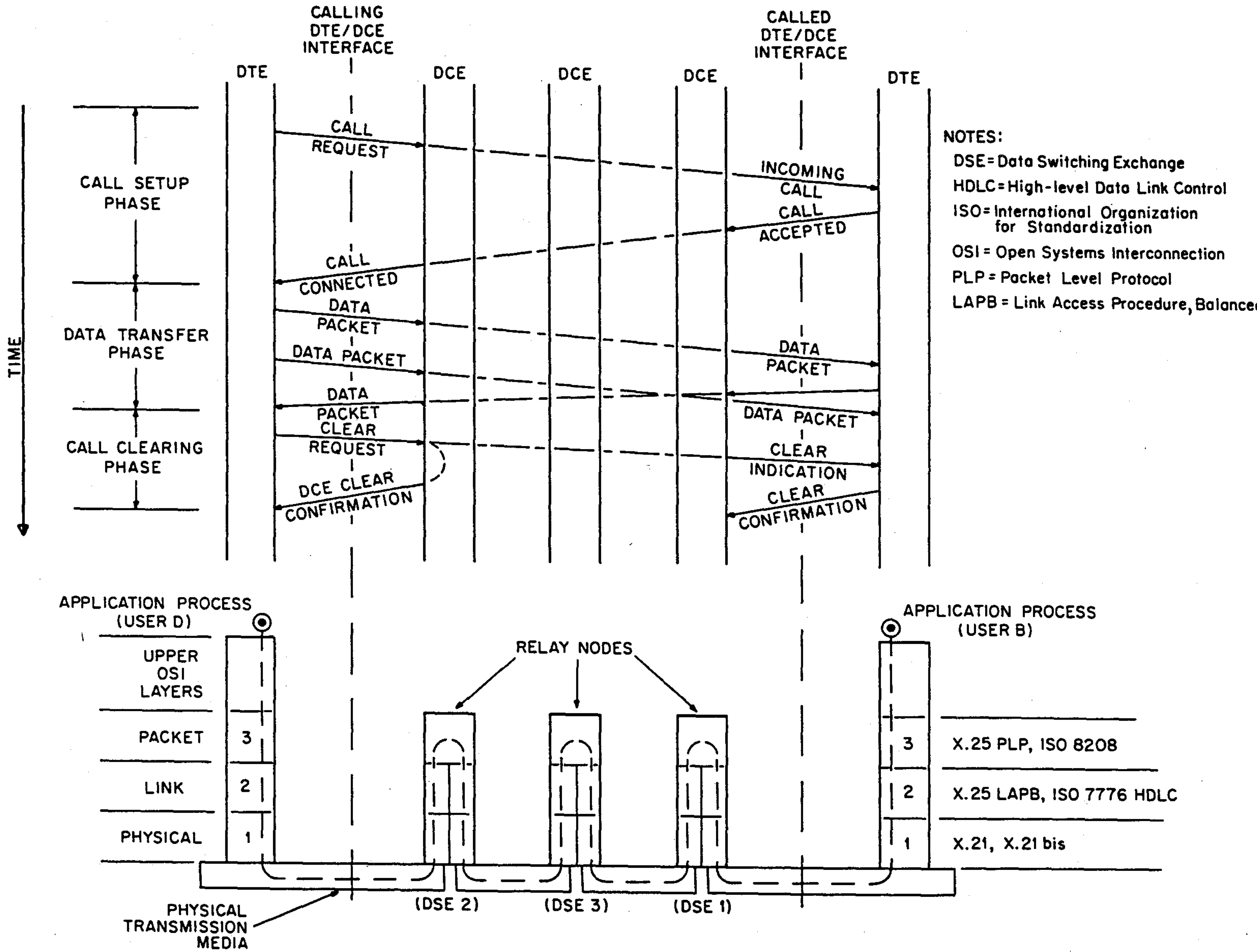


Figure 6. DTE package exchange and relation to open systems interconnection.

Both reasons translate into a cost of changeover. For an "interim period," X.21 bis (CCITT, 1984d) which encompasses EIA-232-C (EIA, 1969) and EIA-449 (EIA, 1977) is acceptable.

At the data link layer (i.e., link level for X.25), the protocol is intended to provide three basic functions:

- o link initialization, which is necessary to begin communication in a known state
- o flow control, between user systems, which is necessary to ensure that data frames are not sent more quickly than they can be received
- o error control, which is necessary to detect mutilated frames and ensure against losing entire frames.

In general, the intent of CCITT X.25 LAPB (and LAP) and ISO 7776 (HDLC) is to control errors on the transmission lines between 1) user equipment and the PSPDN or 2) two DTEs without an intervening network.

At the network layer (i.e., packet level for X.25) the protocol function is to access a public (or private) packet-switched network through a dedicated or circuit-switched connection, with the switched connection being according to ISO 8208. The packet level protocols (PLPs) deal with addressing, call setup and clearing, data transfer and delivery confirmation, flow and error control related to the communications network, and provide a reset and restart capability. The reset and restart enables the reinitializing of communication network paths should error(s) occur at the packet level.

There are three supplemental standards related to CCITT X.25 that define a PAD facility. These are CCITT Recommendations X.3 (CCITT, 1984e), X.28 (1984f), and X.29 (1984g). The PAD facility allows nonintelligent asynchronous DTEs (without the capability to incorporate X.25 procedures) to communicate over a packet-switched network with a host computer or terminal that uses X.25. The PAD is a separate box containing hardware and software that is attached to the terminal. The standards define the facility as follows:

- o X.3 describes the PAD functions and parameters that are used to control the nonintelligent start-stop terminal
- o X.28 describes the protocol between a terminal and PAD
- o X.29 describes the protocol between two PADs or between a PAD and a packet mode DTE.

3.1 Physical Level

This section will describe the functions and operation of CCITT X.21 and EIA-232-D. The first is described because of its embedded relationship within X.25, the second because of its dominant position in the United States as a DTE/DCE interface standard.

3.1.1 X.21 Interface

CCITT Recommendation X.21, "Interface Between the Data Terminal Equipment (DTE) and Data Circuit-Terminating Equipment (DCE) for Synchronous Operation on Public Data Networks," is applicable for use with both circuit- and packet-switched networks.

Earlier, an X.25 DCE was described as being different than the normally understood definition of a DCE. Differences will now be described concerning CCITT X.21, which is often considered only as a physical layer interface standard. The misconception arises from two factors: 1) X.21 specifies physical characteristics of the interface, and 2) call control procedures for data connection in a circuit-switched network are analogous to data transfer in a physical circuit. Assigning call control procedures within the physical layer is incorrect because circuit- and packet-switched call establishment has similar functionality--that is, to establish network connections (Pense, 1984).

There is, however, a difference in functionality between call setup and data transfer states for circuit- and packet-switched networks. In circuit-switched networks, the first three layers of the OSI reference model are involved during call establishment. For example, the network layer is involved in switching and routing between end users. Once the connections between users are made only the physical layer is involved in the data transfer phase.

In packet-switched networks the functionality of the first three layers of the OSI reference model is involved not only during the call setup state, but during the data transfer state as well. The critical point is that X.21 is literally a two-part standard. In the first part, the physical elements of X.21 apply to circuit- and packet-switched public data networks. In the second part, the recommendation describes the control procedures for connections in a circuit-switched network. Ordinarily, only the physical elements of the first part will apply to X.25.

At layer 1 of the OSI reference model, X.21 provides for data signaling rates that apply to circuit- and packet-switching. (Appendix B identifies standards concerning electrical, functional, and mechanical characteristics for X.21, X.21 bis, and equivalent U.S. standards.)

Layer 2, the data link layer of the OSI reference model, provides for synchronization, error detection, error recovery, and flow control functions. These functions are specified within X.21 for circuit-switched applications using a character-oriented protocol. For packet-switched networks, these same functions are performed by bit-oriented protocols such as X.25 LAPB and ISO 7776 HDLC.

Layer 3, the network layer of the OSI reference model, provides for connection control, multiplexing, and network-dependent error and flow control. For circuit switching, X.21 specifies only connection establishment and release i.e., connection control. Connection control and other layer 3 functions for packet switching are according to X.25 and ISO 8208 packet level protocols.

3.1.2 Description: X.21

The electrical characteristics of X.21 comply with CCITT Recommendations X.26 (CCITT, 1984h) and X.27 (CCITT, 1984i). These are equivalent to CCITT V.10 and V.11, respectively. (See Appendix B.) A 15-pin, D-type connector is defined by ISO 4903. The connector carries eight DTE/DCE interchange circuits that are defined according to procedural definitions in CCITT X.24 (CCITT, 1984j). The DTE/DCE physical interface lines are depicted according to conventional understanding in Figure 7. According to X.24, the interface between the DTE and DCE is located at a connector that is the interchange point

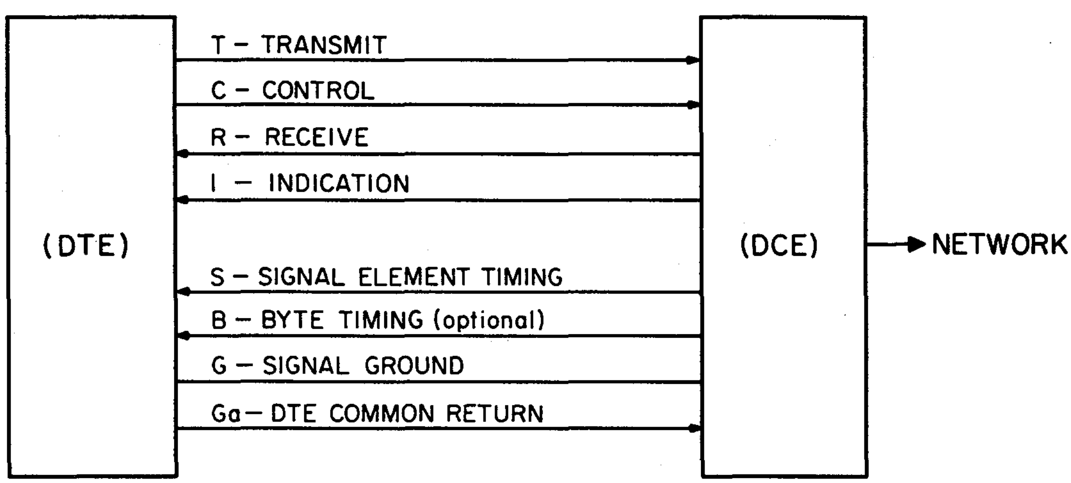


Figure 7. X.21 signal interchange lines.

between the equipment. As explained in Section 2, this DTE/DCE physical interface is not necessarily the X.25 interface. This depiction is best suited to a circuit-switched network. It illustrates one of the many anomalies that exist in standards work.

The functions of the interchange circuits are as follows:

- Circuit T: Transmit (to DCE)
  Carries control signals during call control phases and data during data transfer phase.

- Circuit C: Control (to DCE)
  Provides control information (i.e., on-hook, off-hook) in conjunction with the T circuit.

- Circuit R: Receive (to DTE)
  Similar to T, but in opposite direction.

- Circuit I: Indication (to DTE)
  Works in conjunction with circuit R by providing indicators that R has data or control signaling from the distant DTE.

- Circuit S: Signal element timing (to DTE)
  Provides bit timing for synchronous operation.

- Circuit B: Byte timing (to DTE)
  Provides signals that are used for grouping bits into octets (optional).

- Circuit G: Signal ground or common return.

- Circuit Ga: DTE common return.

Extensive information is contained in figures and tables of X.21 describing transition states for call control and data transfer during circuit-switched service. There are two basic phases of the interface to consider: quiescent and operational (Table 1). There are two states in the quiescent phase: ready and not ready. All characters for call control purposes are selected from International Alphabet No. 5 (IA5) according to Recommendation T.50 [equivalent to ISO 646, ANSI X3.4 (American Standard Code for Information Interchange--ASCII), and FIPS PUB 15]. During call control when information is exchanged between the DTE and DCE, correct alignment of characters is necessary. Two or more "SYN" characters precede each sequence of call control characters to establish alignment.

Table 1. X.21 Phases of Interface Signals

Quiescent Phase	Result
Ready State DTE T = 1, C = off DCE R = 1, I = off	DTE or DCE can enter operational phase.
Not Ready State DTE T = 0, C = off DCE R = 0, I = off	DTE or DCE is inoperative.
Operational Phase	**Result**
DTE DTE T = DATA, C = on DCE R = DATA, I = on	States needed during circuit and packet-switched data transfer.

An edited version of transitions between states is given in Table 2. Based on an example by Tannenbaum (1981) this illustration of a circuit-switched connection between DTEs illustrates some features of X.21. An originating DTE places a call to a remote DTE, data bits are exchanged, and then the connection is cleared by the originating DTE. The transitions are described in two parts according to X.21 terminology (state) and as an analogy with the telephone system.

According to CCITT convention, one is OFF and zero is ON. In the READY (on-hook) state the four signaling lines are all ones (Step 1 in Table 2). To place a call, a DTE sets T = 0 and C = ON (Step 2). This is similar to a person picking up the handset to place a telephone call. The DCE begins sending an IA5 (ASCII) "+" character on the R line (a digital dial tone) signaling the DTE that address dialing can begin (Step 3). The remote DTE is dialed by IA5 characters being sent on the T line (Step 4). Call progress signals are now sent by the DCE to inform the DTE of call status such as call completed (phone rings) or try again (number busy) and others according to CCITT Recommendation X.96 (Step 5). If the call is accepted the DCE sets the I line to ON (Step 6) and, in a full-duplex connection, data exchange can be begin (Step 7). Either the originating or remote DTE can begin call termination by setting the C line to OFF. With this action a DTE cannot send

Table 2. Some X.21 Transitions for Call Placement, Data Transfer, and Call Clearing

Step	State	DTE		DCE		Telephone Analogy
		T	C	R	I	
1	Ready	1	off	1	off	No connection, Idle (on-hook)
2	Call Request	0	on	1	off	DTE picks up phone
3	Proceed to Select	0	on	+	off	DCE gives dial tone
4	Selection Signal	IA5	on	+	off	DTE dials phone number
5	Call Progress Signal (X.96)	1	on	IA5	off	Remote phone rings
6	Call Accepted	1	on	1	on	Remote phone picked up
7	Data Transfer	Data	on	Data	on	Conversation
8	DTE Clear Request	0	off	Data	on	DTE says goodbye
9	DCE Clear Indication	0	off	0	off	DCE hangs up
10	DCE Clear Confirmation	0	off	1	off	DCE hangs up
11	Ready	1	off	1	off	DTE hangs up (on-hook)

Notes:
1) T = Transmit (to DCE)
2) C = Control (to DCE)
3) R = Receive (to DTE)
4) I = Indication (to DTE)

more data, but it must accept data from the other DTE until the transfer is completed (Step 8). The originating DCE now sets the I line to OFF (Step 9). After the remote DTE sets its C line to OFF, the DCE at the originating DTE will set R = 1 (Step 10). The originating DTE then sets T = 1 as an acknowledgment to the DCE and the interface is again in a Ready (on-hook) state.

In the event of call collision, when outgoing and incoming calls arrive simultaneously, the incoming call is cancelled and the outgoing call is placed.

The link and packet level protocols of X.25 function when the C and I lines are ON (Steps 6 and 7).

3.1.3 Description: EIA-232-D

Interface standard EIA-232-D (EIA, 1985) is a revision to EIA-232-C (EIA, 1969), one of the four options in X.21 bis. The revisions bring the standard into compliance with CCITT and ISO standards. Electrical characteristics comply with CCITT Recommendation V.28 (CCITT, 1984l) and functional characteristics with V.24 (CCITT, 1984m). A 25-pin, D-type connector is defined by IS 2110. Specific revisions reflect the addition of a specification for the 25-pin interface connector, inclusion of the Local Loopback, Remote Loopback and Test Mode interchange circuits, redefinition of Protective Ground, and the addition of Shield. Terminology changes are Driver to Generator and Terminator to Receiver (EIA, 1985).

The electrical characteristics specify digital signaling parameters for the interchange circuits between the DTE and DCE. For timing and control circuits, the function is considered ON when the voltage is more positive than +3 v with respect to signal ground (circuit AB) and OFF when the voltage is more negative than -3 v with respect to signal ground (Table 3). The signaling rate is to be 20 kb/s, or less, when the effective shunt capacitance of the load is 2500 pf, or less. A distance is not specified for the signaling rate in EIA-232-D. However, EIA-232-C specified 15 m for 20 kb/s.

The interchange circuits between DTEs and DCEs fall into four categories:

ground or common return
data circuits
control circuits
timing circuits.

Table 3. EIA-232-D Interchange Voltage Interpretations

Interpretation	Interchange Voltage	
	< -3 v	> +3 v
Binary State	1	0
Signal Condition	Marking	Spacing
Function	OFF	ON

Table 4 provides a list of equivalent interchange circuits for EIA-232-D, CCITT V.24, and EIA-449. A footnote for Table 4 identifies those circuits that are specified for leased circuits, packet-switched service (X.25, Level 1) of direct call and address call facilities. Those 14 circuits will now be defined.

Circuit AB (CCITT 102) - Signal Ground or Common Return
Common ground reference for all interchange circuits.

Circuit BA (CCITT 103) - Transmitted Data
Data generated by the DTE for transmission.

Circuit BB (CCITT 104) - Received Data
Data received by the DTE from a remote DTE.

Circuit CA (CCITT 105) - Request to Send
Conditions the local DCE for data transmission.

Circuit CB (CCITT 106) - Clear to Send
Indicates to the DTE whether the DCE is ready to send data in response to Request to Send.

Circuit CC (CCITT 107) - DCE Ready
Signals on this circuit indicate status of local DCE (e.g., off-hook condition).

Circuit CD (CCITT 108.2) - DTE Ready
Signals on this circuit control switching of the DCE to the communication channel.

Circuit CE (CCITT 125) - Ring Indicator
The DCE indicates to the DTE through an ON condition that a ringing signal is being received. Not needed for leased or packet-switched services.

Table 4. Equivalent Interchange Circuits

EIA-232-D	CCITT V.24	EIA-449	Description	Gnd	Data		Control		Timing	
					From DCE	To DCE	From DCE	To DCE	From DCE	To DCE
AB	102[1]	SG	Signal Ground/Common Return	X						
BA	103[1]	SD	Transmitted Data			X				
BB	104[1]	RD	Received Data		X					
CA	105[1]	RS	Request to Send					X		
CB	106[1]	CS	Clear to Send				X			
CC	107[1]	DM	DCE Ready				X			
CD	108.2[1]	TR	DTE Ready					X		
CE	125[2]	IC	Ring Indicator				X			
CF	109[1]	RR	Received Line Signal Detector				X			
CG	110	SQ	Signal Quality Detector				X			
CH	111	SR	Data Signal Rate Selector (DTE)					X		
CI	112	SI	Data Signal Rate Selector (DCE)				X			
DA	113	TT	Transmitter Signal Element Timing (DTE)							X
DB	114[1]	ST	Transmitter Signal Element Timing (DCE)						X	
DD	115[1]	RT	Receiver Signal Element Timing (DCE)						X	
SBA	118	SSD	Secondary Transmitted Data			X				
SBB	119	SRD	Secondary Received Data		X					
SCA	120	SRS	Secondary Request to Send					X		
SCB	121	SCS	Secondary Clear to Send				X			
SCF	122	SRR	Secondary Received Line Signal Detector				X			
RL	141[3]	RL	Remote Loopback					X		
LL	140[1]	LL	Local Loopback					X		
TM	142[1]	TM	Test Mode				X			

Notes:
1) These interchange circuits are listed in X.21 bis for synchronous transmission using leased-circuit service, packet-switched service (X.25, Level 1), or direct call and address call facilities.
2) Add for use with direct call or address call facilities.
3) Add for use with leased circuits and packet-switched services.

Circuit CF (CCITT 109) - Received Line Signal Indicator
Indicates to the DTE that a carrier signal is being received by the DCE.

Circuit DB (CCITT 114) - Transmitter Signal Element Timing
The DCE provides clocking signals to the DTE so that data on Circuit BA (Transmitted Data) is timed according to Circuit DB.

Circuit DD (CCITT 115) - Receiver Signal Element Timing
Clocking signal for Circuit BB (Received Data).

Circuit LL (CCITT 141) - Local Loopback
The DTE initiates action so that signals are used to control the LL test condition in the local DCE. This determines whether the DCE and local interface are working properly.

Circuit RL (CCITT 140) - Remote Loopback
The DTE provides control signals to the DCE to activate a loopback at the remote DCE while isolating the remote DTE during the test.

Circuit TM (CCITT 142) - Test Mode
Signals indicate whether the local DCE is in a test condition.

A subset of the control circuits is usually implemented to control data transmission and reception. There are five control circuits (CA, CB, CC, CD, CF) that must be in the ON condition for this implementation of the OSI physical layer to allow data to be sent (Circuit BA) and received (Circuit BB).

Table 4 shows equivalency for EIA-449 (EIA, 1977) circuits that can operate to 100 kb/s for 12 m using EIA-423-A (unbalanced configuration) and 100 kb/s for 1200 m using EIA-422-A (balanced configuration). This distance will decrease to 12 m at 10 Mb/s. These signaling rates are transmitted on 24 AWG twisted-pair copper conductors. Despite better performance characteristics of EIA-449, the implementation has not matched EIA-232-D (and preceding versions) due to higher cost and the entrenchment of the latter.

3.1.4 CCITT V.35/V.28/V.24

Another option within X.21 bis is the combination of CCITT Recommendations V.35, V.28, and V.24. Appendix II of V.35 (CCITT, 1984k) specifies electrical characteristics for <u>balanced</u>, double-current interchange circuits that are used for data and timing. CCITT V.28 (CCITT, 1984l) applies to electrical characteristics for <u>unbalanced</u>, double-current control circuits (Table 5). The functions of the interchange circuits for V.35 and V.28 are defined in V.24 (CCITT, 1984m).

Table 5. V.35/V.28/V.24 Circuits

	Interchange Circuit (V.24)	Function
Data and Timing (V.35)	103	Transmitted Data
	104	Received Data
	114	Transmitter Signal Element Timing
	115	Receiver Signal Element Timing
	102	Signal Ground or Common Return
Control (V.28)	105	Request to Send
	106	Ready for Sending
	107	Data Set Ready
	109	Data Channel Receive Line Detector

Voltage levels for V.35 operation are as shown in Table 3. This X.21 bis option is intended for 48 or 56 kb/s operation. Further study has been proposed to perform a test of cable length corresponding to actual operation.

3.1.5 Signaling Rates

CCITT X.25 operates in user classes of service 8 to 11 as defined in CCITT X.1. User classes of service are data signaling rates of 2.4, 4.8, 9.6, and 48 kb/s for DTEs operating in the synchronous mode using the X.25 interface. Since 56 kb/s is a standard signaling rate in North America according to ANS X3.1, it is recommended in place of 48 kb/s. The use of 64 kb/s (also part of X.1) is for Integrated Services Digital Network (ISDN) service.

3.2 Link Level

Link access procedures that are used for data interchange between a DCE and a DTE or between two DTEs are described in this section. One of these procedures, the HDLC is a bit-oriented protocol. Other protocols that are based on HDLC, but incompatible, are ANSI X3.66, Advanced Data Communications Control Procedures (ADCCP), Burroughs Data Link Control (BDLC), IBM Synchronous Data Link Control (SDLC), and Sperry Universal Data Link control (UDLC).

The HDLC, X.25 LAPB, and the other protocols satisfy the basic functions of the OSI data link layer. The link layer provides for three basic DTE functions.

- link initialization, which allows the DTE to begin operation in a known state.
- flow control, which ensures that frames are sent at a rate that does not create an overflow between DTEs or a DTE and a DCE.
- error control, (at the link layer) to detect errors in frames through a cyclic redundancy check (CRC) and sequence numbers to protect against the loss of entire frames.

Both LAPB and LAP are described in the link level element (Section 2) of X.25. Both procedures can operate over a single physical circuit but LAPB can also operate over multiple physical circuits (also known as multilink operation). The LAP protocol, which was originally developed for X.25 (1980), is not part of X3.100 nor FIPS PUB 100/FED STD 1041. The LAP is part of X.25 in support of existing systems; LAPB, compatible with HDLC, is the preferred procedure.

It should be noted that CCITT X.25 LAPB is a description of operation as viewed by the DCE while ISO 7776 provides a description as viewed by the DTE at the link level. CCITT X.25 specifies the DCE side of the DTE/DCE interface. ISO 7776 (and 8208 at the packet level) specify the DTE/DTE interface and the DTE side of the DTE/DCE interface. Some differences may exist between LAPB and ISO 7776 but there is compatibility.

3.2.1 Basic Characteristics

There are three types of stations, three types of link configurations, and three data transfer modes defined in the HDLC and related standards. From the following we will determine the definitions that apply to X.25 LAPB.

The station types are

- Primary: This station has the responsibility of controlling the operation of a link. A primary station sends commands and receives responses from the secondary station(s) on the link.
- Secondary: This station operates under the control of the primary station. A secondary station receives commands from, and sends responses to, the primary station.
- Combined: This station is used where equal control is required at both ends of a link by combining the features of primary and

secondary stations. A combined station sends and receives both commands and responses.

The link configurations are

- o Unbalanced: a configuration that has one primary station and one or more secondary stations. This configuration is used in point-to-point and multipoint operation with half-duplex and duplex transmission (Figure 8a).

- o Symmetrical: a configuration that has two independent, point-to-point, unbalanced logical station configurations multiplexed on a single data link (Figure 8b). There are two primary-to-secondary station logical channels with the primary stations having overall responsibility for mode setting. Half-duplex and duplex operation is supported. This configuration is used in the original LAP, which is part of X.25 (1984). It is not supported in ISO 7776 HDLC.

- o Balanced: a configuration that consists of two combined stations that are connected only for point-to-point operation. Half-duplex and duplex operation is supported (Figure 8c). This configuration is used in X.25 LAPB with duplex transmission.

Communication between two stations is conducted in three logical states: information transfer, initialization, or logically disconnected. There are three modes of operation for information transfer:

- o Normal Response Mode (NRM): This mode is an unbalanced configuration where the secondary station may transmit information only as the result of responding to a primary station (i.e., polling). This mode is on multi-drop lines and point-to-point links although not efficient on the latter due to polling overhead.

- o Asynchronous Response Mode (ARM): This mode is an unbalanced configuration in which the secondary station may initiate transmission without receiving explicit permission from the primary station. This mode is used infrequently.

- o Asynchronous Balanced Mode (ABM): This is a balanced configuration where transmission can be initiated without receiving permission from the other combined station.

There is one mode during the initialization state. During the Initialization Mode (IM), a secondary or combined station may be initialized by a primary or combined station when it appears, for example, that the secondary or other station is not operating normally.

There are two modes during the logically disconnected state (LDS). In the Normally Disconnected Mode (NDM) the secondary station is logically

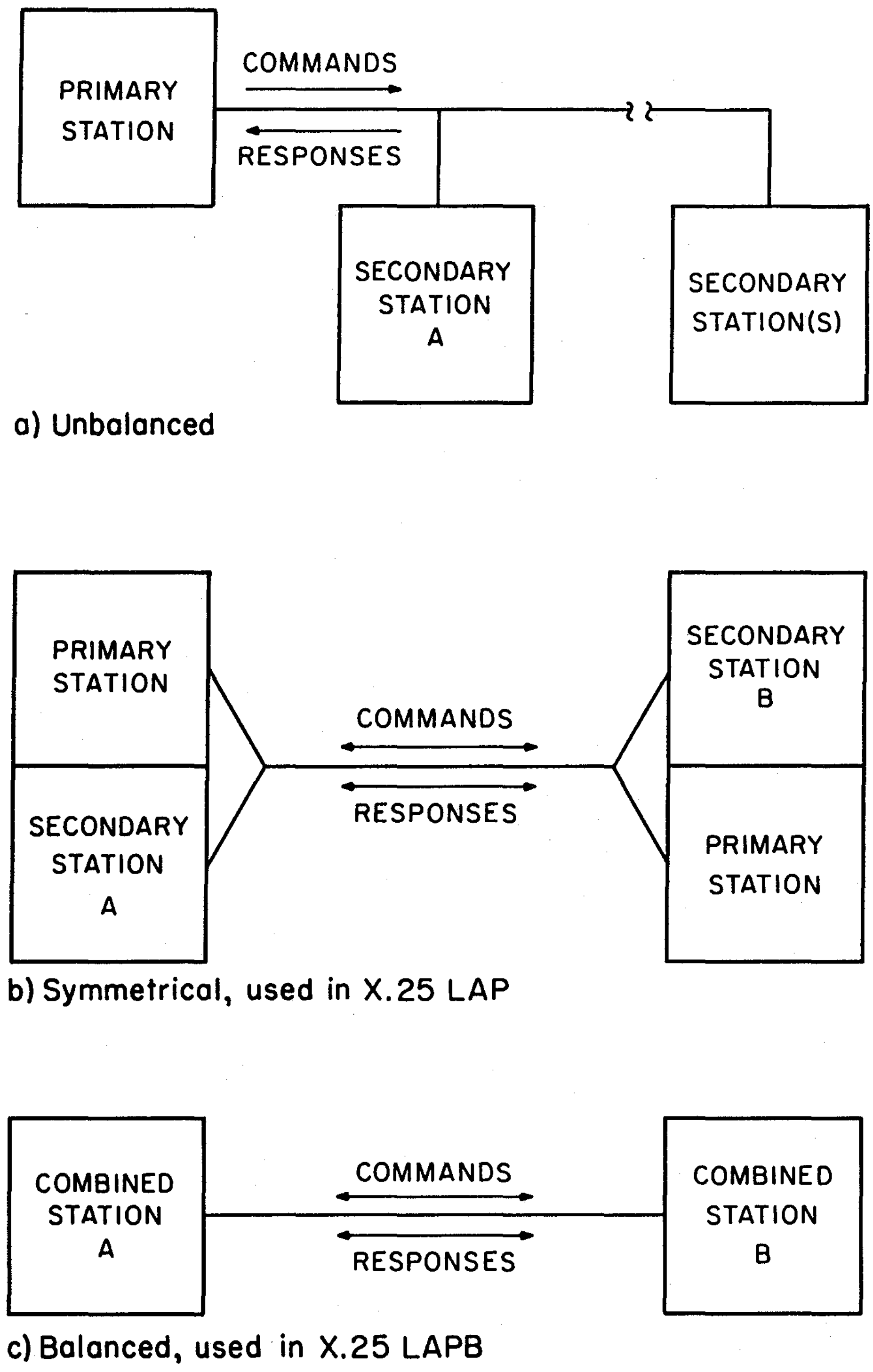


Figure 8. Link configurations.

disconnected from the unbalanced data link configuration and cannot receive or initiate information. The Asynchronous Disconnected Mode (ADM) applies to balanced or unbalanced link configurations. In ADM a secondary or combined station is logically disconnected from the link and is not permitted to initiate or receive information. However, a single frame indicating station status can be sent by the secondary/combined station without explicit permission.

From the definitions for stations, link configurations, and modes of operation during logical states one can determine which apply to X.25 LAPB (Table 6).

Table 6. HDLC Characteristics Applicable to X.25 LAPB

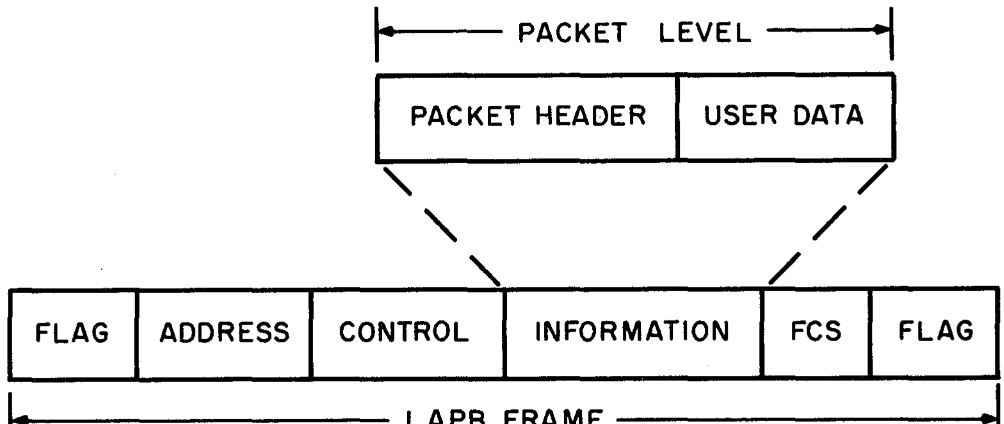
Characteristic	Operation
Station	Combined
Link Configuration	Balanced
Modes	Asynchronous Balanced Mode (ABM)
	Asynchronous Disconnected Mode (ADM)
	Initialization Mode (IM)
Transmission	Duplex, Synchronous

As can be seen, many of the procedures that have been defined are unnecessary for packet network operation. The following sections will concentrate on the applicable requirements for X.25 LAPB operation.

3.2.2 Frame Structure

There are two frame structures, one for basic (modulo 8) and one for extended (modulo 128) operation. The LAPB modulo 8 procedure is available on all networks while the LAPB modulo 128 is optional according to CCITT X.25. The modulo 128 provides an extended frame sequence numbering where more packets need to be outstanding (without acknowledgment) between stations as in a satellite transmission where delays are longer. Also, there are single-link procedures (SLPs) for data interchange between a DCE and a DTE over a single physical circuit (LAPB or LAP) or optionally over multiple physical circuits (LAPB). The initial descriptions of the frame structure will adhere to modulo 8 single-link procedures while the modulo 128 and multilink procedure will be mentioned as appropriate.

The frame structure is shown in Figure 9. Also shown is the relationship of packet level data within the information field. The packet level descriptions are given in the next section.



<u>FIELDS</u>

Flag: 8 bits = 01111110
Address: one octet
Control: one (modulo 8) or two (modulo 128) octets
Information: variable
Frame Check Sequence (FCS): 16 bit cyclic redundancy check (CRC)

Figure 9. Frame structure and packet level relationship.

<u>FLAG FIELD (8 bits)</u> - All frames start and end with the sequence 01111110. Synchronization is achieved as the DTE hunts continuously for this sequence. Only one flag is needed as both the closing flag for one frame and the opening flag for the next frame. "Bit stuffing" is used to avoid the loss of synchronization. A transmitter inserts a zero bit in any field within a frame (between flags) after the occurrence of five consecutive ones. The receiver continuously examines the bit stream to determine the appearance of five ones. If the sixth bit is a zero, that bit is deleted and the five 1s are passed as data; if the sixth bit is a 1, the receiver inspects the seventh bit; if the seventh bit is a zero, a flag sequence has been received; if it is a 1, an abort has been received. An abort is performed by the transmitter when at least 7, but less than 15 contiguous one bits are sent without zero insertion. (Note that this discussion could be interpreted to center on the second through eighth bits in a flag field.)

ADDRESS FIELD (one octet) - The address field identifies the intended receiver of a command frame and the transmitter (i.e., combined station) of a response frame. The address field also allows for differentiation between single link or the optional multilink operation through bit encoding (2.42/X.25). (Note: this notation indicates the paragraph number in X.25.)

CONTROL FIELD (one or two octets) - The control field consists of one octet for modulo 8 (basic operation) and one or two octets for modulo 128 (extended operation): one octet for frame formats that do not contain sequence numbers and two octets for those that do (2.3.2/X.25).

There are three types of control field formats. A frame can contain an information (I), supervisory (S), or unnumbered (U) control field (Figure 10).

BIT ORDER	1*	2	3	4	5	6	7	8
I: Information	0	N(S)			P	N(R)		
S: Supervisory	1	0	S	S	P/F	N(R)		
U: Unnumbered	1	1	M	M	P/F	M	M	M

* Low order bit transmitted first

N(S) = Send sequence number
N(R) = Receive sequence number
S = Supervisory function bit
M = Modifier function bits
P/F = Poll/Final bit
P = Poll bit (Poll = 1)

Figure 10. LAPB control field formats for basic operation.

o The I format is used to transfer data for the station. Only I frames have the send sequence number N(S), the number of the transmitted frame. Variable S acts as a frame counter and takes on the value of the modulus (8 or 128) minus one. For modulo 8 operation the maximum value of outstanding (unacknowledged) frames would be 7 (k = 7). The variable S is incremented by one each time there is a completed I frame transmission.

The I frames (and S frames) also contain N(R) which is the expected sequence number of the next received I frame. The variable R is equal to the expected N(S) contained in the next I frame received. The use of N(S) and N(R) is for flow and error control between the DTE and DCE. N(R) serves as an acknowledgment for frames received.

The poll (P) bit set to one is used by the DCE or DTE to solicit a response from the DTE or DCE, respectively.

- The S format is used by the DTE to perform data link supervisory control functions such as to acknowledge request transmission, or to request the temporary suspension of transmission of I frames. In a response frame the P/F bit is known as the final (F) bit. When set to one by the DCE or DTE it indicates that the response frame sent by the DTE or DCE, respectively, is the result of a poll command. The supervisory (S) function bits in the format are encoded for commands and responses to indicate receive ready (RR), reject (REJ), and receive not ready (RNR).

  RR - is a supervisory frame used by the DCE or DTE to indicate command or response such as

  - readiness to receive an I frame
  - acknowledge previously received I frames
  - clearance of a busy condition due to RNR
  - status request (P = 1) of the DTE or DCE, respectively.

  RNR - indicates a busy condition or asks for DTE and DCE status with P = 1.

  REJ - is used to request transmission of I frames starting with N(R). Lower numbered frames [N(R) - 1] are acknowledged. Also used to indicate clearance of a busy condition due to RNR and request for DTE or DCE status with P = 1.

  Note that the three supervisory and five unnumbered commands that are used in X.25 LAPB and ISO 7776 are a subset of the complete HDLC/ADCCP command/response repertoire.

- The U format is used by the DTE to provide additional data link control functions. This format is unnumbered because it carries no sequence numbers, but it does include a P/F bit that may be set to 0 or 1. The five modifier (M) bits can be encoded for commands to indicate set asynchronous balanced mode (SABM) and disconnect (DISC). The M bits can also be encoded to indicate unnumbered acknowledgment (UA), disconnected mode (DM), and frame reject (FRMR). These are defined as follows:

  SABM - an unnumbered command that is used to place the addressed DCE or DTE in an ABM information transfer phase where all command/response fields will be one octet in length. SABME applies to extended (modulo 128) operation (2.3.4.5/X.25).

  DISC - an unnumbered command that terminates the mode (e.g., ABM) previously set by the DCE or DTE (2.3.4.6/X.25).

  UA - an unnumbered response by the DCE or DTE that acknowledges mode-setting commands (i.e., SABM, SABME, DISC). A UA response indicates the clearance of a busy condition that was reported earlier by the same DCE or DTE through an RNR frame (2.3.4.7/X.25).

DM - an unnumbered response that reports a status where a DTE or DCE is logically disconnected from the link, and is in the disconnected phase (2.3.4.8/X.25).

FRMR - an unnumbered response by the DCE or DTE that reports an error condition not recoverable by retransmission of the identical frame. Examples are receipt of a command or response control field that is undefined and receipt of an I frame where the information field exceeds the maximum permitted length (2.3.4.9/X.25).

Commands and responses within the supervisory and control field formats will be supported by DCEs and DTEs for basic and extended operation (2.3.4/X.25).

FRAME CHECK SEQUENCE FIELD (16 bits) - The FCS field shall be a 16-bit sequence. The notation used to describe the FCS is based on the property of cyclic codes that a code vector can be represented by a polynomial (2.2.7/X.25).

The order of bit transmission is such that addresses, commands, responses, and sequence numbers shall be transmitted with the low-order bit first (2.2.8/X.25).

3.2.3 Link Level Operation

The following text is adapted from "Examples of the Operation of Bit-Oriented Data Link Control Protocols," by J. W. Conard. It is part of a data communications tutorial series called OSI Data Transfer that is available from Omnicom, Incorporated, 501 Church Street NE, Suite 206, Vienna, VA, 22180. This text has been specifically edited to reflect LAPB operation.

The conventions that are used for illustrations in this section are shown in Figure 11. Each heavily marked arrow represents a single frame transiting a data link between two stations. The two stations involved are the data terminal equipment on the left, whose hypothetical link address is "A" (DTE A), and the DCE or remote DTE equipment on the right, whose link address is assumed to be "B" (DXE B).

Each heavy arrow includes a legend that describes the content and meaning of that particular frame. The legend includes the address, carried in the address field of the frame; the command or response type, coded in the control field of the frame; the setting of the P/F bit, bit five of the control field; and, where appropriate, sequence numbers. As is explained later, some examples do not include the address designator. P/F is only indicated where bit five is set to one. A "P" indicates that bit five of a command frame is set to one. An "F" indicates that bit five of a response frame is set to one. The absence of a P or F indicates that bit five is set to zero and has no meaning.

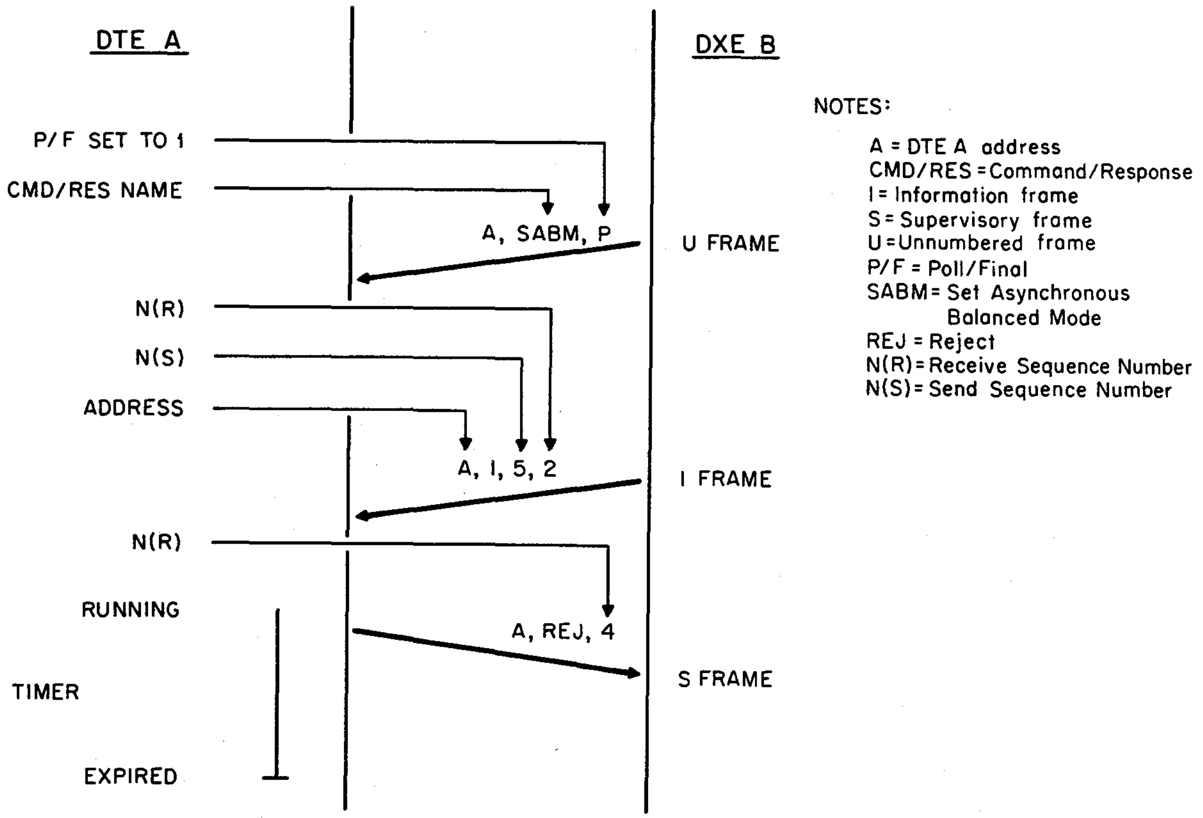


Figure 11. Conventions used in balanced operation examples.

Frames may be any of three types, each of which is illustrated in Figure 11. The U frame is an unnumbered command or response used to convey link control information. It is unnumbered because it carries no sequence numbers. The designation "A,SABM,P" in the example indicates that this frame is a Set Asynchronous Balanced Mode command addressed to station A and that it has the P-bit set to 1 to force a response.

The I frame is the information frame. It is the vehicle used to carry user data across the data link. The information frames are sequentially numbered. Each I frame carries both send and receive sequence numbers. The send sequence number, called N(S), is the number of each frame. The receive sequence number, called N(R), is the acknowledgment number. It indicates that all frames up to and including N(R)-1 have been successfully received. The N(R) is the next in-sequence frame expected to be received. In Figure 11, the legend "A,I,5,2" indicates that this is a command information frame sequence numbered 5 addressed to station "A". It also indicates that the sender, station "B", is expecting to receive frame number 2 next. It therefore acknowledges the correct receipt of frames numbered 1 and below.

The third frame shown in the convention example, the S frame, is a supervisory frame. The S frames are used to provide basic link supervision functions. There are three types of LAPB basic or extended supervisory commands and responses: Receive Ready (RR), Receive Not Ready (RNR), and Reject (REJ). The example "A,REJ,4" illustrates a Reject frame carrying the link address "A". Supervisory frames carry an N(R) indicating the next frame expected by the sender. In this case the sender next expects to receive frame number 4 and therefore acknowledges frames numbered 3 and below.

Link Addresses in Balanced Operation

There are some unique differences in the way the link level address is used in balanced operation as contrasted with the unbalanced operation. In unbalanced configurations, a unique address is assigned to each secondary station on the link. This address is contained in the address field of every frame transmitted by the primary to a secondary. This same address is also used by the secondary in every response frame that it sends to the primary. As a result, in unbalanced operation, the frame address field always identifies the secondary.

In balanced operation, a unique address is assigned to each of the two stations. Since the stations combine the attributes of both primary and secondary stations, they send both commands and responses to the other station, so that each station also receives both commands and responses from the other station. The address field is the mechanism used to tell the difference between a command and response. Another way to look at this is that the address field is used as the multiplexing tool to separate the two logically independent data streams sharing the link. While this sometimes seems confusing, there is a simple rule that may be applied to sort out the combined station address convention: Commands always carry the destination address; responses always carry the source address. Figure 12 illustrates address application in balanced configurations.

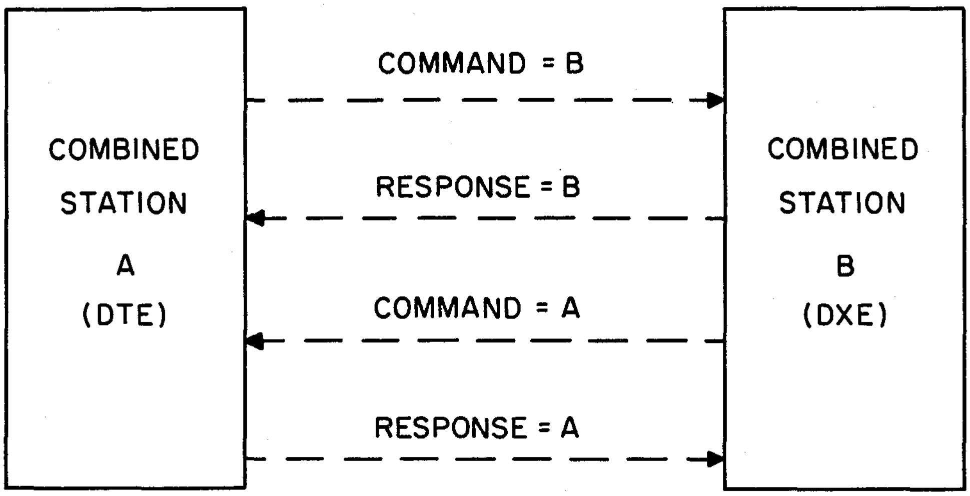


Figure 12. Balanced station address convention.

The examples of balanced operation that follow will make use of these conventions. Frame nomenclature will include the address. Link establishment, data transfer, link disconnect, and error recovery examples are shown. The examples also include the use of the Reject (REJ) option. These are useful in the balanced class of operation. Note that the examples of balanced protocol are directly applicable to the link level of X.25 LAPB. In the illustrations, station B on the right is identified as a DXE, designating it as either a DCE or a DTE.

In Figure 12, the receive algorithm from the perspective of station A is:

- If the address of the incoming frame is "A", the frame is a command,
- If the address of the incoming frame is "B", the frame is a response,
- If the address is neither "A" nor "B", discard the frame.

Establishing the Balanced Data Link

Normal Link Set-up. Balanced stations usually indicate that they are active by sending continuous flags over the link. As illustrated in Figure 13, many also go through a disconnect procedure prior to initializing the link. This, although not required by the rules, has the advantage of making sure the station is alive and ready to start up the link.

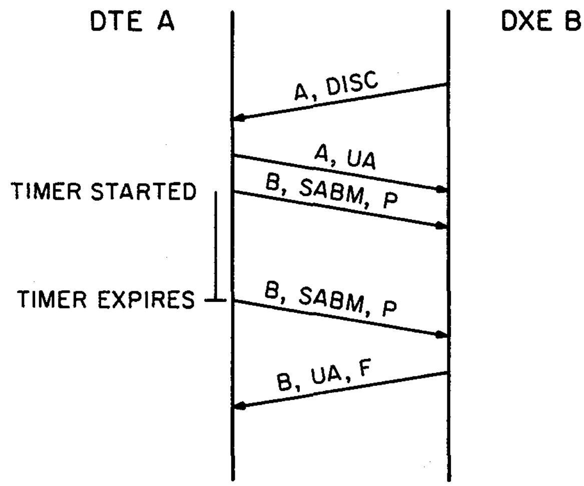


Figure 13. Balanced link set-up, no contention.

A station wishing to set up the data link transmits a Set Asynchronous Balanced Mode (SABM) command with the P bit set and starts the response timer. The other station, upon receiving the SABM, returns an Unnumbered Acknowledgment (UA) response and sets the local variables and counters to their initial values. The initiating station receives the UA response, resets its variables, and stops the timer. The data link is now active and either station may begin sending information frames.

Should the timeout expire without a UA response from the other station, the originator will repeat the SABM, as illustrated. This would be repeated until a UA is received or until, after N tries, the link is declared non-operational. In this case, higher-level intervention will be necessary (2.4.4/X.25).

Timers are used at the DTE or DXE to detect whether a required action or response has taken place within a predetermined interval--for example, an unnumbered response to a command. Error recovery or the reissuance of the P-bit occurs when the timer expires as shown in Figure 13.

Contention During Link Establishment. Since both stations on a balanced link have equal status, it is possible that they will both attempt to initialize simultaneously. This is called mode-setting contention and is resolved simply by giving a station the choice of when to assume the operational mode. Figure 14 illustrates this procedure.

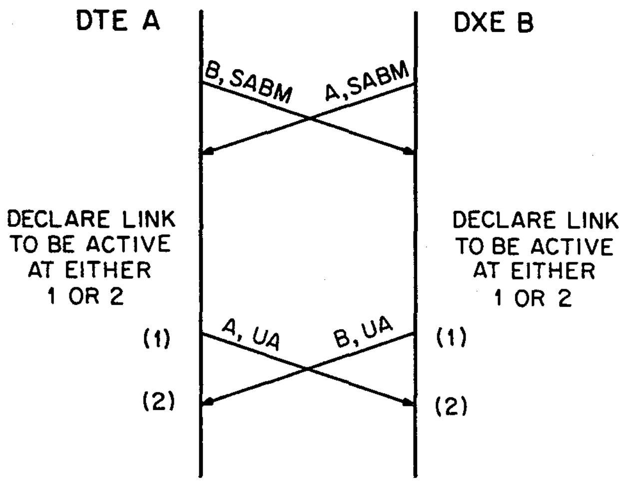


Figure 14. Balanced link set-up, with contention.

Assuming that the sent and received mode commands are identical, each station sends a UA response. The stations then may enter the operational mode either upon sending the UA response to the incoming command [(1) in the figure], or upon receipt of the UA response to their mode-setting command [(2) in the figure]. If the UA response is not received, the station can enter the mode after the timer expires or it may reissue the command.

If the colliding commands are different, the stations should go to disconnect mode and transmit a Disconnect Mode (DM) response before retrying.

Data Transfer Over Balanced Links

Examples of a simple one-way and a more complicated two-way simultaneous data transfer are given next. These are followed by illustrations of some error recovery situations.

Simple One-Way Data Transfer. Figure 15 illustrates a case of simple one-way transfer of user data between the DTE and DXE. Remember that in the case of X.25, the DXE represents the network node.

After the data link has been activated (Figure 13), either station can begin sending I frames. In this case, the DTE has been sending, and as the example begins, the DTE is sending an I frame carrying sequence number 5. Since the DTE has received no information frames from the DXE, frame 5 carries an N(R) of 0, indicating that the DTE is expecting frame 0. The DXE acknowledges frame 5 by sending an RR with an N(R) of 6. The RR is used because the DXE has no information frames to send.

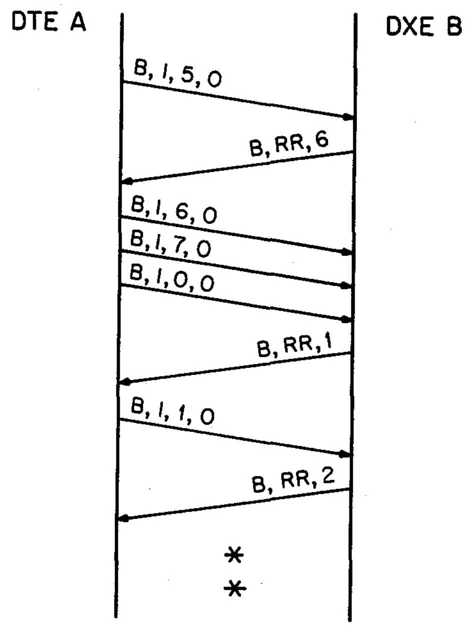


Figure 15. Simple one-way data transfer.

The DTE continues to transmit information in frames sequentially numbered 6, 7, and 0. (Remember that the modulus of sequence numbers is 8. An option for a modulus of 128 exists but is not used in these examples.) The DXE confirms receipt of frames 6, 7, and 0 with RR 1. The DTE then sends frame 1, which is acknowledged by the RR 2. Data transfer continues in this manner as long as the link is active.

Two-Way Simultaneous Data Transfer. Figure 16 illustrates the exchange of information frames in both directions simultaneously. Although it seems much more complicated, careful study will shown that it can be broken down quite simply. The apparent complexity arises primarily from the fact that acknowledgments of incoming frames are "piggy-backed" on outgoing frames.

In the example, DXE B is sending information frames sequentially numbered 0 through 5 to DTE A. Simultaneously, DTE A is sending information frames 0 through 3 to the DXE. Note that at the instant DTE A launches frame 1 (B,I,1,1), it has received frame 0 from the DXE but has not received frame 1. The N(R) of outbound frame 1 is therefore 1 acknowledging frame 0.

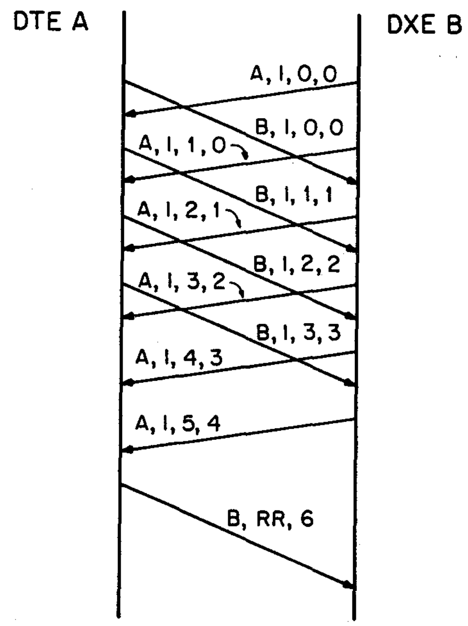


Figure 16. Two-way simultaneous data transfer.

Continuing with the fourth information frame from DTE A to DXE B, the frame is marked B,I,3,3. This acknowledges the receipt of three frames from DXE B. Further information frames are not sent from DTE A to DXE B, but three more frames arrive at DTE A that were received after B,I,3,3 was launched. The last frame sent from DTE A to DXE B is supervisory and acknowledges the receipt of six frames from DXE B. Note that N(S) is incremented with the transmission of each I frame.

As one studies the example, remember that a send sequence variable, called V(S) and manifested as the N(S) in the frame, and a receive sequence variable, called V(R) and manifested as the N(R) in the frames, exists for each direction of data flow. An information frame being transmitted carries, as the N(S), the current value of the station's V(S)--that is the sequence number of this frame. The frame also carries, as the N(R), the current value of this station's V(R)--this is the implicit "piggy-backed" acknowledgment of information frames numbered N(R) - 1 and below (2.4.5/X.25).

Flow Control and Busy Conditions. A "station busy" condition may arise whenever the station is temporarily unable to accept incoming information frames. This situation can be caused by some internal constraint, such as the receive buffers being exhausted or the station being engaged in some higher-priority task. Whenever the busy condition arises, the station must "throttle down" the input to avoid being overwhelmed by the incoming data. This process is called flow control. An example of flow control is given in Figure 17.

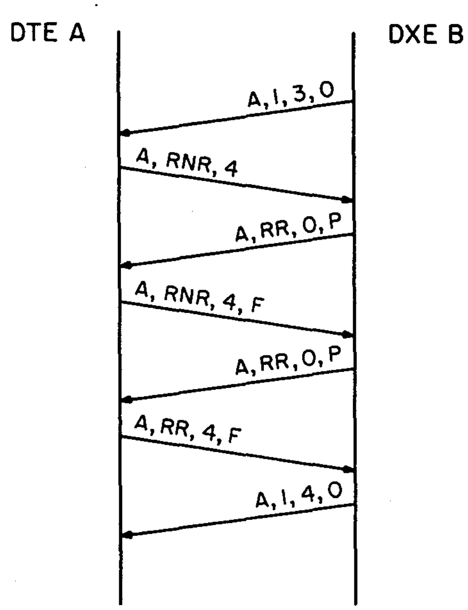


Figure 17. Station busy and flow control.

In the example, station A is receiving incoming information frames. For some system-dependent internal reason, it cannot accept additional frames. It indicates this to the other station by transmitting a Receive Not Ready (RNR) supervisory frame. Under the protocol rules, the station receiving the RNR, in this case DXE B, is to stop transmitting information frames immediately. The busy station is permitted to discard any information frames arriving after it sends the RNR.

The station receiving the RNR will usually poll the busy station at some periodic interval looking for a "not busy" response in the form of an RR. When the condition that caused the busy is cleared, the station sends an RR and data transfer can resume, beginning with the frame indicated by the N(R) in the "not busy" RR frame. As shown, the P or F bit is set.

Terminating a Balanced Data Link

It is important that all outstanding information frames be accounted for before an exchange is completed or before an active link is terminated. This procedure is illustrated in Figure 18.

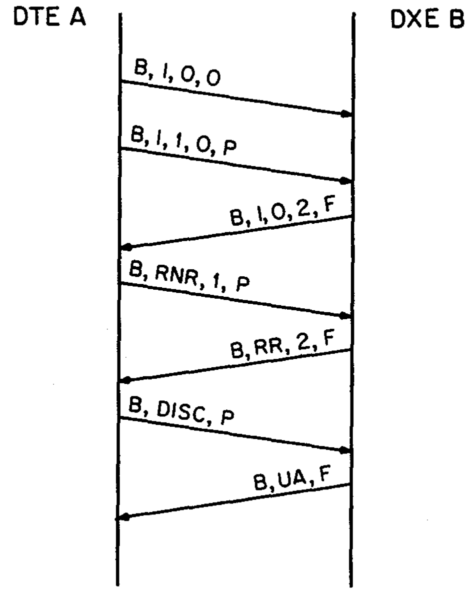


Figure 18. Closeout and termination.

DTE A, wishing to close out operations with DXE B sends a Receive Not Ready (RNR) command with the P bit set to one. This supervisory command acknowledges all outstanding information frames from DXE B. DXE B responds with an RR and an F bit. The response confirms that DXE B has received all DTE A transmissions. If DTE A wishes DXE B to remain in an active state, the sequence ends at this point. If, however, DTE A wishes to logically disconnect from DXE B, it will transmit a DISC command. DXE B will respond with a UA response and assume a logically disconnected state awaiting a subsequent mode-setting command.

Error Recovery in Balanced Operation

The final group of examples illustrates the basic error recovery procedures used in the balanced mode of operation. Most examples are applicable to all modes, subject only to the constraints imposed by station type, i.e., primary, secondary, or combined, and by the nature of the underlying facility--waiting for an idle link on an HDX circuit before transmitting, for example.

Timeout Recovery. Timeout functions are used to detect that the expected acknowledgment to a previously transmitted frame has not been received. Expiration of the response timeout causes recovery to be initiated (2.3.5.2.2/X.25).

Figure 19 illustrates the need for timer recovery. In this case, the last frame in a sequence of information frames (frame 3 here) was errored during transmission. Since it was the last frame, the receiver cannot know, by receiving a subsequent out-of-sequence frame, that the error occurred. The transmitter, however, started a response timer as the frame was transmitted. This timer has a duration long enough to span the expected response time. When the timer expires, the station initiates recovery action. This is usually done by polling the other station with an RR status request with the P bit set. Since the poll demands a response, the station will receive the current value of the V(R) at the other station as an N(R). In the case of the example, this will indicate that frame 3 is still expected and was, therefore, never received. With this information the lost frame can be retransmitted.

Reject Recovery. Bit-oriented protocols provide a recovery mechanism called Reject (REJ) which must be implemented by both stations (2.3.4/X.25). With REJ, the station detecting a sequence error can inform the sender immediately instead of waiting for the sender to detect the missing response through a P/F exchange. This makes operation on duplex links more efficient.

In Figure 20, the DXE becomes aware of the missing (discarded due to error) frame 4 as soon as it receives frame 5. At this point it transmits a REJ with an N(R) of 4. This cues the DTE to initiate retransmission of all frames sent, beginning with frame 4. It may continue to send additional frames after the retransmitted frames.

Only one REJ may be outstanding at any instant because of the implicit acknowledgment carried in the N(R) of the REJ. To send another REJ before recovering the first would be to acknowledge receipt of the frame that the station just said it was missing. The REJ condition is cleared upon receipt of an information frame with a sequence number equal to the N(R) of the reject frame (2.3.5.2.1/X.25).

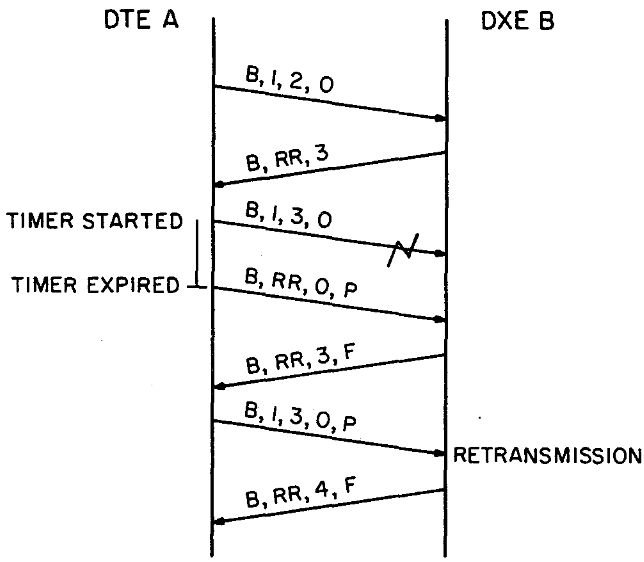


Figure 19. Timeout recovery.

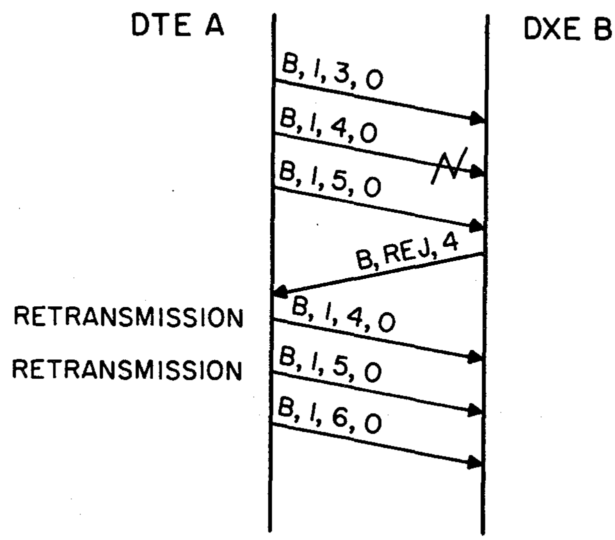


Figure 20. Reject recovery.

Frame Reject and Link Reset. Occasionally an abnormal condition occurs that is not recoverable by the normal recovery procedures. These situations call for the use of the Frame Reject (FRMR) response. Such conditions also will usually result in the resetting of the link and all variables and sequence numbers. Conditions that result in the transmission of an FRMR include the receipt of invalid or nonimplemented commands, receipt of an incorrectly constructed frame, receipt of an information field that is too long, or receipt of an invalid N(R), i.e., an N(R) that acknowledges a frame that has not been sent. This last case is illustrated in Figure 21.

The FRMR includes a link layer information field that is intended to aid the other station in diagnosing the problem. This information field includes a copy of the control field of the defective frame, the current values of the sender's sequence variables, and a group of four bits indicating the nature of the problem.

In the example, the DXE sends information frame 0 to the DTE and receives an RR 3 in response. The RR 3 confirms receipt of frame 2, a frame that has not been sent. In response, the DXE launches an FRMR frame that indicates "invalid N(R)" as a reason code. Since it now becomes obvious to the DTE that sequence number control has been lost, it reinitializes the link by sending an SABM command.

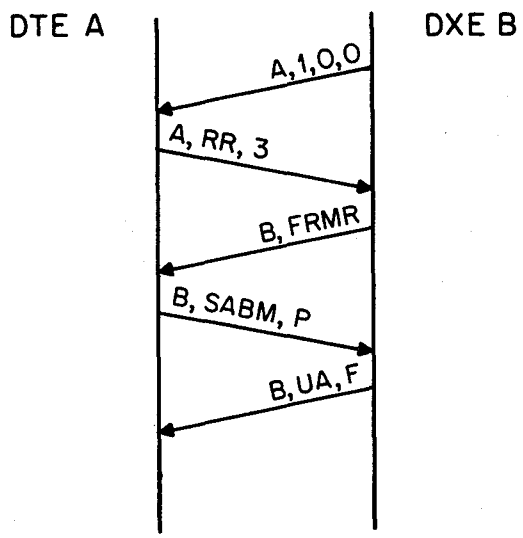


Figure 21. Frame reject and link reset.

It must be remembered that unacknowledged frames that are outstanding at the instant of a link reset remain unacknowledged and must be recovered, perhaps at a higher level.

3.3 Packet Level

The packet level governs the transfer of packets at a DTE/DCE or DTE/DTE interface. The packet level in a sending DTE performs the function of packetizing messages delivered from a higher level and then delivering the information to a link level protocol for transmission to a DXE (i.e., DTE or DCE). At the receiving DTE, the packet level receives packets from the link level, checks packets for correctness, removes packet level headers, and formulates messages from the packetized user data before transfer to a higher level. The packet level provides the following capabilities:

- multiplexing--sharing of communication facilities
- data transfer--sending and receiving data
- flow control--controlling data transfer rates
- interrupt transfer--transfer of information independent of the data stream
- error control--packet level error detection

- o reset and restart--to reinitialize communication paths should packet level errors occur.

Through these capabilities the packet level provides for two types of virtual circuits: the virtual call, which is similar to a telephone dial-up connection for data transfer between DTEs, and the permanent virtual circuit, which is similar to a leased line between DTEs (see Section 2).

The previous section described the envelopment of packet level data at the link level. The link access procedure, LAPB, a subset of the asynchronous balanced mode of HDLC, serves to provide negligible bit error rates and minimizes lost, duplicated, or out-of-sequence packets. Each packet to be transferred across the DTE/DXE interface is contained within the information field of the LAPB frame. The following section describes the packet types within the information field.

3.3.1 Packet Formats and Types

Both CCITT X.25 (Section 5) and ISO 8208 (Section 12) begin the description of packet formats with a potential for incorrect interpretation. Each document starts by describing the general format identifier (GFI) field. This might cause one to believe that the GFI follows the control field (see Section 3.2.2) in a LAPB frame. Not true. In an actual transmission the logical channel group number (LCGN) subfield, which is part of the logical channel number (LCN), follows the control field of the link level. The reason for this apparent discrepancy is the depiction of the packet format (Figure 22). Normally not noted by the reader is a clarification found in X.25 and 8208: "Bits of an octet are numbered 8 to 1, where bit 1 is the low-order bit and is transmitted first. Octets of a packet are consecutively numbered starting from 1 and are transmitted in this order." Many packet formats are described in X.25 and 8208, but all use the same basic format starting with the same three octets that contain the LCGN, the GFI, the LCN, and the packet type identifer.

<u>Logical Channel Group Number Field (4 bits)</u> - The LCGN combines with the eight bits of the second octet (LCN) to potentially identify 4096 logical channels. The LCGN has local significance only and is not part of the network channel numbering. The significance can be, for example, to identify a group of channels that are to be used for VCs, PVCs, and whether duplex or half-duplex transmission is used.

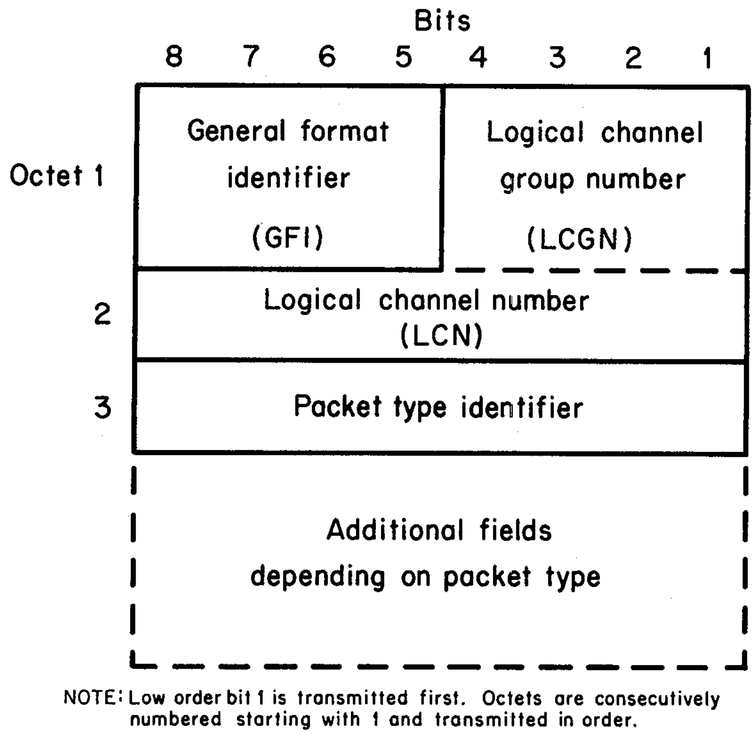


Figure 22. General packet format.

General Format Identifier Field (4 bits) - The GFI indicates sequence number modulo 8 or 128 and the type of packet that will follow. These include call setup, clearing, flow control, interrupt, and data packets. The GFI bits are as follows.

- Bit 8 is the Qualifier bit (Q-bit) in data packets that is used to identify two levels of operation. When Q = 1 it indicates data packets, but Q = 0 indicates all the other packet types. It is also used in X.29 to indicate control information or user data, respectively.

- Bit 7 is the delivery confirmation bit (D-bit). When D is set to one in the data and call set-up (i.e., call accepted, call connected) packets delivery confirmation of user data is requested from the remote DTE.

- Bits 6 and 5 are used to distinguish between modulo 8 and modulo 128 sequence numbering.

Logical Channel Number Field (8 bits) - The LCN combined with the LCGN provides 12 bits that are used to identify channels 0 to 4095 (Figure 23). Channel 0 is only for diagnostic or restart packets and not for a VC or PVC.

The assignment of the number of VC or PVC logical channels is made arbitrarily so that there is flexibility in the number of channels assigned. If there are no PVCs, the VC can start with logical channel 1. For incoming calls from the network to a DTE, the DCE will assign the lowest numbered logical channel that is available. To minimize collision, outgoing calls are assigned the highest numbered available channel number by the DTE.

The LCGN and LCN appear in every packet except restart, diagnostic, and registration packets.

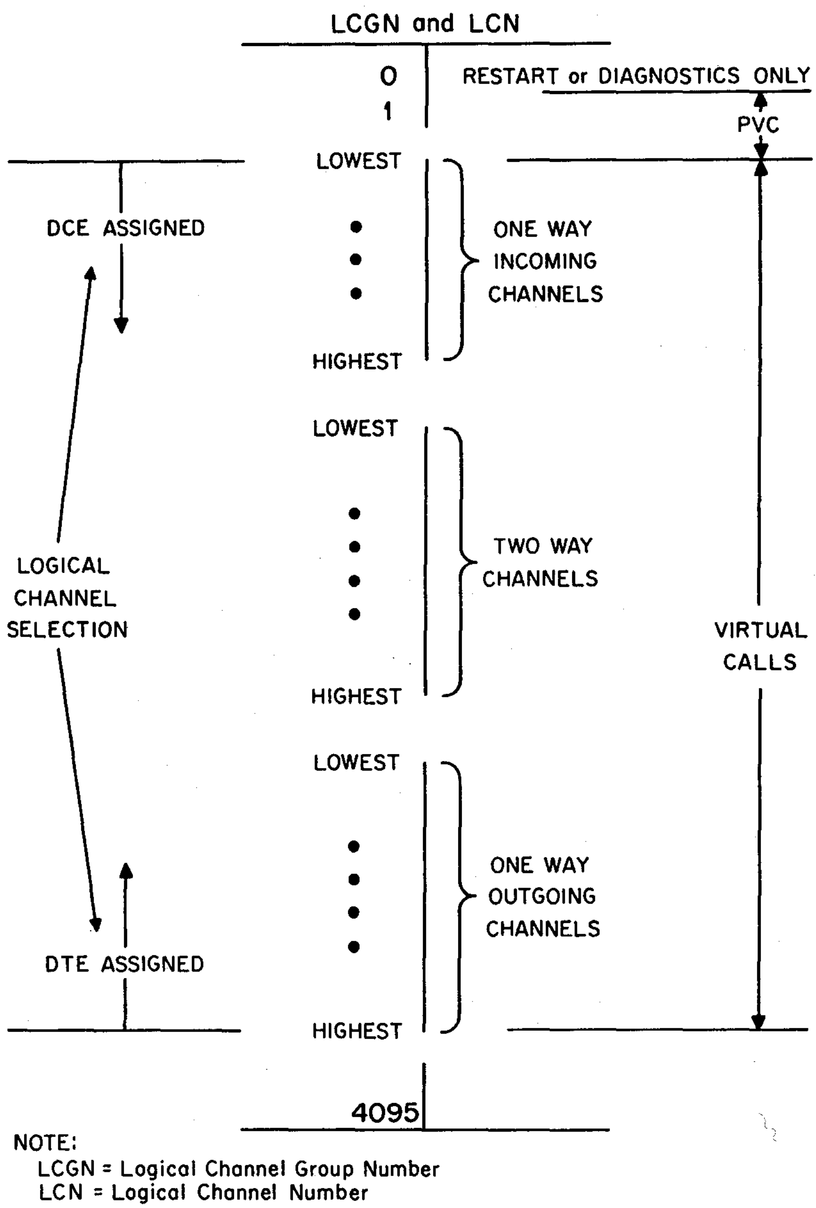


Figure 23. Logical channels for VCs and PVCs.

Packet Type Identifier Field (8 bits) - The packets in X.25 are divided into six groups as shown in Table 7. Some of these packet types, such as those used for call set-up, data transfer, and call clearing are depicted earlier in Figure 6. Within the context of ISO 8208, the packet types are also for DTE/DTE operation. Coding for the packet type identifier occupies the eight bits of the third octet of the packet. Flow control and reset packet types (RR, RNR, and REJ) are coded for modulo 8 or 128 operation.

3.3.2 Call Request and Incoming Calls

The Call Request and Incoming Call frame and packet sequence as it would be transmitted, low-order bit first, is shown in Figure 24. As shown, the frame and packet structure would be applicable to VC service. The relation of CCITT X.25 LAPB and ISO 7776 HDLC to the OSI data link layer is shown at each end of the frame. The packet level fields of X.25 and 8208 are shown relative to the OSI network layer. The packet is part of the link level frame as it is transmitted across the physical layer and transmission media between users (Figure 6).

According to ISO 8208, the Call Request and Incoming Call packets are the same between two DTEs, but are two different "physical" packets between a DTE and DCE because of the intervening network (Figure 5).

The flag, address, and control fields were described in Section 3.2.2. These fields are followed by the LCGN, GFI, LCN, and packet type identifier fields which are common to all packets. These are followed by four address fields, two facility fields, and the call user data field.

Address Length Fields - The low-order bits (1, 2, 3, 4) in this octet indicate the length of the called DTE address. The high-order bits (5, 6, 7) indicate the length of the calling DTE address. The address-length indicators are binary coded.

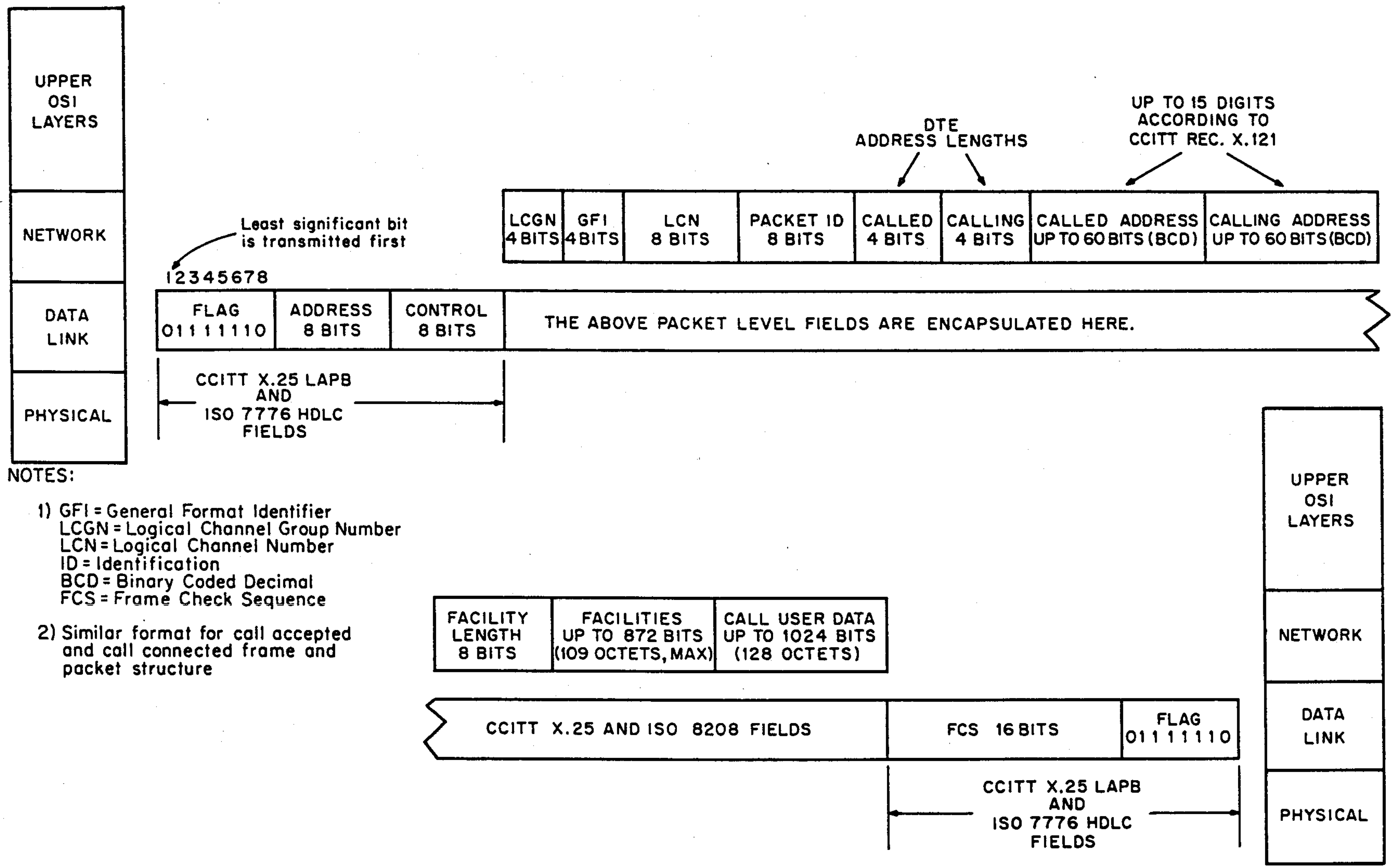
Address Field - The called address and the following calling address are based on CCITT Recommendation X.121. Each address is allowed up to 60 bits. Binary-coded decimal (BCD) is used for encoding. Using 4 bits per digit this translates to a maximum of 15 digits. CCITT X.121 has a maximum of 14 digits, thus allowing one spare digit. Note that this field is BCD while the other fields are binary coded.

Facility Length Field - This octet following the address field indicates the length of the facility field.

Table 7. X.25 Packet Types

Packet Type (1)	
From DCE to DTE	From DTE to DCE
Call Set-up and Clearing	
Incoming Call	Call Request
Call Connected	Call Accepted
Clear Indication	Clear Request
DCE Clear Confirmation	DTE Clear Confirmation
Data and Interrupt	
DCE Data	DTE Data
DCE Interrupt	DTE Interrupt
DCE Interrupt Confirmation	DTE Interrupt Confirmation
Flow Control and Reset (2)	
DCE RR	DTE RR
DCE RNR	DTE RNR
	DTE REJ
Reset Indication	Reset Request
DCE Reset Confirmation	DTE Reset Confirmation
Restart	
Restart Indication	Restart Request
DCE Restart Confirmation	DTE Restart Confirmation
Diagnostic	
Diagnostic	
Registration	
	Registration Request
Registration Confirmation	

Notes: 1) All packets apply to virtual call (VC) service. Call setup and clearing packets are not used for permanent virtual circuit (PVC) service.
2) RR = Receive Ready
RNR = Receive Not Ready
REJ = Reject



NOTES:

1) GFI = General Format Identifier
   LCGN = Logical Channel Group Number
   LCN = Logical Channel Number
   ID = Identification
   BCD = Binary Coded Decimal
   FCS = Frame Check Sequence

2) Similar format for call accepted and call connected frame and packet structure

Figure 24. Call Request and Incoming Call frame and packet format.

Facility field - This field provides for optional network facilities such as fast select and recognized private operating agency (RPOA) selection, which will be described later. (Both of these are required in FED STD 1041 although optional in X.25.) The maximum length of the field does not exceed 109 octets although the actual length depends on the facilities that are available from the network.

Call User Data Field - This field when used has 16 octets in all cases except when used with the fast-select facility. When used with fast select it has a maximum of 128 octets. Call user data may consist of a user password at the destination DTE.

The FCS and flag fields of the link level complete this frame.

3.3.3 Call Accepted and Call Connected

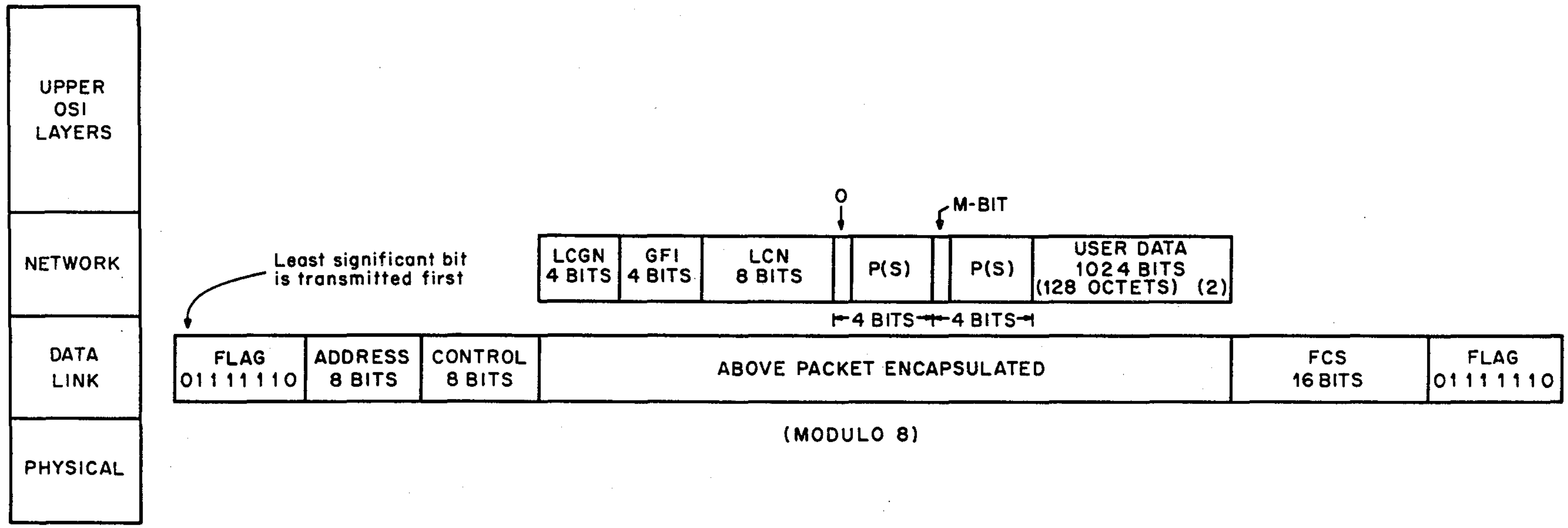
The Call Accepted and Call Connected frame and packet structure is similar to the Call Request and Incoming Call structure. However, only the first three octets are mandatory. These packets are used, for example, with the D-bit set to one in the GFI to indicate that D-bit procedures can be used in the call.

3.3.4 Data Packets and Flow Control

The same flag, address, control, and FCS fields that were shown for the Call Request and Incoming Call frame and packet structure also apply for Data packets (Figure 25). The LCGN, GFI, and LCN were described in Section 3.3.1. The uniqueness of the Data packet fields lies in the use of techniques that can control the rate of packet transmission through the acknowledgment of packet delivery. This is accomplished through the use of send and receive sequence numbers and the D-bit confirmation. Also, there is a similarity of flow control procedures between the link and packet levels. At both levels there is a procedure of counter incrementation to keep track of frames (see Section 3.2.2) or packets.

The following description of flow control procedures for Data packets applies to VC or PVC logical channels. The basic premise is that the transmission of Data packets across a DTE/DXE interface is controlled separately in each direction by authorizations/acknowledgments from the receiver (ISO, 1985b).

Data packets in each direction of transmission are sequentially numbered 0 through 7 (modulo 8) or 0 through 127 (modulo 128). The modulo, 8 or 128, is



NOTES:

1) GFI = General Format Identifier
LCGN = Logical Channel Group Number
LCN = Logical Channel Number
P(R) = Packet Receive Sequence Number
M-BIT = More Data Bit
P(S) = Packet Send Sequence Number

2) Standard maximum user data field length = 128 octets.
Others may be offered: 16, 32, 64, 256, 512, 1024, 2048, 4096

Figure 25. DTE and DCE Data frame and packet format.

the same in both directions of transmission. This sequential packet sequence number, P(S), is contained only in the Data packet (Figure 25). The first Data packet in a sequence is numbered P(S) = 0.

Next, a window (W) through which packets can be sent is defined. The window defines the consecutively numbered packets that can cross a DTE/DXE interface according to the P(S). The default value W = 2 is demonstrated in Figure 26 where P(S) = 0 and P(S) = 1 are authorized. The "lower window edge" has the P(S) = 0 for the first packet to be sent. The "upper window edge" is P(S) = 1 for the second packet authorized to be sent. In this example, only these two packets can be sent before a packet receive sequence number, P(R), acknowledgment is sent by the receiver. The P(R) identifies the next packet sequence number that is expected. Upon acknowledgment of the first packet, P(S) = 0, through P(R) = 1, the window (W = 2) can slide up so that P(S) = 2 can be sent. For modulo 8, the P(S) and P(R) numbers rotate 0 through 7 as the packets are sent. Sending the P(R) implies acceptance of the Data packets up to and including P(R) - 1. Incrementation of P(R) can be greater than one. In this example, P(R) can equal two if both packets have been received.

The use of P(R) as a flow control technique is based on changing the rate at which the value of P(R) is incremented. If necessary, this allows a slowing of packets across the DTE/DXE interface so that network capacity is not exceeded. The P(R) is conveyed in Data, Receive Ready (RR), and Receive Not Ready (RNR) packets.

The delivery-confirmation bit (GFI, bit 7) has the following significance for data packets:

- o When D = 1 in a data packet, the returned P(R) indicates receiving that packet by a remote DTE.

- o When D = 0, a local update takes place. This is <u>not</u> an acknowledgment of receipt from a remote DTE.

The standard user data field in the Data packet is 128 octets. Other data fields that can be offered by the network are 16, 32, 64, 256, 512, 1024, 2048, or 4096 octets.

The M-bit, when set to one in the Data packet, indicates that a DTE or DCE will be sending more data in subsequent packets. The M-bit procedure works in combination with the D-bit procedure.

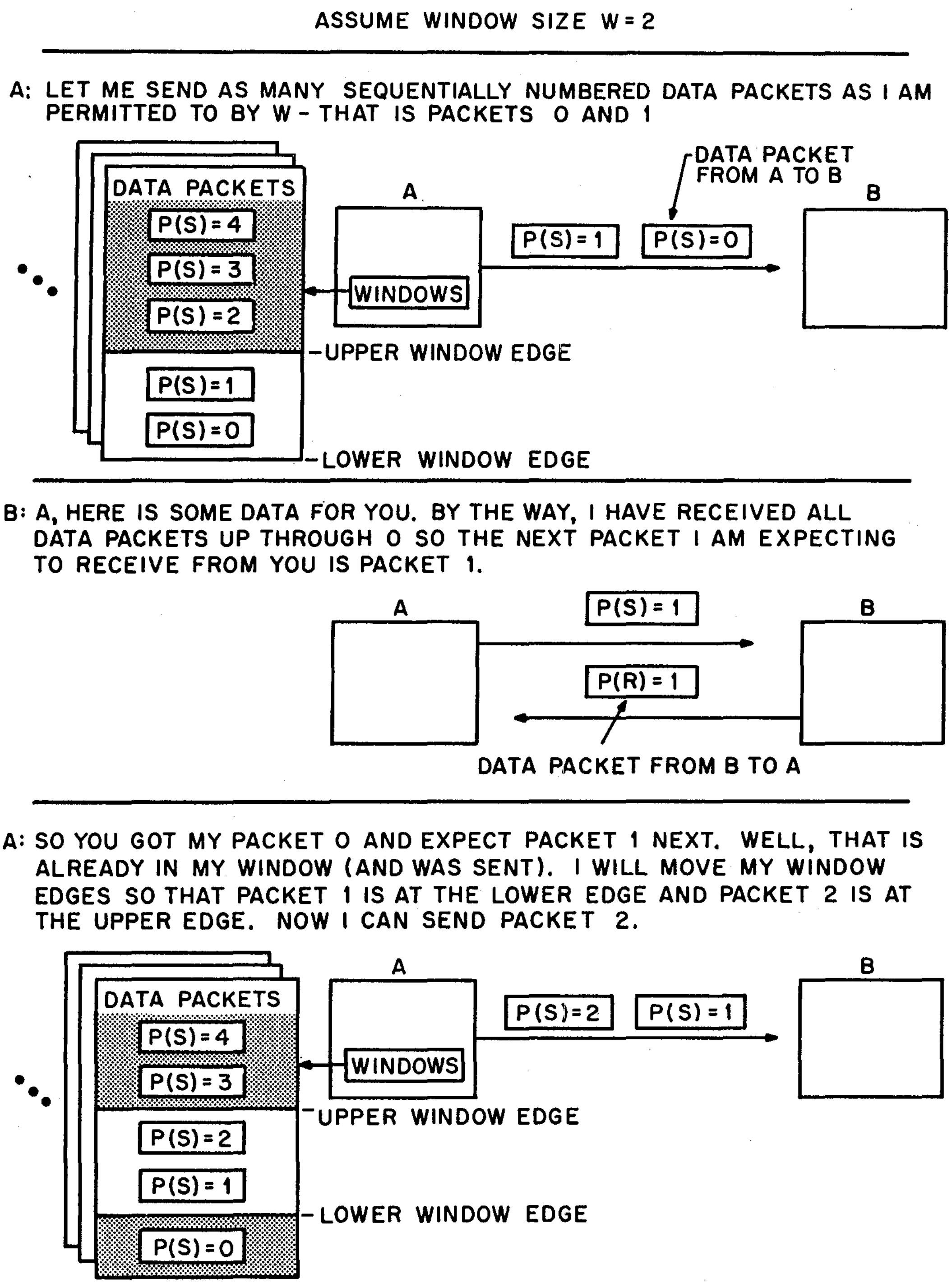


Figure 26. Flow control schematic (ISO, 1985b).

3.3.5 Call Clearing and Diagnostics

A call or call request may be cleared across the DTE/DXE interface of a logical channel by any party at any time. A virtual call can be terminated by a called or calling DTE because of call completion or error detection. (In Figure 6, the clear request is generated by user D.)

The Clear Request and Clear Indication frame and packet structure is shown in Figure 27. The LAPB/HDLC flag, address, and control fields are the same as described in Section 3.2.2. The packet level fields, LCGN, GFI, LCN, and packet type identifier, are described in Section 3.3.1. The cause field (octet 4) and diagnostic code (octet 5) are shown in the packet level of Figure 27. Other fields follow these when the extended format (modulo 128) is used. For modulo 8 only the frame check sequence and concluding flag follow the diagnostic code field.

The clearing cause field (eight bits) contains the reason for clearing the call. A listing of applicable reasons and definitions for each clearing cause is contained in Table B1 of FIPS PUB 100/FED STD 1041 (Appendix C of this report). The coding of the clearing causes is according to Table 18 of X.25.

The diagnostic code field contains additional information concerning the reason that a call is cleared. The diagnostic code is optional in a Clear Request packet. The coding of X.25 network-generated diagnostic fields is given in Annex E of CCITT X.25. Some reasons for not allowing a packet (Annex E/X.25) are that it is unidentifiable, too short, too long, unauthorized, or that the GFI is invalid.

3.3.6 Clear Confirmation

The clear confirmation is sent by a DCE (for local significance) or remote DTE in response to a clear request (Figure 6).

The DTE and DCE Clear Confirmation frame and packet format is shown in Figure 28. The basic (modulo 8) packet format within the frame contains only three octets consisting of the LCGN, GFI, LCN, and packet type identification. The extended format that is shown in Figure 28 is used for DCE Clear Confirmation only in conjunction with charging information which is an optional user facility (6.22/X.25). The charging information is also shown as part of Table A1 in FIPS PUB 100/FED STD 1041 (Appendix C of this report).

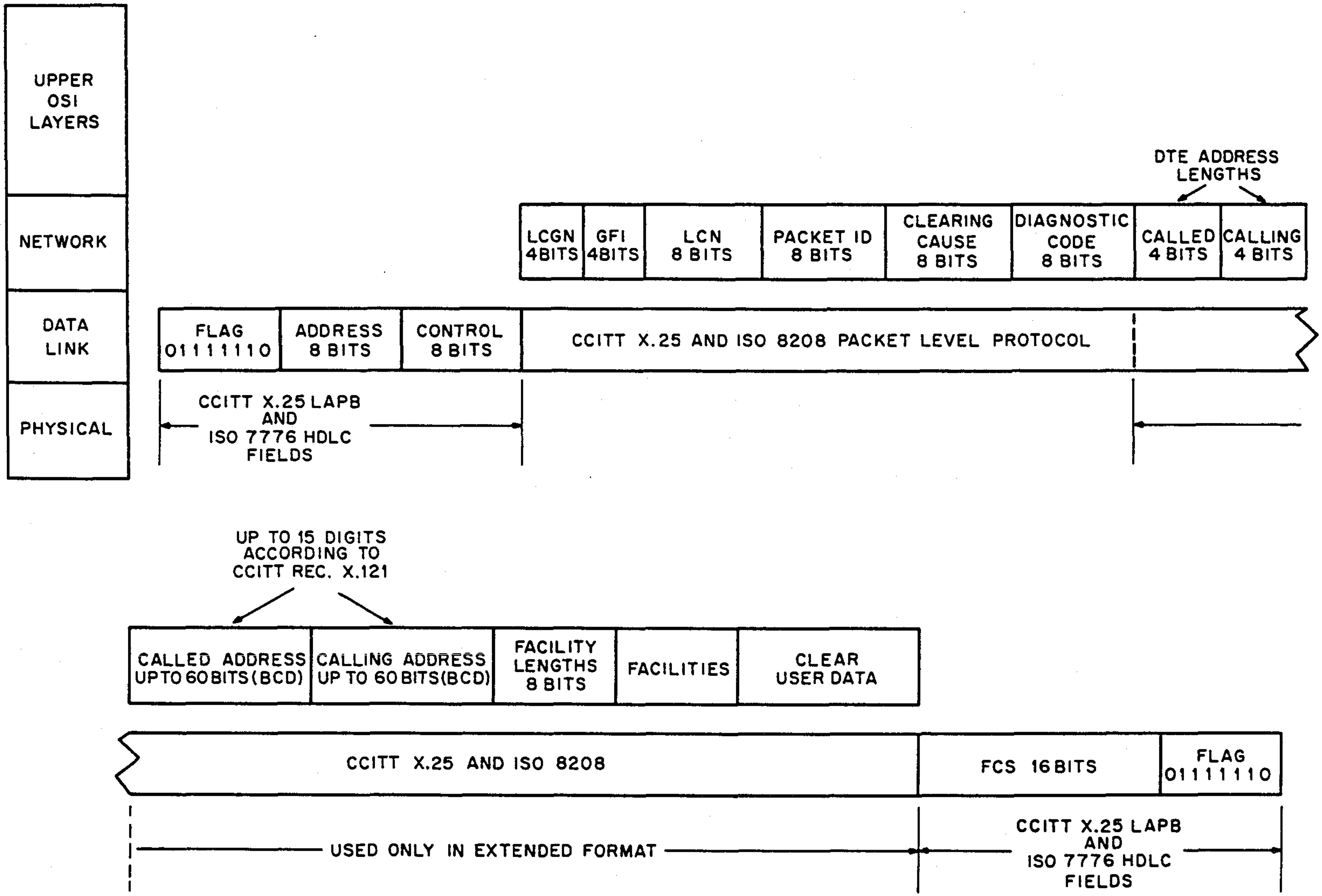


Figure 27. Clear Request and Clear Indication frame and packet format.

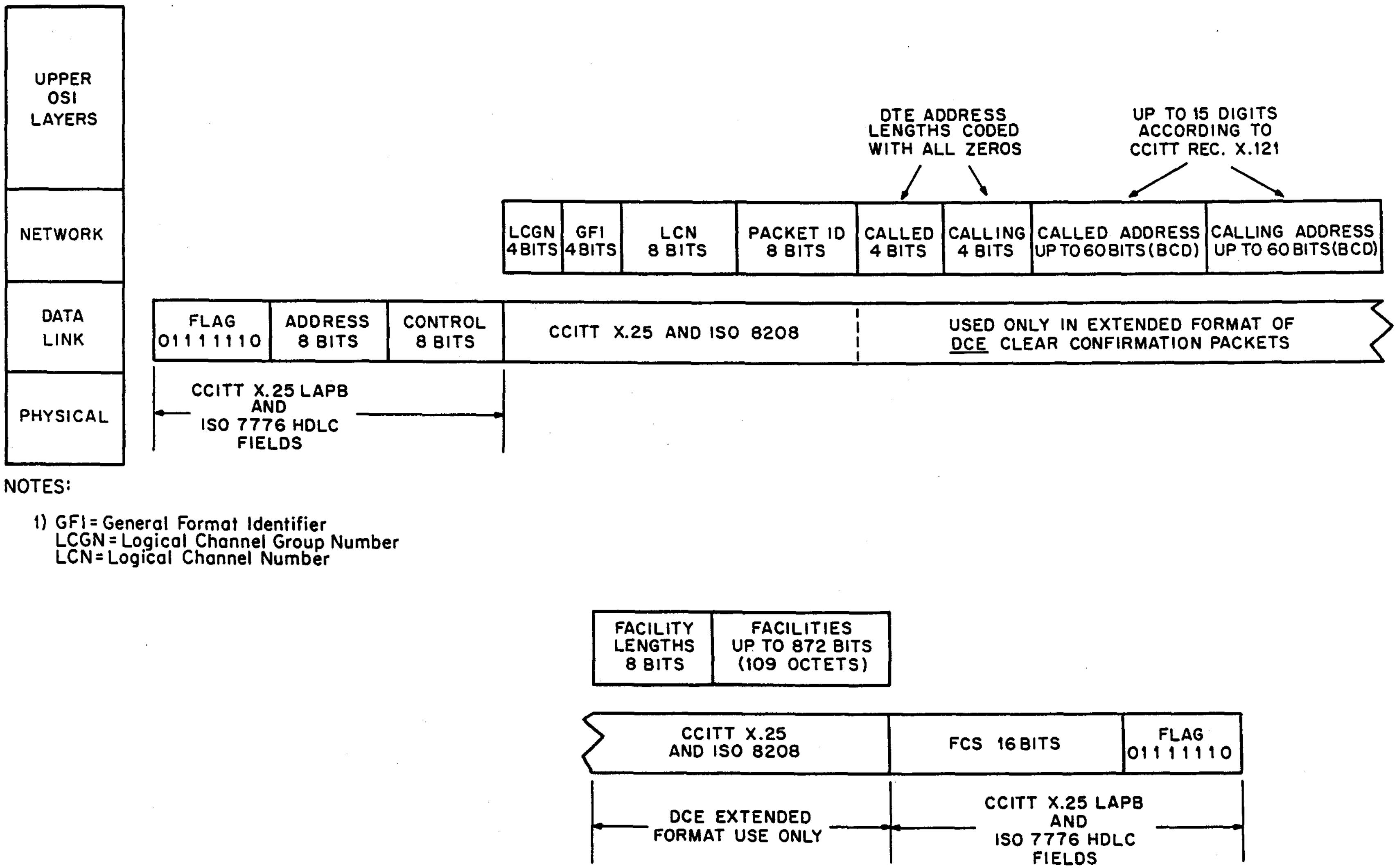


Figure 28. DTE and DCE Clear Confirmation frame and packet format.

3.3.7 Optional User Facilities

Optional user facilities are added packet level capabilities for use between a DTE or DXE (DCE or DTE). Table A1 in FIPS PUB 100/FED STD 1041 is a list of facilities for packet-switched data networks. The following is a description of some of the facilities that are in Sections 6 and 7 (coding) of CCITT X.25 and Sections 13 and 15 (coding) of ISO 8208.

Flow Control Parameter Negotiation (6.12/X.25; 13.12/8208). Flow control parameters are the packet and window sizes at the DTE/DXE interface for each direction of data transmission. Negotiation through this facility allows changes to be made in packet and window default values. "Packet size" refers to the maximum user data field lengths in Data packets.

When this facility is subscribed, a calling DTE may request, in the Call Request packet, window and packet sizes for both directions of data transmission in a virtual call. Window and packet sizes can be different at each end of the virtual call. Default values of packet and window sizes are assumed for both directions of data transmission by the DXE when packet and window sizes are not specified in the Call Request packet. Default packet sizes should be 128 octets (6.9/X.25) and the default window size is 2 (6.10/X.25). The called DTE accepts the call if the flow control parameters can be supported.

Packet sizes that can be negotiated are 16, 32, 64, 256, 512, 1024, 2048, and 4096 octets (7.2.2.1.1/X.25). The window sizes (7.2.2.12/X.25) can be 1 through 7 for normal numbering and 1 through 128 for extended sequence numbering (6.2/X.25).

Throughput Class Negotiation (6.13/X.25; 13.13/8208). The throughput class refers to the signaling rate that can be used for data transmission. The negotiation can be coded in the Call Request/Incoming Call and Call Accepted/Call Connected packets (Figure 6). The values of throughput classes are 75, 150, 300, 600, 1200, 2400, 4800, 9600, 19200, and 48000 bits per second (Table 28/X.25). However, it appears appropriate to use 56 kb/s rather than 48 kb/s since the former is common in North America.

Throughput classes can be different for each direction of data transmission. When throughput classes are not requested by the DTE, the DXE will assume that default values of throughput are applicable in each direction.

Closed User Groups (6.14/X.25; 13.14/8208). This optional user facility enables users to form groups of DTEs to and/or from which access is restricted.

Other DTEs that are not members of a closed user group (CUG) are not permitted access so that a CUG is the equivalent of a private network. However, a DTE can be a member of one or more CUGs.

There are seven CUG facilities:

- Closed User Group (6.14.1/X.25)
  This is the basic facility that permits a DTE to belong to one or more CUGs.

- Closed User Group with Outgoing Access (6.14.2/X.25)
  This facility allows a DTE that belongs to a CUG(s) to originate virtual calls to a DTE that does not belong to any CUG or to a DTE that belongs to a CUG with incoming access.

- Closed User Group with Incoming Access (6.14.3/X.25)
  This facility allows a DTE that belongs to a CUG(s) to receive virtual calls from a DTE not belonging to a CUG or from DTEs belonging to CUGs with outgoing access.

- Incoming Calls Barred within a Closed User Group (6.14.4/X.25)
  A DTE within a CUG can originate virtual calls to other DTEs within the same CUG but incoming calls are not permitted.

- Outgoing Calls Barred within a Closed User Group (6.14.5/X.25)
  A DTE can receive virtual calls from other DTEs in the CUG but outgoing calls are not permitted.

- Closed User Group Selection (6.14.6/X.25)
  This facility enables a calling DTE to specify in the Call Request packet which CUG has been selected for a call. The Incoming Call packet indicates to the called DTE the CUG that has been selected. A basic format is used to allow a DTE to belong to 100 or fewer CUGs. An extended format is required for membership between 101 and 10,000 CUGs.

- Closed User Group with Outgoing Access Selection (6.14.7/X.25)
  This facility can be used if a DTE does not belong to a preferential CUG. This facility can be used if the network supports it and if the DTEs subscribe to a CUG with outgoing access or to a CUG with incoming access or both. Up to 10,000 CUGs are permitted in this facility.

Fast Select (6.16/X.25; 13.16/8208). This optional user facility, which is essential in FIPS PUB 100/FED STD 1041, applies only to virtual call service for a particular call (per-call basis). Fast select allows the exchange of 128 octets of user data during call set-up and call clearing. If there is no restriction on response, the fast-select facility allows the Call Request/Incoming Call packet to contain 128 octets of user data in the call user data field. (See Figure 6 to clarify packet transmission.) During call establishment the DXE is authorized to send 128 octets via a Call Connected packet (call user data field) or a Clear Indication packet (clear user data field). During call clearing, fast select allows the calling DTE and DXE to send 128 octets in the clear user data field of the Clear Request or Clear Indication packet. If there is restriction on response, the DCE is not authorized to transmit a Call Connected packet.

The importance of fast select is the ability to exchange user data during short duration calls. This facility also acts as a partial datagram service which to date has not been implemented by any commercial packet network. According to FED STD 1037A (NCS, 1985), a datagram is a self-contained, independent unit of data routed between DTEs without prior communication being required between the DTEs or the network. In other words, a virtual circuit does not have to be established prior to data transmission. Necessary addressing and routing information exists within each packet thus creating a high overhead factor for each packet.

Fast Select Acceptance (6.17/X.25; 13.17/8208). This optional user facility applies only to virtual call service for a period of time agreed to by the DTE and DCE. When this user facility is subscribed to, the network DCE is authorized to transmit to the DTE incoming Fast Select packets. If the Fast Select Acceptance is not subscribed to, the DCE will block incoming Fast Select calls to the DTE.

RPOA Selection (6.23/X.25; 13.23/8208). The use of Recognized Private Operating Agency (RPOA) selection in FIPS PUB 100/FED STD 1041 is essential (E) although it is designated additional (A) in CCITT Recommendation X.2. This user facility allows a user to specify one or more specific RPOA networks through which a virtual call is to be routed. The facility field of a Clear Request packet in basic format contains the identification of one RPOA (6.23/X.25). The extended format is used for a Clear Request packet that identifies multiple RPOAs that are selected. The RPOAs are identified according to the data network identification codes (DNIC) of CCITT Recommendation X.121. The identification codes should appear in the facilities field in the order that the subscriber wishes the RPOA transit networks to be traversed. The last RPOA selected could be an international record carrier for calls to a foreign country.

The value of RPOA selection is that it is very possible that more than one packet network may be required to permit two DTEs to communicate within a country. This allows the calling DTE to define the required networks. The selection could also allow a user to take advantage of security features that may exist on particular networks. Another advantage could be in performance by selecting networks that match user throughput requirements.

Within the United States, the RPOA selection can be important in meeting regulatory requirements that relate to the competitive nature of the communications industry.

4. CHARACTERISTICS OF FIPS PUB 100/FED STD 1041

A summary of some of the required elements in the federal packet switching standards is given in Table 8. Each element is listed under physical, link, or packet level. This description can also apply to ANS X3.100.

4.1 Physical Level

Only two data signaling rates are required: 4.8 and 9.6 kb/s. Other transmission rates are permissible as long as they comply with those defined by CCITT X.1 (CCITT, 1984n) and ANS X3.1. For example, according to these standards asynchronous operation can be at 300 or 1200 b/s while synchronous operation might be at 2.4 or 4.8 kb/s. However, 56 kb/s is a standard rate in North America so that it is preferred over 48 kb/s. A transmission rate of 64 kb/s is recognized because it is planned for the user's DTE through the Integrated Services Digital Network (ISDN).

There is a choice among physical interface standards that are appropriate at the DTE/DCE interface. The choice is dependent on the data signaling rate that will be used. For signaling rates of 19.2 kb/s or less, EIA-232-D is the choice. It supercedes EIA-232-C, which is acceptable until the new standard is implemented by equipment manufacturers. There are two choices for the interface standard when the signaling rate exceeds 19.2 kb/s: 1) CCITT V.35 in combination with V.28 and V.24, or 2) EIA-449. Electrical characteristics for EIA-449 may be according to EIA-422-A for balanced voltage circuits or EIA-423-A for unbalanced circuits.

Note that the EIA physical level interface standards come under CCITT X.21 bis within X.25. CCITT X.21 bis, as part of X.25, covers V.35 (for data and timing circuits), V.28 (for control circuits), and V.24 for interchange circuits. All of these standards and their equivalents are shown in Appendix B.

Table 8. Typical Requirements of FIPS PUB 100/FED STD 1041

	Physical Level	
3.1.1	Data Signaling Rates	4.8, 9.6 kb/s
3.1.2	Interfaces	EIA-232-D, EIA-449, V.35/V.28/V.24
	Link Level	
3.2	Procedure	LAPB/ISO 7776 HDLC
3.2.1	Configuration	Point-to-Point
3.2.2	Operation	Duplex
3.2.3	Frame Check Sequence (FCS)	16-Bit
3.2.4	Single Link Addresses: DCE	10000000
	DTE	11000000
3.2.5	Smallest N1 Supported: DCE	263 Octets
	DTE	135 Octets
3.2.6	Outstanding Information Frames	k = 7
	Packet Level	
3.3	Procedure	X.25/ISO 8208
3.3.1	Services	Virtual Call and Permanent Virtual Circuit
3.3.2	Packet Sequence Numbering	Modulo 8
3.3.3	User Data Field	Octet Aligned
3.3.5	Diagnostic Packets	Optional Support B4 Networks
3.3.6	Diagnostic Code	Standard/Nonstandard
3.3.12	Retransmission Request	Environment Dependent
3.3.17	D-Bit Procedure	Supported by All DCEs
3.3.19	Interrupt Packet User Data Field	1 to 32 Octets
3.3.20(2)	RPOA Selection	Basic and Extended
3.3.24	Address Extension Facilities	40 Digits (20 Octets)

Note: Section numbers from FIPS PUB 100/FED STD 1041 are shown for each requirement.

4.2 Link Level

Section 3.2 of FIPS PUB 100/FED STD 1041 contain specific link level requirements that are to be used in the United States and by the U.S. Government. Otherwise the link level procedures are according to X.25 LAPB and ISO 7776 HDLC. The LAP procedures in X.25 (1984) are not part of the domestic packet mode standards. This section provides a discourse in the same order as the clauses appear in FIPS PUB 100/FED STD 1041.

Provisions are made for the operation of two combined stations that are connected in a point-to-point, single-link operation or as an option in a multilink configuration. An address field identifies a frame as a command or a response. The address field also allows for recognizing single-link or the optional multilink operation by different address pair encoding. This is done by assigning codes to DCEs (10000000) and DTEs (11000000) for single link operation. Another pair of codes is assigned to DCEs (11100000) and DTEs (11110000) for multilink operation. For DTE/DTE operation, when there is no intervening packet network between DTEs, and dedicated paths or a circuit-switched network are used, one of the DTEs uses a DCE address (e.g., DTE 1 (10000000) and DTE 2 (11000000)).

There are specific requirements for the maximum number of bits (N1) that are to be supported in an information frame. There may be two different values that a DCE will accept from a DTE or that a DTE will accept from a DCE. In the first case the DCE must accept from the DTE frames containing up to and including 2104 bits (263 octets). This is known as DCE N1 and does not include flags and zero bits that are inserted for transparency. The value of 263 octets differs from X.25 and ISO 7776. [It was arrived at by members of Accredited Standards Committee (ASC) X3S3.7 and resulted in a contribution to change CCITT X.25.] In the second case the DTE will accept from the DCE frames containing up to and including 1080 bits (135 octets). This is the value of DTE N1 and again excludes flags and transparency bits.

Three types of control field formats are described in Section 3.2.2. They are information, supervisory, and unnumbered frames. The information frames contain send sequence numbers, N(S), and receive sequence numbers, N(R). The supervisory frame contains only N(R) while the unnumbered frames contain neither. The value of k relates to N(S) and N(R) and indicates the maximum number of sequentially numbered I frames that may be unacknowledged by a DTE or DCE. For modulo 8 operation, k = 7; for modulo 128 operation, k = 127.

4.3 Packet Level

The provisions of CCITT X.25 and ISO 8208 apply to packet level operation. These, however, are subject to particular clauses that are contained in Section 3.3 of FIPS PUB 100/FED STD 1041.

The services for packet-switched data networks are from CCITT Recommendation X.2 which states that virtual call service and permanent virtual circuit service are essential to packet data transmission.

Packet level operation requires that packet sequence numbering will be modulo 8 or optionally, modulo 128. A description of data packets and the use of packet sequence numbering and flow control is given in Section 3.3.5 of this reference manual (Clause 3.3.2/1041).

The first three octets of the packet are described in Section 3.3.1 of this reference. They consist of the logical channel group number (LCGN) and the general format identifier (GFI) in the first octet, the logical channel number (LCN) in the second octet, and packet identification in the third octet. After that, an integral number of octets is required. Receipt of a packet with a nonoctet aligned field is considered an error. If the link level does not provide error recovery, then appropriate procedures are invoked at the packet level. In this case, diagnostic code #82 is invoked as a local procedure error according to Annex C of X.25 and Clause 3.7 of ISO 8208 (Clause 3.3.3/1041).

Diagnostic codes are useful because they allow a DTE to take recovery actions after an error procedure has occurred. In the event a virtual call is cleared with a diagnostic code indicating network congestion, the DTE may wish to wait an interim period before attempting another call. However, if the diagnostic code indicates a procedural error (i.e., local procedure error), maintenance may be required to correct a problem at the DTE/DCE interface. To facilitate recovery action, the Federal Government prefers that only standard diagnostic codes be used in the Clear Request, Reset Request, and Restart Request packets (3.3.6/X3.100). Nonstandard diagnostics can be used by DTEs in other networks as required.

Annex C of CCITT X.25 deals with action to be taken by the DCE on receipt of packets in a given state. Annex C also contains the diagnostics for error conditions in the different packet types. The diagnostics are encoded according to Annex E. The X.25 diagnostic coding has nonassigned coding in the range of 128-255. There are additional codings specified within that range in Figure 14 of ISO 8208.

According to X.25 and ISO 8208, "The first diagnostic in each grouping is a generic diagnostic and can be used in place of the more specific diagnostics within the grouping." However, FIPS PUB 100/FED STD 1041 has a specific clause (3.3.8) that requires that, "A generic diagnostic code shall not be used when a more specific diagnostic code is known to be applicable."

Optional user facilities for a packet switched data network are given in CCITT Recommendation X.2 while facilities available for use between a DTE and DXE are given in ISO 8208. The specific procedures for the facilities are described in Sections 2 and 6 of CCITT X.25 and Sections 13 and 14 of ISO 8208. Some of the optional facilities are available for an agreed period (as for PVCs) while others are available on a per-call basis (as for VCs). The table of optional user facilities in CCITT X.2 has been adapted and reordered to conform to the order that facilities are described in Section 6 of X.25. It appears as Table A1 (Appendix A) and has a column that references the X.25 paragraphs. It also has another column that indicates whether the facility applies to DTE/DTE operation according to ISO 8208. Examples of optional facilities are nonstandard default packet sizes 16, 32, 64, 256, 512, 1024, 2048 (128 is standard) and nonstandard default window sizes (2 is standard).

Table A1 also has a column indicating essential (E) or additional (A) for virtual calls. Most of these facilities do not apply for PVCs because the channels are already connected. The E classification indicates whether the facility must be provided by an X.25 network. The A classification of facilities is optional. This leads one to observe that while the tables in X.2 and 8208 have a column, "Optional user facility," some facilities are required. Within FIPS PUB 100/FED STD 1041, the E facilities shall be provided by the network. Examples of E facilities in Table A1 are basic RPOA selection and fast select. Although RPOA selection is designated A in CCITT X.2, it is identified as basic (E) and extended (E when required) in FIPS PUB 100/FED STD 1041.

Table B1 in Appendix B of X3.100 and FIPS PUB 100/FED STD 1041 has a list of applicable call progress signals adopted from CCITT Recommendation X.96. The call progress signals are encoded in clear indication, reset indication, restart indication, and registration confirmation packets according to Tables 18, 19, 20, and 21 in X.25. This is indicated by a column in Table B1. Some of the call progress signals are mandatory in all networks (e.g., local procedure error). Other call progress signals are mandatory where an optional user facility is provided. Examples of matchups between user facilities and call progress signals are RPOA selection and RPOA out of order, reverse charging acceptance and reverse charging acceptance not subscribed, and fast select acceptance and fast select acceptance not subscribed.

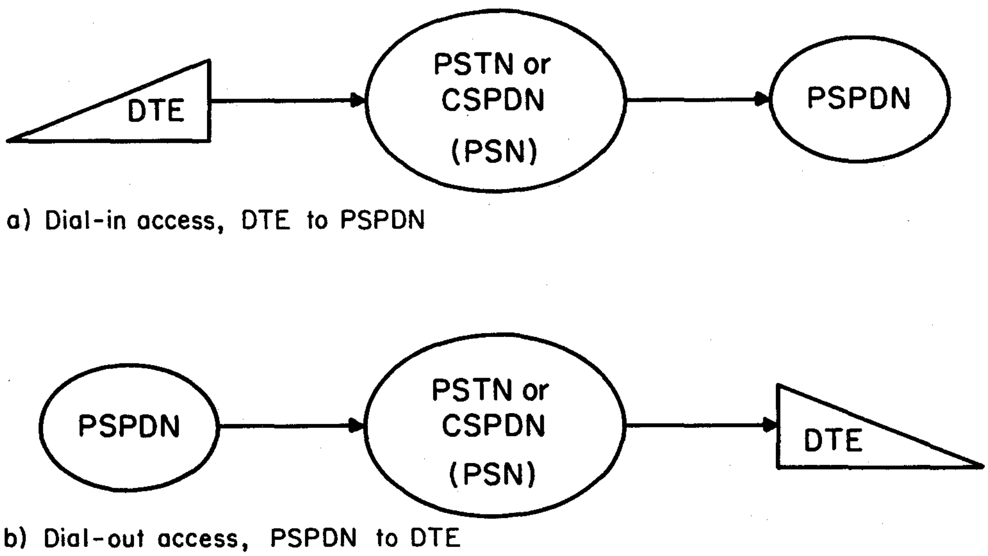
5. CCITT X.32: DIAL-IN, DIAL-OUT PACKET MODE

The CCITT has recognized the need for a DTE/DCE interface that would allow access to a PSPDN through a public switched network (PSN), either a PSTN or a CSPDN. CCITT Recommendation X.32 (CCITT, 1986) allows a dial-in, dial-out access capability between a DTE and a PSPDN when a dedicated circuit is not economical nor obtainable. Initially approved in 1984, a revised, much more comprehensive version was approved for the 1986 CCITT Gray Book.

Basically, X.32 allows for a public switched network between a DTE and the packet network. The DCE remains defined as it was in Section 2 (i.e., a data switching exchange with X.25 intelligence in a PSPDN). Probably the most significant aspect of X.32 is the emphasis that is placed on DTE and DCE identification, including the optional use of encryption, before a virtual call is placed. Another part of X.32 specifies the CCITT V-Series modem characteristics for the physical level interface when a DTE accesses a PSPDN via a PSTN. While using a CSPDN access, the X.32 DTE/DCE interface recommendation is CCITT X.21 or X.21 bis. As can be expected, X.25 LAPB access and packet level procedures, with some additions, are used for the virtual call.

A DTE dial-in operation for accessing a PSPDN can take place using an automatic or manual call procedure (Figure 29a). Another packet mode operation allows a dial-out access from a PSPDN to a DTE (Figure 29b). In this case, an automatic answering procedure is recommended, but manual answering is permitted. Following "dial-in by the DTE" or "dial-out by the PSPDN" procedures a DTE may then initiate or receive virtual calls. The virtual calls are independent of the dial-in and dial-out.

According to X.25 procedures, a DTE accesses a PSPDN via a leased-line, dedicated circuit. Another DTE attached to the packet network is then accessed through another dedicated circuit. This takes place according to X.25 intelligence in the DTEs and the DCE. A DTE without X.25 capability can access a PSPDN via a PAD based on CCITT X.3, X.28, and X.29 procedures and a switched-circuit network. Other DTEs on the network cannot reach a DTE that does not have X.25 intelligence. In contrast, CCITT X.32 procedures allow DTEs to communicate following dial-in, or dial-out, and after establishing the virtual call.



NOTES:
CSPDN = Circuit Switched Public Data Network
DTE = Date Terminal Equipment
PSN = Public Switched Network
PSPDN = Packet Switched Public Data Network
PSTN = Public Switched Telephone Network

Figure 29. CCITT X.32 dial-in, dial-out access.

5.1 Services

There are three types of DTE services defined in X.32. The switched access available to a DTE depends on whether the DTE is unidentified (i.e., nonidentified according to X.32), identified, or customized. All three service types support dial-in, dial-out operation. Switched access capabilities, called attributes, are offered to each service in varying degrees and set each service apart (Table 9).

For nonidentified service, the attributes are either not provided, or a network default is in effect. The identified services are somewhat similar to the nonidentified services with an important exception: charges can be handled by an identified DTE. A nonidentified service does not allow paid calls to be made, nor reverse charges to be received, by a DTE. Other nonidentified service parameters are

- o DTEs are allowed to operate with different networks without subscribing to them, and

- o some optional user facilities (i.e., incoming and outgoing calls barred; one-way logical channel outgoing and incoming) are not allowed.

Table 9. Summary of X.32 DTE Services and Attributes

Attributes \ Services	Nonidentified	Identified	Customized
1. DTE Identity	No	Yes	Yes
2. DTE Identification Method	No	Yes (ND)	Yes (ND)
3. Registered Address	No	Yes (1)	Yes
4. Registered PSN Number	No	No	Yes (2)
5. X.25 Subscription Set	Yes (ND)	Yes (3)	Yes (2)
6. Logical Channel Assignment	Yes (ND)	Yes (ND)	Yes (2)
7. Dial-out-by-the PSPDN Availability	Yes (ND)	Yes (1)	Yes (2)
8. Modem Selection	Yes (ND)	Yes (ND)	Yes (2)
9. Temporary Location	No	No	Yes (2)
10. Secure Dial-Back	No	No	Yes (2)
11. DCE Identity Presentation	Yes (ND)	Yes (ND)	Yes (ND)
12. Link Level Address Assignment	Yes (ND)	Yes (ND)	Yes (2)

Notes: ND = Network Default; NUI = Network Unit Identifier
1) Can be optional or by network default.
2) Selected by user when desired.
3) A network default, or if NUI and NUI override permission are in effect, then the user selects this X.25 packet level facility.

Customized DTE service requires a registered address prior to virtual call placement. The attributes are user selectable according to network-provided options.

The range of optional user facilities available to the three service types is based on CCITT X.2 and is listed in FIPS PUB 100/FED STD 1041 (Appendix A).

5.2 DTE and DCE Identification

The DTE identification is used for billing and accounting purposes. Identification may also be used to provide a calling DTE address to a called

DTE, or to allow a DTE to obtain a service not available to DTEs that have not established an identity.

Identification of a PSPDN is of value to the DTE. Identification allows

- o the exchange of encrypted keys and passwords between the DTE and DCE,
- o DTE selection of network parameters or procedures, and
- o PSPDN identification that has been accessed by the PSN so that the proper CUG operation can take place.

The DCE identity consists of the Data Network Identification Code (DNIC) from CCITT X.121 and an optional designator.

The registered address of a DTE may be

- o an X.121 number from the PSPDN numbering plan [DNIC + Network Terminal Number (NTN)], or
- o an X.121 number from the PSN numbering plan. For a CSPDN this is DNIC + NTN. For a PSTN the number is PSTN number (assigned from the DNIC) + National Number (NN), or 9 + Telephone Country Code (TCC) + NN, although in the future, the CCITT may decide which of these two schemes is preferable.

A DTE is considered identified when two components, administrative and procedural, are fulfilled. Administrative registration can be explicit or implicit. An explicit registration is a direct arrangement between the DTE and the PSPDN. An implicit registration is a direct arrangement between a DTE and a PSN, after the PSN has reached an agreement with the PSPDN. The procedural component is fulfilled when the identity of the DTE is given to the DCE by one of the four methods described below. Three of the methods can be fulfilled prior to virtual call establishment while one of the methods is used per virtual call. A DTE that is identified prior to virtual call establishment can obtain either identified or customized service.

Prior to virtual call establishment, DTE identification can be provided by the PSN, through a link level Exchange Identification (XID) procedure, or packet level registration. Per virtual call DTE identification is through a network user identification (NUI) facility.

PSN-provided DTE identification. For dial-in, a DTE that is a subscriber to a PSN can have its identity signaled by the PSN to the PSPDN during the connection establishment stage. For dial-out, the DTE identity can become known to the PSPDN through information at the PSN that has been registered for dial-out operation.

XID procedure for DTE identification. The XID frames are link level commands and responses occurring before the logical link for a virtual call is established. The XID may be used by the DCE and DTE, for DTE and DCE identification, authentication, or selection of optional user facilities. An unnumbered control field format is used in the XID procedure.

Registration procedure for DTE identification. A Registration Request packet can be sent by the DTE to the DCE during packet level procedures for DTE identification and to possibly specify X.32 optional user facilities. A Registration Confirmation packet must be returned to the DTE by the DCE to complete the registration procedure.

NUI facility for DTE identification. The NUI is an optional facility that can be offered by the PSPDN on a per-virtual-call basis at the packet level. It is also optional for the DTE to use it. When used, the DTE identification occurs during call set-up and is contained in the facility field of the Call Request packet.

Identification of the DCE can be provided by the PSN, XID procedure, or packet level registration, but everything is not the same as it is for DTE identification. For dial-out by the PSPDN, the PSN number identifying the DCE can be provided by the PSN to the DTE. DCE identification can also be optionally provided by the XID, and packet level registration procedures, according to the identification protocol that is used to guard against inaccurate DCE identification. "The identification protocol consists of exchanges between the 'challenged' party and the 'questioning' party. The 'challenged' party provides and, optionally, certifies its identity and the 'questioning' party checks and authenticates this identity" (2.9/X.32).

5.3 Physical Level

For a switched access between a DTE and a PSPDN across a CSPDN, the DTE/DCE interface is according to CCITT X.21 or X.21 bis. However, for a switched access path between a DTE and a PSPDN via a PSTN, the physical level interface is according to the CCITT V-Series characteristics and interfaces for modems. Duplex or half-duplex operation can be available across the PSTN when the modem characteristics are used (Table 10). Table 10 also indicates the primary and fall-back signaling rates, and other requirements for modem operation with the PSTN.

Table 10. V-Series Modem Characteristics

Transmission	Signaling Rate (b/s)	CCITT Recommendation
Duplex	1200 2400/1200 (1) 9600/4800 (1)	(2) V.22, alternatives A, B, or C mode (i) (3) V.22 bis, modes (i) or (iii), or (3) V.26 ter, modes (i) or (iii) V.32
Half-Duplex	2400 4800/2400 (1)	(4) V.26 bis, alternative B V.27 ter

Notes: (1) These are primary and fall-back signaling rates.
(2) Alternatives A, B, or C, mode i refers to 1200 b/s synchronous operation over the DTE/DCE interface with particular circuit, scrambling, and encoding requirements.
(3) Modes (i) or (iii) refers to 2400 to 1200 b/s synchronous operation.
(4) Alternative B refers to the phase encoding of the line signal.

5.4 Link Level

Link level requirements in X.32 are based on the ISO HDLC balanced classes of procedure and are met through the use of X.25 LAPB. Duplex transmission is recommended and half-duplex is optional. The address assignment to the DTE and DCE depends on the direction of the switched access call, whether dial-in, or dial-out. The balanced station address convention is used where commands always carry the destination address and responses always carry the source address (Subsection 3.2.3).

This link level operation allows for the additional use of the unnumbered control field format XID command and response. The XID frames can be used for identification, authentication, and selection of X.32 optional user facilities. Following successful completion of these procedures, the data link is then established under normal LAPB procedure.

A half-duplex transmission module (HDTM) extends LAPB operation over a PSTN where half-duplex circuits are used. The HDTM is located between the physical level and the LAPB (Figure 30). Together, the HDTM and LAPB compose the link level. The use of LAPB in this way is called LAPX--link access procedure, half-duplex (or extended).

The purpose of the HDTM is to convert the LAPB duplex operation to half-duplex operation by coordinating the use of the half-duplex line in the PSTN between the DTE and DCE. Coordination is accomplished by exchanging signals with the remote HDTM, and interacting with the physical level and LAPB. A physical circuit through the PSTN must be established by call control procedures before the HDTM can begin operation.

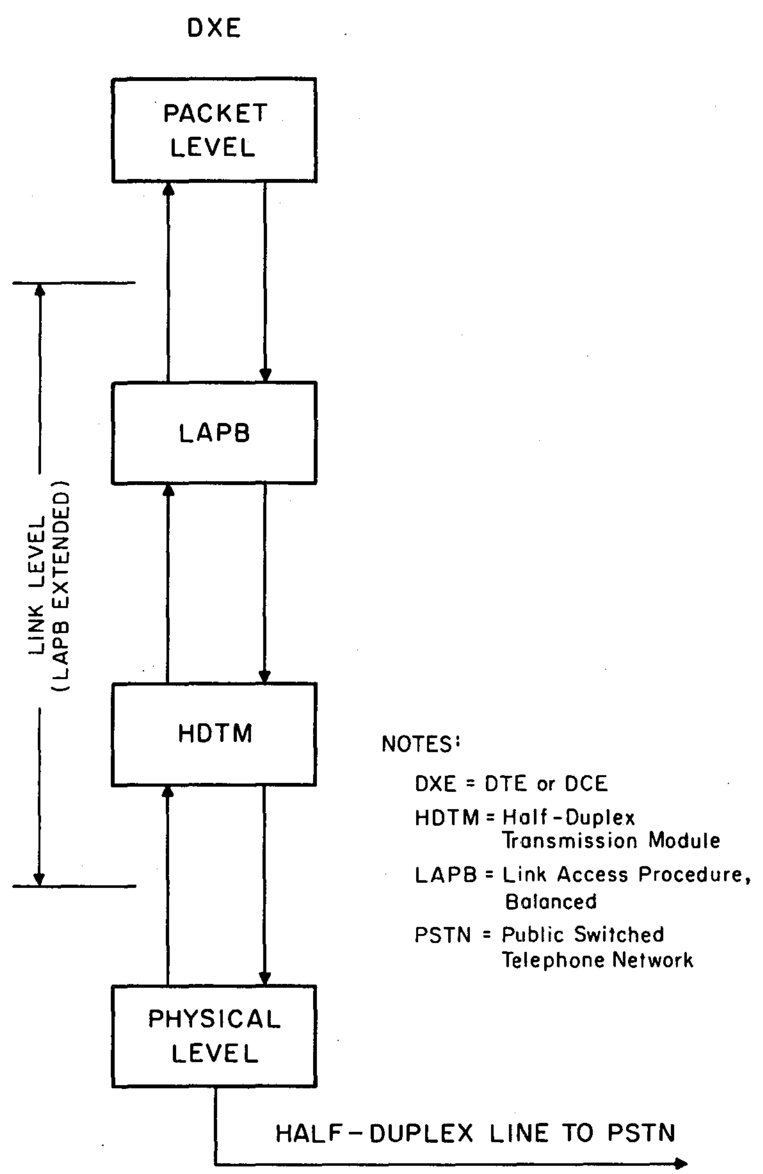


Figure 30. Level relationships at a DTE or DCE with LAPB and HDTM for PSTN access.

5.5 Packet Level

At the packet level, the CCITT X.32 formats and procedures are according to CCITT X.25 and additional instructions in X.32.

According to X.32, the identification and authentication of DTEs and DCEs can also take place at the packet level. If a failure takes place at the physical and/or the link levels, the packet level identification and authentication of the DTE and DCE are no longer valid.

For DTE and DCE registration, the DTE must first send a Registration Request packet to the DCE. For DTE or DCE identification to be completed, it is necessary for a Registration Confirmation packet to be sent from the DCE to the DTE. For DCE identification, the DTE initiates action by sending a Registration Request packet so that the DCE has an opportunity to identify itself. Again, for the registration procedures to be complete, a confirmation packet must be sent by the DCE after the identification protocol is concluded.

The identification protocol allows exchanging one or more pairs of messages between a "questioning" and the "challenged" party. There are two security options that can be used for exchanging identification and authentication information between a DTE and the DCE. The basic option is security grade 1; the enhanced option is security grade 2. Security grade 1 provides for one exchange of protocol elements between the challenged parties (i.e., one pair of messages is exchanged). Security grade 2 allows the exchange of an additional pair of protocol elements, if the first exchange is valid. The first exchange provides identification; the second provides authentication for greater security. "Are you really who you say you are?" can be ascertained.

An additional option in security grade 2 provides for the use of encryption to prevent unauthorized access to the PSPDN. A public key encryption technique that is endorsed by X.32 is the Rivest, Shamir, Adleman (RSA) algorithm. It is described in Appendix II of the document.

The identification protocol elements in security grades 1 and 2 are transmitted between the parties in either a sequence of XID frames, or registration packets. Both methods may be offered by a network, but the identification and authentication must be done entirely with one method.

The NUI facility and its NUI override permission are also within the scope of packet level operation. The NUI override permission creates the priority for a DTE to annul facilities subscribed to by the DTE. The override is coded in the facility field of the Call Request packet. The NUI override permission applies only to a particular virtual call and does not apply to existing, or subsequent, virtual calls on an interface. When the NUI override permission is in effect, a series of X.25 network facilities can be chosen by the DTE (Table 11). This table is a subset of Table A1 in FIPS PUB 100/FED STD 1041 (Appendix C).

5.6 Optional Facilities

Secure dial-back and temporary location are two X.32-exclusive optional user facilities. Secure dial-back offers still more security as part of the customized DTE service. A DTE dials in to the PSPDN, identifies itself, and then disconnects. The PSPDN then dials out to the DTE, using the DTE's registered PSN number, and identifies itself. Then the DTE identifies itself again. Elements of the identification protocol are used in this procedure.

The temporary location facility applies to DTEs, with registered PSN numbers, that accept dial-out calls from the PSPDN. If a DTE is moved to another location, the DCE can reach it by using a number that is different from the registered number. The alternate access number is an X.121 number from the PSTN numbering plan. Currently, temporary location access is only via a PSTN and it remains for study by the CCITT to determine whether access via a CSPDN will be permitted.

6. SUMMARY AND CONCLUSION

This reference manual has described packet-mode standards that have culminated in ANS X3.100 and FIPS PUB 100/FED STD 1041. The approach has been to start with a description of packet-switched virtual circuit services and the components that are used to implement a packet network. The components include terminals, modems, leased lines, data switching exchanges and the location of X.25 interfaces. The network implementation was then related to call setup, data transfer, and call clearing phases and the OSI reference model.

Next, the packet-switching related standards were described. These include CCITT Recommendation X.25 which encompasses CCITT X.21 and CCITT X.21 bis for the physical level, LAPB for the link level, and the packet level protocol. Parts of CCITT X.21 bis include EIA-232-D, EIA-449, and CCITT V.35/V.28/V.24. The ISO counterparts for the link level (ISO 7776, HDLC) and the packet level (ISO 8208, PLP) are also part of the reference manual.

Table 11. X.25 Facilities Available in X.32 When NUI Override Permission is in Effect

Packet Level Facility	Availability
On-line Facility Registration	No
Extended Packet Sequence Numbering	No
D-bit Modification	No
Packet Retransmission	No
Incoming Calls Barred	No
Outgoing Calls Barred	No
One-way Logical Channel Outgoing	No
One-way Logical Channel Incoming	No
Nonstandard Default Packet Sizes	Yes
Nonstandard Default Window Sizes	Yes
Default Throughput Classes Assignment	Yes
Flow Control Parameter Negotiation	
- subscription-time	Yes
Throughput Class Negotiation	
- subscription-time	Yes
Closed User Group Related Facilities	
- Closed User Group	Yes
- Closed User Group With Outgoing Access	Yes
- Closed User Group With Incoming Access	No
- Incoming Calls Barred Within a Closed User Group .	No
- Outgoing Calls Barred within a Closed User Group .	Yes
Bilateral Closed User Group Related Facilities	
- Bilateral Closed User Group	Yes
- Bilateral Closed User Group With Outgoing Access .	Yes
Fast Select Acceptance	No
Reverse Charging Acceptance	No
Local Charging Prevention	No
Charging Information - subscription-time	Yes
RPOA Selection - subscription-time	Yes
Hunt Group	No
Call Redirection	No

Yes - can be chosen or set to a nondefault value by the DTE, if supported by the PSPDN.
No - cannot be chosen by the DTE.

Particular characteristics and requirements of FIPS PUB 100/FED STD 1041 were then described where they may not have been discussed within CCITT X.25 and related standards.

The contents of the next section then described CCITT Recommendation X.32, which will be available in a CCITT Gray Book during 1987. CCITT X.32 is an interface that allows terminals with packet-mode capabilities to access a packet-switched public data network through a public switched network, such as a circuit-switched public data network or a public switched telephone network.

The thrust of this manual has been to provide a reference document for physical, link, and packet level standards. While a significant amount of discussion described physical, link and packet level operation, other publications, [Dally (1986), Dhas and Konangi (1986)] and the standards themselves are recommended to gain further detailed insight into packet networks.

7. ACKNOWLEDGMENT

The author wishes to thank Mr. W. J. Pomper for helpful discussion concerning X.25 implementation, Mr. J. M. Harman for creating the figures, and Ms. K. E. Mayeda and Ms. K. S. Marvin for their proficiency in word processing.

8. REFERENCES

Note:

ANSI documents are available from:

American National Standards Institute, Inc.
1430 Broadway
New York, NY 10018
Telephone: (212) 354-330

ISO documents are also available from ANSI.

CCITT documents are available from:

U.S. Department of Commerce
National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
Telephone: (703) 487-4650

EIA documents are available from:

Electronic Industries Association
Engineering Department
2001 Eye Street, NW
Washington, DC 2006
Telephone: (202) 354-3300

ANSI (1986), ANSI X3.100-1986, American National Standard for information systems - interface between data terminal equipment (DTE) and data circuit-terminating equipment (DCE) for operation with packet-switched data networks (PSPDN), or between two DTEs, by dedicated circuit.

CCITT (1984a), CCITT Recommendation X.25, Interface between data terminal equipment (DTE) and data circuit-terminating equipment (DCE) for terminals operating in the packet mode and connected to public data networks by dedicated circuits, Red Book, Fascicle VIII.3.

CCITT (1984b), CCITT Recommendation X.200, Reference model of open systems interconnection for CCITT applications, Red Book, Fascicle VIII.5.

CCITT (1984c), CCITT Recommendation X.21, Interface between data terminal equipment (DTE) and data circuit-terminating equipment (DCE) for synchronous operation on public data networks, Red Book, Fascicle VIII.3.

CCITT (1984d), CCITT Recommendation X.21 bis, Use on public data networks of data terminal equipment (DTE) which is designed for interfacing to synchronous V-Series modems, Red Book, Fascicle VIII.3.

CCITT (1984e), CCITT Recommendation X.3, Packet assembly/disassembly facility (PAD) in a public data network, Red Book, Fascicle VIII.2.

CCITT (1984f), CCITT Recommendation X.28, DTE/DCE interface for a start-stop mode data terminal equipment accessing the packet assembly/disassembly facility (PAD) in a public data network situated in the same country, Red Book, Fascicle VIII.3.

CCITT (1984g), CCITT Recommendation X.29, Procedures for the exchange of control information and user data between a packet assembly/disassembly (PAD) facility and a packet mode DTE or another PAD, Red Book, Fascicle VIII.3.

CCITT (1984h), CCITT Recommendation X.26, Electrical characteristics for unbalanced double-current interchange circuits for general use with integrated circuit equipment in the field of data communications, Red Book, Fascicle VIII.3. (Equivalent to CCITT V.10.)

CCITT (1984i), CCITT Recommendation X.27, Electrical characteristics for balanced double-current interchange circuits for general use with integrated circuit equipment in the field of data communications, Red Book, Fascicle VIII.3. (Equivalent to CCITT V.11.)

CCITT (1984j), CCITT Recommendation X.24, List of definitions for interchange circuits between data terminal equipment (DTE) and data-circuit terminating equipment (DCE) on public data networks, Red Book, Fascicle VIII.3.

CCITT (1984k), CCITT Recommendation V.35, Data transmission at 48 kilobits per second using 60-108 kHz group band modems, Red Book, Fascicle VIII.1.

CCITT (1984l), CCITT Recommendation V.28, Electrical characteristics for unbalanced double-current interchange circuits, Red Book, Fascicle VIII.1.

CCITT (1984m), CCITT Recommendation V.24, List of definitions for interchange circuits between data terminal equipment and data circuit-terminating equipment, Red Book, Fascicle VIII.1.

CCITT (1984n), CCITT Recommendation X.1, International user classes of service in public data networks and integrated services digital networks (ISDNs), Red Book, Fascicle VIII.2.

CCITT (1986), CCITT Recommendation X.32, Interface between data terminal equipment (DTE) and data circuit-terminating equipment (DCE) for terminals operating in the packet-mode and accessing a packet switched public data network through a public switched telephone network or a circuit switched public data network. To be available in a CCITT Gray Book in 1987.

Dally, K. L. (1986), CCITT Recommendation X.25, Open Systems Data Transfer, Transmission #23, available from Omnicom, Inc., 501 Church Street, NE, Suite 302, Vienna, VA, 22180, (703) 281-1135.

Dhas, C. R., and V. K. Konangi (1986), X.25: an interface to public packet networks, IEEE Communications Magazine 24, 9, September.

EIA (1969), Interface between data terminal equipment and data communication equipment employing serial binary data interchange, EIA-232-C, October.

EIA (1977), General purpose 37-position and 9-position interface for data terminal equipment and data circuit-terminating equipment employing serial binary data interchange, EIA-449, November.

EIA (1985), Interface between data terminal equipment and data circuit-terminating equipment employing serial binary data interchange, EIA-232-D, final draft, December.

ISO (1985a), ISO 7776, Information processing systems - Data communications-High-level data link control procedures - Description of the X.25 LAPB-compatible DTE data link procedures.

ISO (1985b), ISO 8208, Information processing systems - X.25 packet level protocol for data terminal equipment.

ISO (1985c), ISO 7498, Information processing systems - Open systems interconnection - basic reference model.

NCS (1985), Glossary of telecommunication terms, Federal Standard 1037A, 25 October 1985. Published by the General Services Administration. Available at GSA Business Service Centers across the country, or from the GSA, Specification Branch (WFSIS), Room 6039, 7th and D Streets, SW, Washington, DC, 20407.

Pense, E. (1984), X.21 circuit-switching protocol in the open systems interconnection environment, Open Systems Data Transfer, Transmission No. 11, August. Available from Omnicom Information Service, 501 Church Street, NE, Suite 206, Vienna,VA, 22180.

Tannenbaum, A. (1981), Computer Networks, (Prentice-Hall, Inc., Englewood Cliffs, NJ, 07632).

APPENDIX A: REVIEW OF OPEN SYSTEMS INTERCONNECTION

The following definitions of Open Systems Interconnection (OSI) and the layers of the reference model are from "Glossary of Telecommunication Terms," Federal Standard 1037A (NCS, 1985). Complete specifications for OSI are in CCITT Recommendations X.200-X.250 (CCITT, 1984) and ISO International Standard 7498 (ISO, 1984).

Figure A-1 depicts the layering concept of the OSI reference model. Layers are called levels within the context of CCITT X.25.

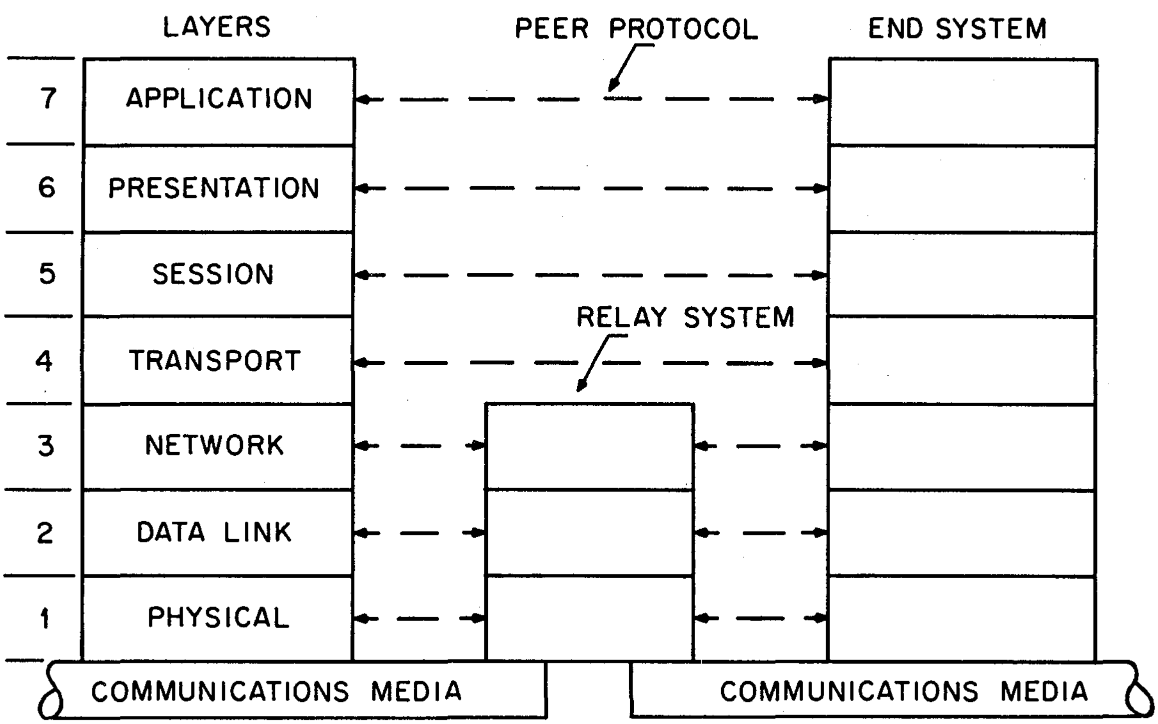


Figure A-1. OSI reference model with relay system and peer protocols.

<u>Open Systems Interconnection (OSI)</u>

A logical structure for network operations standardized within the OSI: a seven-layer network architecture being used for the definition of network protocol standards to enable any OSI-compliant computer or device to communicate with any other OSI-compliant computer or device for a meaningful exchange of information.

Open Systems Interconnection (OSI) - Protocol Specifications

The lowest level of abstraction within the OSI standards scheme. Each OSI-Protocol Specification operates at a single layer. Each defines the primitive operations and permissible responses required to exchange information between peer processes in communicating systems to carry out all or a subset of the services defined within the OSI-Service Definitions for that layer.

Open Systems Interconnection - Reference Model (OSI-RM)

An abstract description of the digital communications between application processes running in distinct systems. The model employs a hierarchical structure of seven layers: 1. physical (lowest), 2. data link, 3. network, 4. transport, 5. session, 6. presentation, and 7. application (highest). Each layer performs value-added service at the request of the adjacent higher layer and, in turn, requests more basic services from the adjacent lower layer.

Physical Layer: The lowest of seven hierarchical layers in the OSI-Reference Model (i.e., layer 1). The physical layer performs services requested by the data link layer (layer 2). The major functions and services performed by the physical layer are: 1. establishment and termination of a connection to a communications media; 2. participation in the process whereby the communication resources are effectively shared among multiple users, e.g., contention resolution and flow control; and, 3. conversion between the representation of digital data in user equipment and the corresponding signals transmitted over a communications channel.

Data Link Layer: Layer 2 of the OSI-Reference Model. This layer responds to service requests from the network layer (layer 3) and issues service requests to the physical layer (layer 1). The data link layer provides the functional and procedural means to transfer data between network entities and to detect and possibly correct errors that may occur in the physical layer. Note: Examples of data link protocols are HDLC and ADCCP for point-to-point or packet-switched networks and LCC for local area networks.

Network Layer: Layer 3 of the OSI-Reference Model. This layer responds to service requests from the transport layer (layer 4) and issues service requests to the data link layer (layer 2). The network layer provides the functional and procedural means of transferring variable length data sequences from a source to a destination via one or more networks while maintaining the quality of service requested by the transport layer. The network layer performs network routing, flow control, segmentation/desegmentation, and error control functions.

Transport Layer: Layer 4 of the OSI-Reference Model. This layer responds to service requests from the session layer (layer 5) and issues service requests to the network layer (layer 3). The purpose of the transport layer is to provide transparent transfer of data between end users, thus relieving the upper layers from any concern with providing reliable and cost-effective data transfer.

Session Layer: Layer 5 of the OSI-Reference Model. This layer responds to service requests from the presentation layer (layer 6) and issues service requests to the transport layer (layer 4). The session layer provides the mechanism for managing the dialogue between end user application processes. It provides for either duplex or half-duplex operation and establishes checkpointing adjournment, termination, and restart procedures.

Presentation Layer: Layer 6 of the OSI-Reference Model. This layer responds to service requests from the application layer (layer 7) and issues service requests to the session layer (layer 5). The presentation layer relieves the application layer of concern regarding syntactical differences in data representation within the end-user systems. Note: An example of a presentation service would be the conversion of an EBCDIC-coded text file to an ASCII-coded file.

Application Layer: The highest layer of the OSI-Reference Model (layer 7). This layer directly interfaces to and performs common application services for the application processes; it also issues service requests to the presentation layer (layer 6). The common application services provide semantic conversion between associated application processes. Note: Examples of common application services of general interest include the virtual file, virtual terminal, and job transfer and manipulation protocols.

Not all open systems provide the initial source or final destination of data. Some open systems act only as relay open systems, passing data to other open systems (CCITT, 1984). Support for forwarding of data is provided in the lower three layers (Figure A-1). Peer protocols operate between similar layers at the end or relay system.

REFERENCES

CCITT (1984), CCITT Recommendations X.200-X.250, Data communication networks open systems interconnection (OSI), system description techniques, Red Book Volume VII - Fascicle VII.5, October. Available from U.S. Department of Commerce, National Technical Information Service, 5285 Port Royal Road, Springfield, VA, 22161. Phone (703) 487-4650.

ISO (1984), International standard 7498, Information processing systems - Open systems interconnection - Basic reference model. Available from ANSI, 1430 Broadway, New York, NY, 10018. Phone (212) 354-3300.

NCS (1985), Glossary of telecommunication terms, Federal Standard 1037A, 25 October 1985. Published by the General Services Administration. Available at GSA Business Service Centers across the country, or from the GSA, Specification Branch (WFSIS), Room 6039, 7th and D Streets, SW, Washington, DC, 20407.

APPENDIX B: DTE/DCE INTERFACE STANDARDS

There are a number of international and U.S. DTE/DCE interface standards that apply to packet- and circuit-switched networks. Note that in CCITT terminology the "V" series Recommendations apply to data transmission over telephone networks;" the "X" series Recommendations apply to "data transmission over public data networks." According to CCITT X.25 the DTE/DCE physical interface elements shall be according to CCITT X.21 or X.21 bis. Based on transmission rate requirements, there are two options for X.21 and four that apply to X.21 bis.

In Table B-1, the international standards are according to the CCITT and ISO. The U.S. counterparts (when applicable) are according to the Electronic Industries Association (EIA) and Federal Standards (FS).

As shown, there are no similar U.S. standards for X.21, X.24, and 4903 except for electrical characteristics that have CCITT, EIA, and FS designations. For unbalanced circuits the equivalences are X.26/V.10/EIA-423-A/FS 1030A. For balanced circuits the equivalencies are X.27/V.11/EIA-422-A/FS 1020A. The ISO 4903 standard specifies a 15-pin connector.

Of the four options within X.21 bis, EIA-232-D is of special interest because it is most commonly used in the United States. The equivalent CCITT standards are V.28 for electrical characteristics, V.24 for functional characteristics, and ISO 2110 which specifies a 25-pin D-type connector.

The next U.S. standard, EIA-449, has two configurations for unbalanced (EIA-423-A) and balanced (EIA-422-A) operation. It has not been widely implemented in the United States for two reasons: the entrenchment of EIA-232-D and preceding versions, and the higher cost of implementing a larger connector (37 pins) with an increased number of wires to perform the functions.

The CCITT V.35 standard is implemented for wideband modems in the United States because of improved performance compared to EIA-232-D. The ISO 2593 standard specifies 34-pins for the connector. Electrical characteristics are specified by V.28 (unbalanced) for control circuits and by V.35 (balanced) for data interchange circuits.

Table B-1. International and U.S. DTE/DCE Interface Standards

A. INTERNATIONAL STANDARDS								
Physical Interfaces		X.21[1] (Two Options)		X.21 bis (Four Options)				
CCITT Recommendations	Signaling Rate	to 100 kb/s	to 10 Mb/s	max. 20 kb/s	to 100 kb/s	(V.35) 48 kb/s	(V.36) 48, 56, 64 72 kb/s
	Electrical Characteristics	X.26 (V.10)[2] X.27 (V.11)	X.27	V.28	X.26 (V.10)	V.35/V.28[3]	X.27 (V.11) Option: X.26 (V.10)
	Functional Characteristics	X.24	X.24	V.24	V.24	V.24	V.24
ISO Standards: Mechanical Characteristics		4903[4]	4903[4]	2110[5]	4902[6]	2593[7]	4902[6]
B. EQUIVALENT U.S. STANDARDS							
EIA Standards		Electrical: EIA-423-A[8]	Electrical: EIA-422-A[8]	EIA-232-D	EIA-449 EIA-423-A	No Equivalent U.S. Standards. V.35 Used for 56 kb/s Wideband Modems	EIA-449 EIA-422-A
Federal Standards		Electrical: 1030A[8]	Electrical: 1020A[8]	None	1031 1030A		1031 1020A

Notes:

1. No equivalent U.S. standard for X.21.
2. To 9.6 kb/s: DTE uses X.26 or X.27 (with or without cable termination in the load); DCE must use X.27 (See ISO 4903 for mandatory pin wiring). >9.6 kb/s: Both DTE and DCE must use X.27 (with cable termination in the load).
3. Control circuits use V.28 electrical characteristics (unbalanced); electrical characteristics of data interchange circuits are defined by V.35.
4. 15-pin Type "D" connector.
5. 25-pin Type "D" connector (EIA-232-C).
6. 37-pin Type "D" connector (EIA-449).
7. 34-pin Type "D" connector.
8. Equivalent standards only for electrical characteristics: X.26 / V.10 / EIA-423-A / FS 1030A, unbalanced.
   X.27 / V.11 / EIA-422-A / FS 1020A, balanced.

On terminology: The CCITT "V" series of Recommendations applies to "data transmission over telephone networks"; the "X" series applies to "data transmission over public data networks."

APPENDIX C: FIPS PUB 100/FED STD 1041

The following version of American National Standard X3.100 serves as a model in anticipation of approval as a Federal Standard. Although this version may still be changed before it becomes an ANSI or Federal Standard, it is close to final form as of January 1987. The desire of the Federal Government is to adopt ANS X3.100 without any changes. This version of X3.100 appears to fulfill government requirements so that adoption as FIPS PUB 100/FED STD 1041 (1987) should proceed smoothly.

dpANS X3.100

CONTENTS PAGE

American National Standard for Information Systems --

Interface between Data Terminal Equipment (DTE) and Data Circuit-Terminating Equipment (DCE) for Operation with Packet-Switched Data Networks (PSDN), or between two DTEs, by Dedicated Circuit.

1. SCOPE

CCITT Recommendation X.25 (1984) (henceforth referred to below as CCITT Recommendation X.25 or X.25), ISO 7776, and ISO 8208 specify the interface between Data Terminal Equipment (DTE) and Data Circuit-Terminating Equipment (DCE) for terminals operating in the packet mode on Packet-Switched Data Networks (PSDN), or between two DTEs, by Dedicated Circuit. CCITT Recommendation X.25 specifies the DCE side of the DTE/DCE interface. ISO 7776 and ISO 8208 specify the DTE/DTE interface and the DTE side of the DTE/DCE interface.

This standard adopts the above three standards and covers both the DTE/DCE and DTE/DTE interfaces.

NOTE: A companion American National Standard (ANS) will be provided upon completion of CCITT Recommendation X.32 for terminals operating in the packet-mode and accessing a Packet-Switched Public Data Network (PSPDN) through a Public Switched Telephone Network (PSTN) or a Circuit-Switched Public Data Network (CSPDN).

2. REFERENCED STANDARDS

2.1 American National Standards

When the following American National Standard is superceded by a revision approved by the American National Standards Institute, Inc., the revision shall apply:

ANS X3.1-1985, Synchronous Signaling Rates for Data Transmission

2.2 Other Publications

This standard is intended to be used in conjunction with the following publications:

CCITT Recommendation V.24 (1984), List of Definitions for Interchange Circuits between Data Terminal Equipment and Data Circuit-Terminating Equipment

CCITT Recommendation V.28 (1984), Electrical Characteristics for Unbalanced Double-Current Interchange Circuits

CCITT Recommendation V.35 (1984), Data Transmission at 48 Kilobits per Second Using 60-108 kHz Group Band Circuits

CCITT Recommendation X.1 (1984), International User Classes of Service in Public Data Networks and Integrated Services Digital Networks

CCITT Recommendation X.2 (1984), International Data Transmission Services and Optional User Facilities in Public Data Networks

CCITT Recommendation X.10 (1984), Categories of Access for Data Terminal Equipment (DTE) to Public Data Transmission Services provided by PDNs and/or ISDNs through Terminal Adaptors

CCITT Recommendation X.21 (1984), Interface Between Data Terminal Equipment (DTE) and Data Circuit-Terminating Equipment (DCE) for Synchronous Operation or Public Data Networks

CCITT Recommendation X.21 bis (1984), Use on Public Data Networks of Data Terminal Equipment (DTE) which is Designed for Interfacing to Synchronous V-Series Modems

CCITT Recommendation X.25 (1984), Interface between Data Terminal Equipment (DTE) and Data Circuit-Terminating Equipment (DCE) for Terminals Operating in the Packet Mode and Connected to Public Data Networks by Dedicated Circuit

CCITT Recommendation X.29 (1984), Procedures for the Exchange of Control Information and User Data between a Packet Assembly/Disassembly (PAD) Facility and a Packet Mode DTE or Another PAD

CCITT Recommendation X.92 (1984), Hypothetical Reference Connections for Public Synchronous Data Networks

CCITT Recommendation X.96 (1984), Call Progress Signals in Public Data Networks

EIA-232-C (1969), Interface between Data Terminal Equipment and Data Communication Equipment Employing Serial Binary Data Interchange

EIA-232-D (1986), Interface between Data Terminal Equipment and Data Communication Equipment Employing Serial Binary Data Interchange [Supercedes EIA-232-C]

EIA-422-A (1978), Electrical Characteristics of Balanced Voltage Digital Interface Circuits

EIA-423-A (1978), Electrical Characteristics of Unbalanced Voltage Digital Interface Circuits

EIA-449 (1977), General Purpose 37-Position and 9-Position Interface for Data Terminal Equipment and Data Circuit-Terminating Equipment Employing Serial Binary Data Interchange

EIA Industrial Electronics Bulletin No. 12 (November 1977), Application Notes on Interconnection between Interface Circuits using EIA-449 and EIA-232-C

ISO 2110 (1980), Data Communication - 25-Pin DTE/DCE Interface Connector and Pin Assignments

ISO 2593 (1986), Data Communication - 34-Pin DTE/DCE Interface Connector and Pin Assignments

ISO 7776 (1985), Information Processing Systems - Data Communication - High-Level Data Link Control Procedures - Description of the 1984 X.25 LAPB-Compatible DTE Data Link Procedures

ISO 8208 (1985), Information Processing Systems - X.25 Packet Level Protocol for Data Terminal Equipment

2.3 Where to Obtain Copies of Publications

2.3.1 CCITT Recommendations, V-Series or X-Series;

U.S. Department of Commerce
National Technical Information Services
5285 Port Royal Road
Springfield, VA 22161
Telephone: (703) 487-4650

Ordering Information:

(1) Series V Recommendations; Fascicle VIII.1
Title: Data Communications over the Telephone Network, Recommendations of the V Series

(2) Recommendations X.1 - X.15; Fascicle VIII.2
Title: Data Communication Networks: Services and Facilities

(3) Recommendations X.20 - X.32; Fascicle VIII.3
Title: Data Communication Networks: Interfaces

(4) Recommendations X.40 - X.181; Fascicle VIII.4
Title: Data Communication Networks: Transmission, Signaling and Switching, Network Aspects, Maintenance and Administrative Arrangements

2.3.2 EIA documents;

Electronic Industries Association
Engineering Department
2001 Eye Street, NW
Washington, DC 20006
Telephone: (202) 457-4900

2.3.3 ISO documents;

American National Standards Institute, Inc.
1430 Broadway
New York, New York 10018
Telephone: (212) 354-3300

3. REQUIREMENTS

This standard adopts CCITT Recommendation X.25 (1984), ISO 7776, and ISO 8208 with the exceptions listed here and in 3.1 through 3.3. A minimum subset of CCITT Recommendation X.25, ISO 7776 and ISO 8208 that is to be supported is defined in 3.1 through 3.3. Requirements apply to both the DTE and DCE unless otherwise specified. These requirements neither prohibit nor discourage the support of additional capabilities.

Aspects of the other CCITT X-Series Recommendations (e.g., X.1, X.2, X.10, X.21 bis, X.29, X.92, and X.96) referenced in CCITT Recommendation X.25 that are relevant to this standard are contained in the material that follows.

The general elements of this standard include:

- A family of physical layer interfaces, from which a particular interface may be selected;
- A single data link layer control procedure; and
- Packet level procedures for virtual calls and permanent virtual circuits.

3.1 Physical Level

At the physical level, the provisions of Section 1 of CCITT Recommendation X.25 shall be used.

3.1.1 Data Signaling Rates

CCITT Recommendation X.1 standardizes user classes of service which are data signaling rates of 2.4, 4.8, 9.6, 48, and 64 kbits/s for packet mode operation. Additional signaling rates are defined by ANS X3.1.

It is required that PSDNs support the data signaling rates of 4.8 and 9.6 kbits/s duplex. Other signaling speeds as defined by CCITT Recommendation X.1 and ANS X3.1 may also be provided. Note that 56 kbits/s is a standard rate specified in North America by ANS X3.1; 56 kbits/s is recommended in place of the 48 kbits/s rate specified by Rec. X.1. The use of 64 kbits/s is recommended in anticipation of the Integrated Services Digital Networks (ISDN).

3.1.2 Physical Interface

In accordance with CCITT Recommendation X.25, either of the following physical interface shall be provided for dedicated access at data signaling rates of 19.2 kbits/s or less:

(1) EIA-232-D
Note: For an interim period, EIA-232-C may be substituted for EIA-232-D; however, EIA-232-D supercedes EIA-232-C, and new implementations should comply with EIA-232-D.

For dedicated access at data signaling rates greater than 19.2 kbits/s, either of the following physical interfaces shall be provided:

(2) Electrical characteristics according to Appendix II of CCITT Recommendation V.35 (for data and timing circuits) and CCITT Recommendation V.28 (for control circuits); interchange circuits according to CCITT Recommendation V.24; connection and pin assignments according to ISO 2593.

(3) EIA-449, with electrical characteristics as provided in either EIA-422-A or EIA-423-A.

The above are options in CCITT Recommendations X.21 and X.21 bis.

Note: DTE purchasers and designers should determine which physical interface(s) is provided by the associated DCE(s).

3.2 Link Level

The provisions in Section 2 of CCITT Recommendation X.25 applying only to LAPB and those of ISO 7776 shall be used. The use of LAP provisions of CCITT Recommendation X.25 are not applicable to this standard.

3.2.1 Two combined stations on a point-to-point single link configuration shall be supported. Optionally, multilink configurations may also be supported.

3.2.2 Two-way simultaneous operation shall be supported.

3.2.3 The FCS shall be a 16-bit sequence. (2.2.7/X.25)

3.2.4 The address of the DCE shall be 10000000 for single link operation and 11100000 for multilink operation. The address of the DTE shall be 11000000 for single link operation and 11110000 for multilink operation (2.4.2/X.25). For direct DTE/DTE operations, one of the DTEs uses the address of the DCE.

3.2.5 The smallest N1 (the maximum number of bits in an information frame excluding flags and zero bit insertion for transparency) to be supported by a DCE shall be 2104 bits (263 octets). An N1 as small as 1080 bits (135 octets) may be supported by the DTE. These values are based on modulo 8 operation at both the link and packet level.

3.2.6 It is required that all implementations be capable of operating with k=7; optionally, values of 1 to 6 are permissible with modulo 8 operation and values 1 to 127 are permissible with modulo 128 operation. Modulo 128 operation is optional.

Note: DTE purchasers and designers should determine what values of k other than 7 are supported by the associated DCE(s).

3.3 Packet Level

The provisions of CCITT Recommendation X.25 and ISO 8208 dealing with Packet Level Procedures shall be used subject to the following:

3.3.1 The services for packet-switched data networks are from CCITT Recommendation X.2 (1984). Networks shall provide Virtual Call Service and Permanent Virtual Circuit Service, both of which are designated as essential (E).

3.3.2 It is required that all implementations be capable of operating with packet sequence numbering modulo 8; optionally, implementations of packet sequence numbering modulo 128 are also permitted.

Note: DTE purchasers and designers should determine if the associated DCEs support packet sequence numbering modulo 128.

3.3.3 Any additional field appended after the first 3 octets shall contain an integral number of octets. When the packet level detects non-octet alignment, the DTE/DCE shall follow the packet level procedures for processing a packet type which is not octet aligned (diagnostic code #82). (Annex C/X.25; 3.7/ISO 8208).

3.3.4 All DCE Restart Confirmation, DCE Reset Confirmation, and DCE Clear Confirmation packets shall be interpreted by the DTE as having local significance only.

3.3.5 Networks may optionally support the Diagnostic packet. In the operational situations listed in Table C-1, Annex C of CCITT Recommendation X.25, the following will apply:

(1) If the network supports the Diagnostic packet it will transmit a Diagnostic packet with an appropriate diagnostic code, or

(2) If the network does not support the Diagnostic packet, it will discard the packet, and take no subsequent action as a direct result of receiving the packet.

No DTE shall reject Diagnostic packets as errors.

3.3.6 A diagnostic code shall be provided in all Clear Request, Reset Request, and Restart Request packets. All DTEs shall support the diagnostic codes listed in Figure 14b of ISO 8208. In addition, under bilateral or multilateral agreements, DTEs may support nonstandard diagnostic codes as provided for in Figure 14a of ISO 8208.

3.3.7 The network diagnostic codes shall be used in accordance with the codes listed in Annex E of CCITT Recommendation X.25 whenever they apply; non-assigned codings in the range of 128-255 in X.25 may be used for events not listed in X.25.

3.3.8 A generic diagnostic code shall not be used when a more specific diagnostic code is known to be applicable.

3.3.9 In the DTE/DCE environment, the selection of a logical channel number for new virtual calls shall follow the procedures suggested in Section 4.1.2, Note 2; Annex A, Note 5; and Annex A, Note 6, of CCITT Recommendation X.25. In the DTE/DTE environment, logical channel number selection shall follow the procedure specified in Sections 5.2.1 (Note 3) and 5.2.5, and Figure 1, in ISO 8208.

3.3.10 In ISO 8208, Section 6.1, the second paragraph, the second sentence, which pertains to Data, interrupt, flow control, reset, and Reject packets reads "While in a state other than d1, the above mentioned packets may be discarded." This shall be interpreted that the receiving DTE/DCE shall follow the packet level procedures for processing these packet types in accordance with Tables C-2/X.25, C-3/X.25, and C-4/X.25.

3.3.11 The following option in Table C-3/X.25 shall not be used. "Some networks may invoke the ERROR #74 procedure if the address length fields are not equal to 0 in the call accepted packet, except when the called line address modified notification facility is present in the facility field."

3.3.12 A DTE may transmit a Reject packet, but it must be able to suppress the generation of that packet if there is no agreement to use the packet retransmission facility. Processing a retransmission request by a DTE shall follow procedures given in 13.4.2/ISO 8208.

3.3.13 Receipt of a Data packet with a nonconsecutive P(S) value, with a user data field length greater than the allowed maximum or a user data field not octet-aligned, is an error condition. For these conditions, a DTE shall ignore the erroneous Data packet and reset the logical channel with cause indicating "DTE originated", and one of the following diagnostics as appropriate: invalid P(S) (#1), packet too long (#39), or non-octet aligned data field (#82). This procedure is in accordance with Table C-4/X.25. For the case of a nonconsecutive P(S) value, alternative b of 11.3/ISO 8208 may be used. Alternative c as defined in Section 11.3 of ISO 8208 shall not be used.

3.3.14 A DTE shall invoke #39 ERROR procedure as defined in Figure 5-G of ISO 8208 when the DTE receives an RR or RNR packet having one or more octets beyond the third octet when modulo 8 numbering is used (or the fourth octet when modulo 128 numbering is used). The alternative action (the packet may be ignored) as defined in Note 2 of Figure 5-G of ISO 8208 shall not be used.

3.3.15 Timeouts and time limits specified in Annex D of X.25 shall be employed by all DTEs and DCEs. T21 shall not be less than the value given in Table D-2/X.25. The actions listed in Tables D-1 and D-2 of CCITT Recommendation X.25 shall be followed. In addition, the window rotation timer, T25, may be optionally supported (11.2.1/ISO 8208).

3.3.16 If the optional procedure at the transmitting DTE to effect recovery from nonreceipt of window-rotation information is used, and if a P(R) that rotates the window is not received before expiration of T25, then the transmitting DTE shall reset the logical channel, indicating the cause DTE-originated with the diagnostic #146. (11.2.1/ISO 8208)

3.3.17 The D-bit procedure shall be implemented by all networks. DTEs need not employ the D-bit procedures when transmitting to the network, but no DTE shall reject incoming packets with the D-bit set to 1 or 0 as having this bit in error unless the receiving DTE knows the remote DTE has not implemented this value of the D-bit; in this case, the receiving DTE may treat such an occurence as an error condition. If the packet is treated as Normal according to ISO 8208 for the state of the interface, this may result in an error with diagnostic #166, D-bit procedure not supported.

3.3.18 DTEs must implement the address length fields and the facility length field in the Call Accepted packet even if they are set to zero (5.2.2.1.2/X.25 and 5.2.2.1.4/X.25; 12.2.2/ISO 8208)

3.3.19 DCEs shall allow the Interrupt packet user data field to contain 1 to 32 octets. (5.3.2.1/X.25; 12.3.2/ISO 8208)

3.3.20 User facilities for packet-switched data networks are given in CCITT Recommendation X.2 and optional user facilities are given in ISO 8208 for DTE/DTE operation. Table A1 is adapted from these standards. These facilities are described in Sections 2 and 6 of CCITT Recommendation X.25. The following further constraints apply:

(1) Networks shall provide the facilities designated as essential (E).

(2) Networks shall implement basic RPOA selection. Networks shall also provide extended RPOA selection to DTEs that require it.

(3) All DTEs which employ any of the facilities classified as additional (A) shall also be capable of operating without employing any A facilities. However, this requirement is not intended to preclude from the scope of this standard specialized intermediary equipment designed principally to operate upon one or more A facility (e.g., equipment to collect and record billing information using the Charging information facility).

(4) The throughput class value of 48 kbits/s may be interpreted as 56 kbits/s in those locations where 56 kbits/s access is used.

3.3.21 The list of the applicable call progress signals adapted from CCITT Recommendation X.96 is given in Table B1 in Appendix B of this standard. Coding of call progress signals in packet cause fields is given in Tables 18/X.25, 19/X.25, 20/X.25, and 21/X.25.

3.3.22 DTEs shall not use a facility marker with a facility parameter field set to all ones in case of intranetwork calls. (7.1/X.25)

3.3.23 DCEs shall support the facility marker for CCITT-specified DTE facilities.

3.3.24 The Address Extension Facilities shall accommodate 40 digits (20 octets) rather than 32 digits (16 octets).

APPENDIX A
FACILITIES FOR X.25 FROM CCITT RECOMMENDATION X.2 (1984) AND ISO 8208 (1985)

The following information is adapted from CCITT Recommendation X.2, International Data Transmission Services and Optional User Facilities in Public Data Networks, Red Book, Volume VIII, Fascicle VIII.2, Geneva 1985 (reprinted with permission of the International Telecommunications Union) and ISO 8208 (1985), Information Processing Systems - X.25 Packet Level Protocol for Data Terminal Equipment. For DTE/DTE operation, reference should be made to ISO 8208 to determine specific conditions that apply to particular user facilities.

Table A1. User Facilities for Packet-Switched Data Networks

	Optional user facility	VC	PVC	DTE/DTE Operation (ISO 8208)	Reference Paragraph in X.25
I.	Optional user facilities assigned for an agreed contractual period				
1	Extended frame sequence numbering	A	A	-	2.1.5
2	Multilink procedure	A	A	-	2.5
3	On-line facility registration	A	-	-	6.1
4	Extended packet sequence numbering (modulo 128) ..	A	A	Yes	6.2
5	D-bit modification	A	A	No	6.3
6	Packet retransmission	A	A	Yes	6.4
7	Incoming calls barred	E	-	No	6.5
8	Outgoing calls barred	E	-	No	6.6
9	One-way logical channel outgoing	E	-	Yes	6.7
10	One-way logical channel incoming	A	-	Yes	6.8
11	Nonstandard default packet sizes 16, 32, 64, 256, 512, 1024, 2048, 4096	A	A	Yes	6.9
12	Nonstandard default window sizes	A	A	Yes	6.10
13	Default throughput classes assignment	A	A	Yes	6.11
14	Flow control parameter negotiation	E	-	Yes	6.12
15	Throughput class negotiation	E	-	Yes	6.13
16	Closed user group	E	-	No	6.14.1
17	Closed user group with outgoing access	A	-	No	6.14.2
18	Closed user group with incoming access	A	-	No	6.14.3
19	Incoming calls barred within a closed user group .	A	-	No	6.14.4
20	Outgoing calls barred within a closed user group .	A	-	No	6.14.5
21	Bilateral closed user group	A	-	No	6.15.1
22	Bilateral closed user group with outgoing access .	A	-	No	6.15.2
23	Fast select acceptance	E	-	No	6.17
24	Reverse charging acceptance	A	-	No	6.19
25	Local charging prevention	A	-	No	6.20
26	Network user identification	A	-	No	6.21
27	Charging information	A	-	No	6.22
28	RPOA selection	FS	-	No	6.23
29	Hunt group	A	-	No	6.24
30	Call redirection	A	-	No	6.25
31	Direct call	FS	-	-	
II.	Optional user facilities on a per-call basis				
1	Flow control parameter negotiation	E	-	Yes	6.12
2	Throughput class negotiation	E	-	Yes	6.13
3	Closed user group selection	E	-	No	6.14.6
4	Closed user group with outgoing access selection .	A	-	No	6.14.7
5	Bilateral closed user group selection	A	-	No	6.15.3
6	Fast select	E	-	Yes	6.16
7	Reverse charging	A	-	No	6.18
8	Network user identification	A	-	No	6.21
9	Charging information	A	-	No	6.22
10a	Basic RPOA selection	E*	-	No	6.23
10b	Extended RPOA selection	A**	-	No	6.23
11	Called line address modified notification	A	-	No	6.26
12	Call redirection notification	A	-	No	6.27
13	Transit delay selection and indication	E	-	No	6.28
14	Abbreviated address calling	FS	-	-	

E: An essential user facility.
A: An additional user facility which may be available in certain data networks.
FS: For further study.
-: Not applicable.
VC: Applicable when the virtual call service is being used.
PVC: Applicable when the permanent virtual circuit service is being used.
*: Although designated A in CCITT Recommendation X.2, this facility is designated E by this standard.
**: This facility is designated E when a DTE requires it.

APPENDIX B

CALL PROGRESS SIGNALS (CAUSE CODES) FOR X.25 FROM CCITT RECOMMENDATION X.96 (1984)

The following information is adapted from CCITT Recommendation X.96, Call Progress Signals in Public Data Networks, CCITT Red Book, Volume VIII, Fascicle VIII.4, Geneva 1985, and reprinted with permission of the International Telecommunications Union.

The call progress signals and the related circumstances giving rise to them are defined in Table B1. The categories listed in Table B1 are defined in notes at the end of the table.

The sequence of call progress signals in Table B1 implies, for Categories C and D, the order of call set-up processing by the network. In general, the DTE can assume, on receiving a call progress signal, that no condition higher up the table is present. Network congestion is an exception to this general rule. The actual coding of call progress signals (see Tables 18/X.25, 19/X.25, 20/X.25, and 21/X.25 of CCITT Recommendation X.25) does not necessarily reflect this sequence.

Users and DTE manufacturers are warned to make due allowance for possible later extensions to this table by providing appropriate fall-back routines for unexpected signals.

Table B1. Categories and Definitions of Call Progress Signals

Call Progress Signal	Definition	Category	Packet Switching		See Note	Reference Table in X.25
			VC	PVC		
Registration/ cancellation confirmed	The facility registration or cancellation requested by the DTE has been confirmed by the network.	B	(M)	(M)	11	20 21
Local procedure error	A procedure error caused by the DTE is detected by the DCE at the local DTE/DCE interface. Possible reasons include: - incorrect format; - expiration of a time-out.	D1	M	M		18 19 20 21
Network congestion	A condition exists in the network such as: - temporary network congestion, - temporary fault condition within the network, including procedure error within a network or an international link.	C2	M	M		18 19 20 21
Network out of order	Temporary inability to handle data traffic.	C2	-	M		19
Invalid facility request	A facility requested by the DTE is detected as invalid by the DCE at the local DTE/DCE interface. Possible reasons include: - request for a facility which has not been subscribed to by the DTE; - request for a facility which is not available in the local network; - request for a facility which has not been recognized as valid by the local DCE.	D1	M	-		18 21
RPOA out of order	The RPOA nominated by the calling DTE is unable to forward the call.	D2	(M)	-	4	18
Not obtainable	The called DTE address is out of the numbering plan or not assigned to any DTE.	D1	M	-		18
Access barred	The calling DTE is not permitted the connection to the called DTE. Possible reasons include: - unauthorized access between the calling DTE and the called DTE; - incompatible closed user group.	D1	M	-		18
Reverse charging acceptance not subscribed	The called DTE has not subscribed to the reverse charging acceptance facility.	D1	(M)	-		18
Fast select acceptance not subscribed	The called DTE has not subscribed to the fast select acceptance facility.	D1	(M)	-		18

Table B1. (continued)

Incompatible destination	The remote DTE/DCE interface or the transit network does not support a function or facility requested.	D1	M	M		18 19
Ship absent	The called ship is absent.	D1	M	-	13	18
Out of order	The remote number is out of order. Possible reasons include: - DTE is uncontrolled not ready; - DCE power off; - network fault in the local loop; - X.25 level 1 not functioning; - X.25 level 2 not in operation.	D1 or D2	M	M	7,8	18 19
Number busy	The called DTE is detected by the DCE as engaged on other call(s), and therefore as not being able to accept the incoming call.	C1	M	-		18
Remote procedure error	A procedure error caused by the DTE or an invalid facility request by the remote DTE is detected by the DCE at the remote DTE/DCE interface.	D1	M	M		18 19
Network operational	Network is ready to resume normal operation after a temporary failure or congestion.	C1	-	M		19 20
Remote DTE operational	Remote DTE/DCE interface is ready to resume normal operation after a temporary failure or out of order condition (e.g., restart at the DTE/DCE interface). Loss of data may have occurred.	C1	-	M		19
DTE originated	The remote DTE has initiated a clear, reset or restart procedure.	B or D1	M	M	12	18 19

- Not applicable.

M Mandatory in all networks.

(M) Mandatory where the relevant optional user facility is provided.

Significance of Categories in Table B1:

A	Call not cleared. Calling DTE is expected to wait.
B	Call cleared because the procedure is complete.
C1 and C2	Call cleared The calling DTE should call again soon: the next attempt may be successful. However, after a number of unsuccessful call attempts with the same response, the cause could be assumed to be in Category D1 or D2. The interval between successive attempts, and the maximum number of attempts will depend on a number of circumstances including: - nature of the call progress signal, - user's traffic pattern, - tariffs, - possible regulations by the Administrations. Reset The DTE may continue to transmit data recognizing that data loss may have occurred.
D1 and D2	Call cleared The calling DTE should take other action to clarify when the call attempt might be successful. Reset (for permanent virtual circuit only). The DTE should cease data transmission and take other action as appropriate.
C1 and D1	Due to subscriber condition.
C2 and D2	Due to network condition.

Notes concerning Table B1:

The following notes are numbered according to Table 1/X.96.

Note 4 - The RPOA out-of-order call progress signal will not be returned to a DTE which does not subscribe to the RPOA selection facility.

Note 7 - Although the basic out-of-order call progress signal is transmitted for these conditions, the diagnostic field in the clearing or resetting packet may give more precision.

Note 8 - The fact that a DTE is also out of order when the link access procedure level is not operating correctly is a subject for further study.

Note 11 - Applicable only to the local DTE/DCE interface.

Note 12 - Possible reasons for this include reverse charging not accepted.

Note 13 - Used only in conjunction with mobile maritime service.

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American National Standard (ANS) X3.100 will be adopted as Federal Information Processing Standards Publication (FIPS PUB) 100 and Federal Standard (FED STD) 1041. These standards are based on CCITT Recommendation X.25 and ISO Standards 7776 and 8208. CCITT X.25 is an interface that is oriented toward data circuit-terminating equipment (DCE) for packet operation. While ISO 7776 and 8208 are compatible with X.25, they also provide added guidance that allows two pieces of data terminal equipment (DTE) to exchange packets over a dedicated path or circuit-switched network without a packet-switched network in between. Hence, ANS X3.100 and FIPS PUB 100/FED STD 1041 provide for operation that may, or may not, include an intervening packet network.

While X.25 requires a dedicated circuit for access, CCITT Recommendation X.32 essentially modifies X.25 and allows switched access to a packet-switched network. Consequently, X.32 has been called a "dial-in, dial-out X.25" through the use of, for example, a public switched telephone network (PSTN). Although X.32 is not part of FIPS PUB 100/FED STD 1041, it is described in this reference manual.

This reference manual provides a tutorial description of terminals operating in the packet mode and the applicable standards at the physical, link, and packet levels. This should permit the reader to begin understanding an area of data communications that has become popular and is being implemented throughout the United States and other countries.

Key words: DTE/DCE interfaces; Federal Standards; high-level data link control (HDLC); ISO 7776; ISO 8208; link access procedure, balanced (LAPB); link access procedure, half-duplex (LAPX); link level; logical channels; open systems interconnection (OSI); packet level protocol (PLP); packet switching; packet switched public data network (PSPDN); physical level; public switched network (PSN); X.21; X.21 bis; X.25; X.32

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