CCITT Packet Switched Networking Standards X Series

In this report:

Synopsis

Editor's Note

In 1984, CCITT published Red Books on wide-ranging topics, including the X.25 packet-switching standards. A set of revisions to the X Series, the Blue Books, was published in 1989. Since that time, standards ratification and publication have been ongoing, continuous processes. Each future addition or revision to the X Series standards will be made available, as soon as they are finalized, in individual gray booklets. Since the major building blocks of the X standards were completed by 1984, all post-1984 technical changes are relatively minor; they are discussed in this report, however.

Major developments in packet switching center around the development of ISDN-related technologies, such as fast packet switching and frame relay, which provide integration of voice, video, and data, and support much higher throughput than traditional X.25 networks. ISDN's relationship with traditional X.25 packet switching is also discussed.

Report Highlights

A packet switched network permits a user's data terminal equipment (i.e., a PC, host computer, or terminal) to communicate with the equipment of other geographically dispersed users. Data must be presented to the network in a prescribed manner, however. A packet assembler/disassembler (PAD), also referred to as data circuit-terminating equipment (DTE), serves as a network entry/exit point, packetizing and depacketizing data according to the rules specified by the X.3, X.28, X.29, X.21, X.25, and X.75 recommendations of the CCITT.

—By Martin Dintzis
Assistant Editor

Analysis

In the early days of packet switching, each Public Data Network (PDN) defined its own network access protocol, which permitted an appropriately equipped computer to communicate with other devices on the network through a physical connection to the PDN. Each of these protocols used a multiplexing technique that enabled a computer to establish and maintain one or more virtual circuits to other network communicating equipment. No industry standard for packet switching existed, however, and most computer manufacturers were reluctant to provide the necessary software to handle the variety of network access protocols.

With the adoption of the X Series Recommendations by the CCITT in 1976, the PDNs could offer a standard network access protocol. The CCITT published revisions to these standards in 1984 and 1989. Since that time, the ratification and publication of revisions have become a continuous, ongoing process.

This report focuses on Recommendations X.3, X.28, and X.29 (informally called the Interactive Terminal Interface [ITI] standards); X.21; X.25; and X.75.

Table 1. CCITT Recommendations—X Series

CCITT Recommendation	Description
X.1	International user classes of service in public data networks: class 8 (2400 bps); class 9 (4800 bps); class 10 (9600 bps); or class 11 (48,000 bps)
X.2	International user facilities in public data networks
X.3	Packet assembly/disassembly (PAD) facility in a public data network; lists options and defaults for interactive asyn chronous terminal connection to X.25 packet networks
X.4	General structure of signals of International Alphabet No. 5 (IA5) code for data transmission over public data networks (IA5 is described in CCITT V.3)
X.20	Interface between data terminal equipment (DTE) and data circuit-terminating equipment (DCE) for async trans mission services on public data networks
X.20 bis	V.21-compatible interface between DTE and DCE for async transmission services on public data network
X.21	General-purpose interface between DTE and DCE for synchronous operation on public data networks
X.21 bis	For use on public data networks by DTE that are designed to interface to synchronous V-Series modems
X.24	List of definitions of interchange circuits between DTE and DCE on public data networks
X.25	Interface between DTE and DCE for terminals operating in the packet mode on public data networks
X.26	Electrical characteristics for unbalanced double-current interchange circuits for data communications equipment
X.27	Electrical characteristics for balanced double-current interchange circuits for data communications equipment
X.28	DTE/DCE interface for asynchronous device access to the PAD facility of a public data network in the same country
X.29	Procedure for the exchange of control information and user data between a packet mode DTE and a PAD facility
X.32	Procedure for communications between users and packet networks through the switched telephone network and through circuit switched public data networks
X.75	Expanded X.25 recommendation for internetwork communications between packet switched networks; interface is defined between two STEs (Signaling Terminal Equipments) that are a part of ISDEs (International Data Switching Exchanges), with expanded support for wideband links, extended sequencing, and an expanded network utility field for international call establishment
X.92	Hypothetical reference connections for public synchronous data networks
X.95	Network parameters in public data networks
X.96	Call progress signals in public data networks
X.121	International numbering scheme for multinetwork communications containing a 4-digit DNIX (Data Network Identification Code), 3-digit area code, 5-digit host identification, a 0- to 2-digit subaddress

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With the adoption of the X Series Recommendations by the CCITT in 1976, the PDNs could offer a standard network access protocol. The recommendations are continually fine-tuned. Revised editions are published at four-year intervals; the 1989 draft incorporates the latest revisions and recommendations. The next published revision will be available in 1992.

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Packet Assembly/Disassembly

Recommendations X.3, X.28, and X.29 define the procedures by which asynchronous terminals, computers, and other devices, often referred to as data terminal equipment (DTE), communicate with other devices via a packet switched network. Packet assemblers/disassemblers, also referred to as DTE, commonly serve as network entry/exit points.

X.3 defines the basic and user-selectable functions of a packet assembler/disassembler (PAD). It also lists 22 parameters necessary to characterize a specific device (e.g., bit rate, the escape character, and flow control technique). The proper setting of these values enables the PAD to correctly interpret the communicating device and vice versa.

X.28, a related standard, defines the procedures for character interchange and service initialization, the exchange of control information, and the exchange of user data between an asynchronous terminal device and a PAD. X.29 defines the procedures for the exchange of PAD control information and the manner in which user data is transferred between a packet mode DTE and a PAD or between two PADs.

Recommendation X.3

CCITT Recommendation X.3, *Packet Assembly/Disassembly Facility in a Public Data Network*, outlines the procedures for packet assembly/disassembly in asynchronous transmissions. These functions can be programmed and built into a microprocessor-based "black box" that is placed between the terminal and the X.25 network at either the customer's premises or the entry point of the network node.

The PAD performs a number of functions, some of which allow it to be configured, by either an asynchronous terminal device or another (remote) PAD, so that its operation is adapted to the asynchronous terminal's characteristics. The PAD's basic functions include:

- The assembly of characters into packets;
- The disassembly of the user data field;
- Virtual call setup, clearing, resetting, and interrupt procedures;
- Generation of service signals;
- A mechanism for forwarding packets when the proper conditions exist;
- A mechanism for transmitting data characters, including start, stop, and parity elements;
- A mechanism for handling a break signal from an asynchronous terminal;
- Editing of PAD command signals;
- A mechanism for setting and reading the current value of PAD parameters;
- A mechanism for the selection of a standard profile (optional);
- Automatic detection of data rate, code, parity, and operational characteristics (optional); and
- A mechanism for the remote DTE to request a virtual call between an asynchronous terminal and another DTE (optional).

The PAD's operation depends on the selectable values of internal variables called PAD parameters. A set of parameters exists independently for each asynchronous terminal. The current value (the binary representation of the decimal value) of each PAD parameter delimits the operational characteristics of the related function. The initial value of each parameter is set according to a predetermined set of values, the initial standard profile. Twenty-two PAD parameters have been standardized by the CCITT. They are as follows:

- ***PAD recall using a character***—allows an asynchronous terminal to initiate an escape from the *data transfer state* or the *connection-in-progress state* in order to send PAD command signals. This parameter has the following selectable values: not possible, possible by character 1/0 (DLE), or possible by a user-defined graphics character.
- ***Echo***—enables characters received from the asynchronous terminal to be interpreted by the PAD and transmitted back to the asynchronous terminal. Selectable values are no echo (0) and echo (1).
- ***Selection of data forwarding characters***—allows the asynchronous terminal to send defined sets of characters, which the PAD recognizes as an indication to complete the packet assembly and to forward a complete packet sequence as defined in X.25. The basic functions of this parameter are encoded and represented by a decimal value. The functions include no data forwarding character (represented by decimal 0); alphanumeric characters A-Z, a-z, and 0-9 (decimal 1); CR (decimal 2); ESC, BEL, ENQ, and ACK (decimal 4); DEL, CAN, and DC2 (decimal 8); ETX and EOT (decimal 16); HT, LF, VT, and FF (decimal 32); and all other characters in columns 0 and 1 of International Alphabet No. 5 (IA5) not included in the above (decimal 64).
- ***Selection of idle timer delay***—permits the selection of the duration of a time interval between successive characters. When data received from the asynchronous terminal exceeds this interval, the PAD terminates the assembly of a packet and forwards it as defined in the X.25 protocol.
- ***Ancillary control***—defines flow control between the PAD and the asynchronous terminal. Decimal 0 represents no use of X-on (DC1) and X-off (DC3); decimal 1 represents use of X-on/X-off (data transfer); and decimal 2 represents the use of X-on/X-off (data transfer and command).
- ***Control of PAD service signals***—provides the asynchronous terminal with the capability to decide whether and in what format PAD service signals are transmitted.
- ***Selection of operation of the PAD on receipt of the break signal***—after receiving a break signal from the asynchronous terminal, the PAD may do nothing, send an *interrupt packet* to a packet mode DTE or another PAD, reset, or send an *indication of break* PAD message to a packet mode DTE or another PAD.
- ***Discard output***—permits a PAD to discard the content of user sequences in packets rather than disassembling and transmitting them to the asynchronous terminal. Selections include normal data delivery or discard output.
- ***Padding after carriage return***—permits the PAD to automatically insert padding characters in the character stream sent to the asynchronous terminal after the occurrence of a carriage return character. This enables the asynchronous terminal printing device to perform the carriage return function correctly. A value between 0 and 255 indicates the number of padding characters the PAD will generate.

- ***Line folding***—permits the PAD to automatically insert appropriate format effectors in the character stream sent to the asynchronous terminal. No line folding or a predetermined maximum number of graphics characters per line may be selected.
- ***Binary speed***—a read-only parameter that neither DTE can change. It enables the packet mode DTE to access a characteristic (known by the PAD) of the asynchronous terminal device. Speeds from 50 bps to 64K bps are represented.
- ***Flow control of the PAD by the start/stop mode DTE***—governs flow control between the asynchronous terminal and the PAD. The asynchronous terminal transmits special characters to indicate whether it is ready to accept characters from the PAD. In IA5, these special characters switch an ancillary transmit device on and off. Decimal 0 represents no use of X-on (DC1) and X-off (DC3); decimal 1 represents use of X-on/X-off.
- ***Line-feed insertion after carriage return***—permits the PAD to automatically insert a line-feed character in the character stream sent to or received from the asynchronous terminal or after echo of each carriage return character. This function applies only in the data transfer state.
- ***Line-feed padding***—permits the PAD to automatically insert padding characters in the character stream transmitted to the asynchronous terminal after the occurrence of a line-feed character. This enables the asynchronous terminal printing mechanism to perform the line-feed operation correctly. This function applies only in the data transfer state.
- ***Editing***—enables character delete, line delete, and line display editing capabilities. During the *PAD command state*, the editing function is always available; use or nonuse of the editing function in the *data transfer state* is selectable.
- ***Character delete, line delete,*** and ***line display***—all editing functions represented by one user-selectable character from IA5.
- ***Editing PAD service signals***—enable the asynchronous terminal to edit PAD service signals for printing devices and display terminals; also used for editing via one character from IA5. Editing is not selectable.
- ***Echo mask***—when echo is enabled, echo mask designates that selected defined groups of characters sent by the asynchronous terminal are not transmitted back. The following may be selected: no echo mask; no echo of CR; no echo of LF; no echo of VT, HT, and FF; no echo of BEL and BS; no echo of ESC and ENQ; no echo of ACK, NAK, STX, SOH, EOT, ETB, and ETX; no echo of editing characters; or no echo of all other characters.
- ***Parity treatment***—permits the PAD to check parity in the datastream from the asynchronous terminal and/or generate parity in the datastream to the asynchronous terminal. No parity checking or generation, parity checking, or parity generation are selectable.
- ***Page wait***—allows the PAD to suspend transmission of additional characters to the asynchronous terminal after the PAD has transmitted a specified number of line-feed characters.

Recommendation X.28

CCITT Recommendation X.28, titled *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*, describes the interfacing procedures that allow the PAD to be connected to an asynchronous terminal. X.28 covers four areas:

- Procedures to establish an access information path between an asynchronous terminal and a PAD;
- Procedures for character interchange and service initialization between an asynchronous terminal and a PAD;
- Procedures for the exchange of control information between an asynchronous terminal and a PAD; and
- Procedures for the exchange of user data between an asynchronous terminal and a PAD.

Modems standardized for use on public switched or leased line facilities establish the procedures for providing an access path (DTE/DCE interface). Procedures for both V and X Series interfaces are defined.

Transmission speeds up to 1200 bps are specified for V-Series interfaces; they are in accordance with either the V.21, V.22, or V.23 standard, depending on facility type and speed. The V-Series specifications define the procedures for setting up and disconnecting the access information path by both the DTE and the PAD.

X-Series interfaces also are used with switched or leased line facilities. The physical characteristics for the DTE/DCE interface are specified in X.20 or X.20 bis. Procedures for setting up and disconnecting the path by both the DTE and the PAD are defined.

X.28 specifies procedures for character interchange and service initialization between an asynchronous terminal and a PAD. Characters sent and received must conform to IA5. The PAD transmits and expects to receive only eight-bit characters. The eighth bit, the last bit preceding the stop element, is used for parity checking.

X.28 describes the action the PAD takes when the value of parameter 21 (X.3, parity treatment) is set to 0, 1, 2, or 3. If parameter 21 is set to 0, the PAD inspects only the first seven bits and ignores the eighth bit. When parameter 21 is set to 1, the PAD treats the eighth bit of the character as a parity bit and checks this bit against the type of parity—odd, even, space (0), or mark (1)—used between the PAD and the asynchronous terminal. If it is set to 2, the PAD replaces the eighth bit of the characters to be sent to the terminal with the bit that corresponds to the type of parity used between the PAD and terminal. When the value is set to 3, the PAD checks the parity bit for characters received from the asynchronous terminal *and* generates the parity bit for characters to be sent to the asynchronous terminal (as in values 1 and 2).

Once the access information path is established, the asynchronous terminal and the PAD exchange binary 1 across the interface. This places the interface in the *active link state* (state 1). When the interface is in the active link state, the DTE transmits a sequence of characters that indicates *service request* (state 2) and initializes the PAD. The service request permits the PAD to detect the data rate, code, and parity used by the asynchronous terminal (DTE) and to select the initial profile of the PAD. The service request may be bypassed, if the terminal is connected to the PAD via a leased line and the PAD knows the speed, code, and initial profile of the terminal or if a default value is used. After the request service signal is transmitted, the DTE transmits binary 1, which places the interface in the *DTE waiting state* (state 3A). If parameter 6 (X.3, control of PAD service signals) is set to 0, the interface immediately enters the *PAD waiting state* (state 5) after receipt of service request. If parameter 6 is set to other than 0, the PAD transmits the *PAD identification PAD service* signal (indicates PAD and port identity; is network dependent), and the interface enters the *service ready state* (state 4). The DTE then transmits a *selection PAD command* signal (state 6), and the PAD transmits an *acknowledgment PAD service* signal, followed by binary 1, which places the interface in the *connection-in-progress* state (state 7).

If parameter 6 is 0, the PAD will not transmit PAD service signals. In this case, the interface is placed in the connection-in-progress state after receipt of a valid selection PAD command signal.

Once the DTE receives the PAD service signal (state 8) or a sequence of signals in response to a PAD command signal, the interface is placed in either the PAD waiting state (state 5) or the data transfer state (state 9).

A *fault condition* exists if a valid service request signal is not received by the PAD within a selectable number of seconds after the transmission of binary 1. If a fault condition occurs, the PAD performs clearing by disconnecting the access information path.

The procedures for the exchange of control information between an asynchronous terminal and a PAD include *PAD command* signals, *PAD service* signals, *break* signals, and *prompt PAD service* signals. PAD command signals flow from the DTE to the PAD; they set up and clear a virtual call, select a standard profile (PAD parameters) that is either CCITT or network defined, request current values of PAD parameters, send an interrupt requesting circuit status, and reset a virtual call. PAD service signals flow from the PAD to the DTE; they transmit call progress signals, acknowledge PAD command signals, and transmit operating information of the PAD to the terminal. Either the PAD or the terminal can transmit the *break* signal. It provides signaling without losing character transparency. The *prompt PAD service* signal indicates the PAD's readiness to receive a PAD command signal.

The temporary storage of characters in an editing buffer provides editing functions in the PAD. These functions permit the asynchronous terminal to edit characters input to the PAD before the PAD processes them. They include character delete, line delete, and line display. Character delete removes the last character in the editing; line delete removes the contents of the editing buffer. Line display causes the PAD to send a format effector followed by the contents of the editing buffer to the terminal.

Procedures for the exchange of user data between an asynchronous terminal and a PAD apply during the data transfer state. The values of the parameters set in X.3 determine which characters are transmitted during the data transfer state. For example, if parameters 1 (PAD recall using a character), 12 (flow control of the PAD by the start/stop mode DTE), 15 (editing), and 22 (page wait) are set to 0, any character sequence may be transmitted by the asynchronous terminal for delivery to the remote DTE during the data transfer state.

User data is sent to the asynchronous terminal in octets (eight-bit characters) at the appropriate transmission rate for the asynchronous terminal; the start/stop bits are added to the data characters. Octets are assembled into packets (see X.25) and forwarded when enough data has been received to fill a packet, when the maximum assembly timer delay period has elapsed, when a data forwarding character is transmitted, or when a break signal is transmitted (parameter 7 is set to other than 0).

Recommendation X.29

CCITT Recommendation X.29, titled *Procedures for the Exchange of Control Information and User Data Between a Packet Assembly/Disassembly Facility (PAD) and a Packet Mode DTE or Another PAD*, provides the final step. X.29 describes the interfacing procedures that allow the PAD to communicate with the X.25 network. It defines the procedures for the exchange of PAD control information and the manner in which user data is transferred between a packet mode DTE and a PAD or between two PADs.

Recommendation X.29 specifies that control information and user data are exchanged between a PAD and a packet mode DTE or between PADs using the data fields described in X.25. Interface characteristics—mechanical, electrical, functional, and procedural—are also defined as in X.25.

X.29 specifies that the *call user data* field of an *incoming call* or *call request* packet going to/from the PAD or the packet mode DTE must consist of protocol identifier and call data fields. A call request packet need not contain a call user data field to be accepted by the PAD. If the call user data field is present, the PAD transmits it, unchanged, to its destination.

A call data field's octets consist of user characters sent from the DTE to the PAD during the call establishment phase. This field is limited to 12 octets. The octet's bits are numbered 8 to 1; bit 1, the low order bit, is transmitted first.

Bits 8, 7, 6, and 5 of octet 1 of a user data field of complete packet sequences are the control identifier field. This field, which consists of four octets, identifies the facility to be controlled. The control identifier field coding for messages to control a PAD for an asynchronous terminal is 0000. When the control identifier field is set to 0000, bits 4, 3, 2, and 1 of octet 1 are defined as the message code field, which is used to identify specific types of PAD messages.

User sequences perform data exchange. They are transferred in the user data fields of complete packet sequences with the Q bit set to 0. Only one user sequence exists per complete packet sequence. The PAD transmits all data packets with the D bit set to 0. The DTE sends a data packet to the PAD with the D bit set to 1. When the PAD *receives* a data packet with the D bit set to 1, it sends the corresponding acknowledgment. The PAD may reset the virtual call, if it does not support the D bit procedure.

Control information is exchanged via *PAD messages*, which contain a control identifier field and a message code field that may be followed by a parameter field. PAD messages are transferred in the user data fields of complete packet sequences with the Q bit set to 1. Only one PAD message exists per complete packet sequence. The PAD *sends* all data packets with the D bit set to 0. The DTE may send data packets to the PAD with both the D bit and the Q bit set to 1. When the PAD *receives* a data packet with both the Q and D bits set to 1, the corresponding acknowledgment is transmitted. The PAD may reset the virtual call if it does not support the D bit procedure. (Figure 5 shows the bit positions for the Q and D bits.)

The PAD forwards a data packet when a *set*, *read*, or *set and read* PAD message is received or when any of the conditions listed in X.28 exist (e.g., enough data has been received to fill a packet, the maximum assembly timer delay period has elapsed, or a data forwarding character is transmitted). The PAD never forwards an empty data packet.

By sending a *set*, *read*, or *set and read* message to the PAD, one can read and change the current values of PAD parameters. Upon receipt of one of these messages, the PAD delivers to the DTE any previously received data before it acts on the PAD message. The PAD responds to a *read* or *set and read* PAD message by sending a *parameter indication* PAD message, which contains a parameter field listing parameter references and current values. *Set* allows the changing of parameters.

X.29 also discusses *invitation to clear* procedures, which are used to request that the virtual call be cleared by the PAD; *interrupt and discard* procedures, which are used to indicate that the asynchronous terminal has requested that the PAD discard received user sequences; *reset* procedures, as defined in X.25; *error handling procedures by the PAD,* which define the actions to be taken by the PAD when errors are detected; and *procedures for inviting the PAD to reselect the called DTE* (optional), which are used by a packet mode DTE to request that the PAD clear the virtual call.

X.21 Interface Specifications

The trends in communications engineering lean toward all-digital networks and the integration of voice and data. Prospective users of these digital, integrated networks are concerned about an interface that can provide access to voice, data, video teleconferencing, and related services. Currently, a wide variety of connectors, electrical standards, and user procedures for various services and networks exists—leading to almost insurmountable technical and economical problems. Therefore, it is likely that standards organizations will develop a *universal service access interface.* Although it would require certain extensions, X.21 is currently the most likely to become a future standard for a universal interface in distributed system implementations.

CCITT Recommendation X.21, *Interface Between Data Terminal Equipment (DTE) and Data Circuit-Terminating Equipment (DCE) for Synchronous Operation on Public Data Networks,* defines the physical characteristics and control procedures for an interface between DTEs and DCEs.

X.21 is the designated interface for CCITT Recommendation X.25, a packet-switching protocol. X.21 can also be used in a non-packet switched environment. At least two X.21-based public data circuit switched networks are currently implemented, one in Scandinavia and one in Japan.

The X.21 standard has not gained wide acceptance in the United States. The reluctance in the U.S. to embrace the X.21 standard is due in part to the firm entrenchment of RS-232-C. Another factor is the cost of implementing X.21. Since X.21 transmits and interprets coded character strings, more intelligence must be built into the interface, at a higher cost than traditional pin-per-function interfaces.

Certain characteristics of X.21 should ensure a more widespread acceptance in the coming years. One immense advantage X.21 has over traditional interfaces is its capability to assign an almost unlimited number of functions, because there are no functional boundaries associated with connector size. Also, X.21 offers a much more sophisticated level of control over the communications process. Another important feature of X.21 is its inherent dialing functions, including the provision for reporting the reasons why a call was not completed. This eliminates the need for a separate data call interface, such as RS-232-C's companion RS-366-A, and in switched facilities, results in improved response times.

Another important aspect is its relationship to X.25. As the packet-switching technique becomes more widely implemented, the demand will be greater for equipment to meet the X.21 standard. Internationally, the combination of X.21, the ISO HDLC protocol, and X.25 has been used to form an effective communications path. Another boost for X.21 is IBM's recognition.

X.21 has some shortcomings. It does not permit the transmission of control information during data transfer. Also, it precludes the insertion of data encryption hardware between the DTE and the DCE. Another drawback is the need to modify the DTE/DCE master/slave protocol techniques and to supply special crossover cables to facilitate DTE-to-DTE or DCE-to-DCE interconnection.

X.21 uses a different interfacing technique than that which is normally associated with physical-level interfaces. Instead of assigning each function a specific pin on the connector (e.g., CCITT V.24 and EIA RS-232-C), X.21 assigns coded character strings to each function.

The following is a summary of the X.21 standard, including the functional descriptions of the interchange circuits, phases of operation, electrical characteristics, and mechanical characteristics.

Functional Descriptions of Interchange Circuits

Four types of X.21 interchange circuits are defined: Ground, Data Transfer, Control, and Timing. These circuits, outlined in Table 2, are described below.

Ground and Common Return Circuits—include two types of common return circuits, DTE Common Return and DCE Common Return, and one ground circuit, Signal Ground.

Signal Ground (Circuit G) establishes the common reference potential for unbalanced double-current interchange circuits. If required, it reduces environmental signal interference.

Lowering signaling rates may require two common return conductors. In this case, two circuits, *DTE Common Return (Circuit Ga)* and *DCE Common Return (Circuit Gb)*, are necessary. For a further explanation of these circuits, see the Electrical Characteristics section of this report.

Data Transfer Circuits—include two Transmit and Receive data transfer circuits.

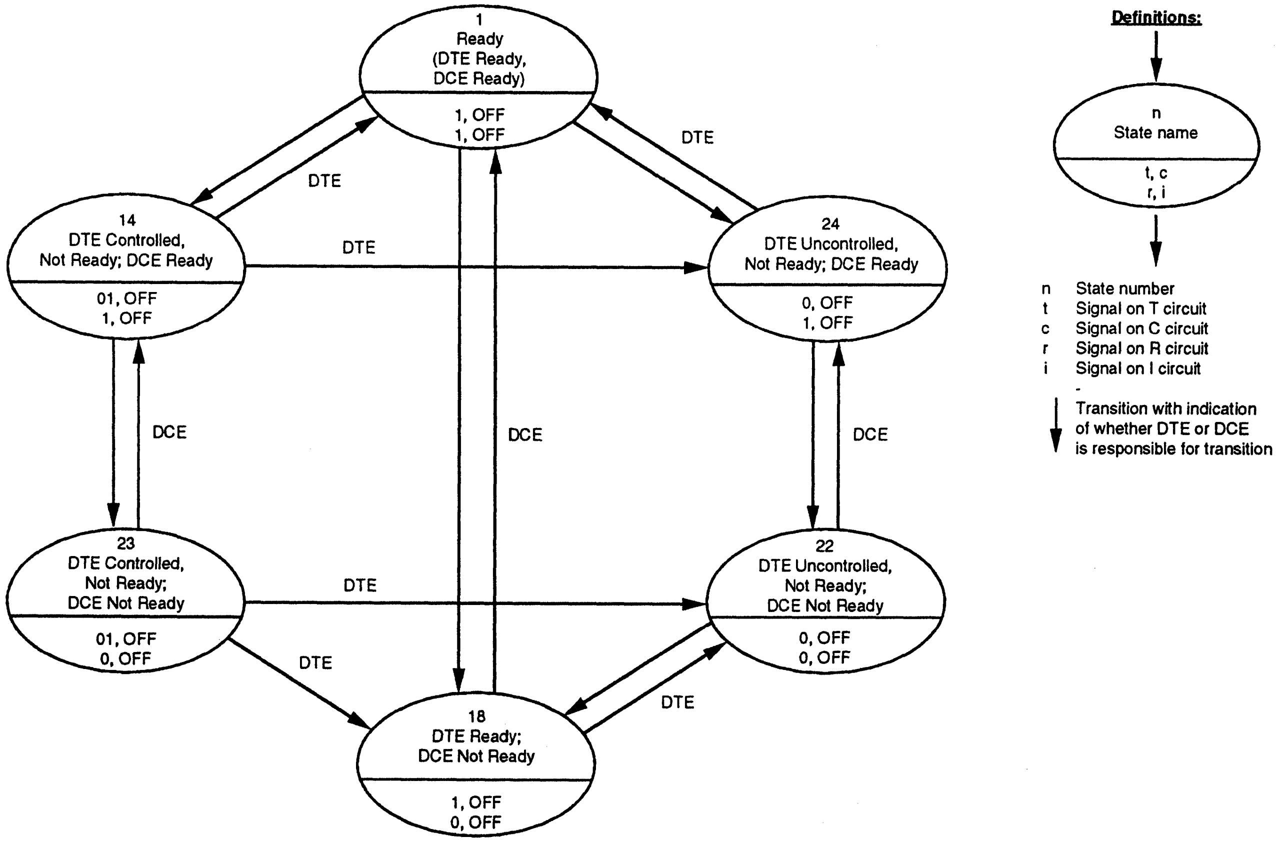
Transmit (Circuit T) transfers signals from the DTE to the DCE during the data transfer phase. It also transfers call control signals to the DCE during call establishment and other call control phases.

Receive (Circuit R) receives signals transmitted by the DCE from a remote DTE during the data transfer phase. This circuit also transfers call control signals from the DCE during the call establishment and other call control phases.

Control Circuits—include Control and Indication circuits.

Control (Circuit C) transmits signals that control the DCE for a particular signaling process. The representation of this signal requires additional coding of the Transmit

Figure 1.
Quiescent States



The above diagram indicates transitions that are allowed in X.21 networks. Other transitions are possible and may be allowed in some networks. See Table 3 for a listing of possible transitions.

circuit, as specified for the procedural characteristics of the interface. During the data phase, Circuit C remains in the ON condition.

Indication (Circuit I) indicates the call control process to the DTE. The representation of this signal requires additional coding of the Receive circuit. When Circuit I is on, it signifies that signals on the Receive circuit contain information from the remote DTE. When Circuit I is off, it signifies a control signaling condition, defined by the Circuit R bit patterns, as specified by the procedural characteristics of the interface.

Timing Circuits—includes Signal Element Timing and Byte Timing.

Signal Element Timing (Circuit S) provides the DTE with signal element timing information. For this function, Circuit S turns on and off for nominally equal periods of time.

X.21 defines different roles for the DTE and DCE in regard to signal element timing. During the off-to-on transition, the DTE presents a binary signal on Circuit T and a condition on Circuit C. The DCE presents a binary signal on Circuit R and a condition on Circuit I during the off-to-on transition. The DCE transfers the signal element timing across the interface as long as the timing source is capable of generating this information.

Byte Timing (Circuit B) provides the DTE with eight-bit timing information for synchronous transmission. Use of this circuit is not mandatory. Circuit B turns off whenever Circuit S is in the ON condition, indicating the last bit of the eight-bit byte. At all other times within the period of the eight-bit byte, Circuit B remains on.

Phases of Operation

The X.21 standard defines four phases of operation: the Quiescent Phase, the Call Control Phase, the Data Transfer Phase, and the Clearing Phase.

Each step of the operational phases places the DTE and DCE in a certain state. See Table 3 for a listing of these states and their associated signals on the interchange circuits.

Quiescent Phase—the quiescent phase is the period during which the DTE and the DCE signal their capability to enter the call control phase or the data transfer phase. It is characterized by the appearance of basic quiescent signals from the DTE and DCE. Various combinations of these quiescent signals result in different interface states, or quiescent states.

There are three DTE quiescent signals. *DTE Ready* indicates the readiness of the DTE to enter the other operational phases. *DTE Uncontrolled Not Ready* indicates the DTE is unable to enter certain operational phases, usually due to an abnormal condition. *DTE Controlled Not Ready* indicates that although the DTE is operational, it is temporarily unable to accept incoming calls for circuit switched service.

There are two DCE quiescent signals: DCE Ready and DCE Not Ready. *DCE Ready* indicates the DCE is ready to enter operational phases. *DCE Not Ready* indicates that no service is available; it is also signaled whenever possible during network fault conditions and during the period when test loops are activated.

There are six quiescent states:

- Ready
- DTE Controlled Not Ready, DCE Ready
- DTE Ready, DCE Not Ready
- DTE Uncontrolled Not Ready, DCE Not Ready
- DTE Controlled Not Ready, DCE Not Ready
- DTE Uncontrolled Not Ready, DCE Ready

See Figure 1 for a diagram of the quiescent states and the transitions that are allowed between these states.

Call Control Phase—the call control phase for circuit switched service contains many elements and procedures. Characters used for call control are selected from IA5, a seven-bit plus parity international code outlined in CCITT Recommendation V.3. Each call control sequence to and from the DCE is preceded by two or more continuous SYN characters. For error checking of call control characters, odd parity is specified.

The following elements of the call control procedure are outlined in X.21: events of call control procedures, unsuccessful call, call collision, direct call, and facility registration/cancellation procedure. These elements are summarized below.

The events of the call control procedures include the following:

- *Call Request*, signaled by the DTE to indicate a request for a call.
- *Proceed to Select*, used when the network is prepared to receive selection information. It is transmitted by the DCE to the DTE within three seconds of the call request signal.
- *Selection Signal Sequence*, transmitted by the DTE. A selection sequence consists of a facility request block, an address block, a facility request block followed by an address block, or a facility registration/cancellation block. A facility request block comprises one or more facility request signals, which consist of a facility request code containing one or more facility parameters. An address block contains one or more address signals. Address signals consist of either a full address signal or an abbreviated address signal.
- *DTE Waiting.*
- *Incoming Call*, indicated by the DCE. In response, the DTE signals Clear Request, DTE Uncontrolled Not Ready, or DTE Controlled Not Ready.
- *DCE Waiting.*
- *Call Progress Signal Sequence* is transmitted by the DCE to the calling DTE to indicate that circumstances have arisen to prevent the connection from being established, to report the progress made toward establishing the call, or to signal that problems have been detected and that the call needs to be cleared and reset.
- *DCE-Provided Information Sequence*, transmitted from the DCE to the calling DTE. It consists of DCE-provided information blocks, such as line identification and charging information. Line Identification is transmitted by the DCE to the calling DTE during the DCE-Provided Information state immediately after all call progress signals, if any, are transmitted. Both calling and called line identification are optional. Line identification consists of the international data number, as assigned in CCITT Recommendation X.121, *International Numbering Plan for Public Data Networks.* The DCE transmits Charging Information during the DCE-Provided Information state. It informs the subscriber of either the monetary charges for a call, the duration of the call, or the number of units used during the call.
- *Connection-In-Progress*, indicated by the DCE.
- *Ready for Data*, transmitted by the DCE when the connection is available for data transfer between DTEs.

An unsuccessful call occurs when a required connection cannot be established. In this case, the DCE indicates the failure and its reason to the calling DTE through a call progress signal.

A *call collision* can occur in one of two ways: a DTE detects a call collision when it receives Incoming Call in response to Call Request. A DCE detects a call collision when it receives Call Request in response to Incoming Call. When the DCE detects a call collision, it will indicate Proceed to select and cancel the incoming call.

The DTE indicates a request for a direct call by signaling DTE Waiting after receiving the Proceed to Select signal. If necessary, the DTE may choose an addressed call by presenting the correct Selection signal.

The facility registration/cancellation procedure is optional. A facility registration/cancellation signal consists of up to four elements in order: facility request code, indicator, registration parameter, and address signal. Not all of these elements are required in the facility registration/cancellation signal. Also, a number of these signals may be linked to form a block. In response to acceptance or rejection of the facility registration/cancellation action, the network provides the appropriate Call Progress Signal.

Data Transfer Phase—when the DTE is in the data transfer phase, any bit sequence may be transmitted. X.21 defines the data transfer phase for three types of connections: switched; leased, point to point; and leased, centralized multipoint.

For operation over switched facilities, the DTE may send bits to a corresponding DTE after receiving the Ready for Data signal. During data transfer, control and interchange circuits are in the ON condition, and data is transmitted over the transmit and receive circuits. Data transfer may be terminated by *clearing*, which is defined below.

Two basic signals are used for operation over leased, point-to-point facilities. Send Data transmits data by the DTE on Circuit T; the remote DTE's Receive Data signal receives data over Circuit R. To terminate the data transfer, the DTE signal places its transmit circuit in the binary 1 condition. The DCE indicates termination of data transfer by placing its receive circuit in the binary 1 condition, its control circuit in the OFF condition, and its indications circuit in the OFF condition.

Both the central and remote DTEs use the Send Data and Receive Data signals for operation over leased, multipoint facilities. The central DTE delivers data transmitted to all remote DTEs; remote DTEs (one at a time) transmit data to the central DTE. A remote DTE may send data to the central DTE while the central DTE is sending to all remote DTEs.

Table 2. CCITT X.21 Interchange Circuits

Interchange Circuit	Name	Direction: to DCE	Direction: from DCE	Circuit Type
G	Signal ground or common return			
Ga	DTE common return	X		Ground
Gb	DCE common return		X	
T	Transmit	X		Data Transfer
R	Receive		X	
C	Control	X		
I	Indication		X	Control
S	Signal element timing		X	
B	Byte timing		X	Timing

Clearing Phase—either the DTE or the DCE may initiate clearing. The DTE indicates its desire to enter the clearing phase by transmitting DTE *Clear Request.* The DCE responds by signaling DCE *Clear Confirmation*, followed by DCE *Ready.*

Clearing by the DCE takes place when it transmits DCE *Clear Indication.* The DTE responds with the DTE *Clear Confirmation* signal, followed by the DCE signaling *DCE Ready.*

Electrical Characteristics

X.21 uses two types of electrical characteristics, each for different system requirements.

For synchronous operation at 9600 bps and below, the interchange circuits at the DCE side of the interface must comply with CCITT Recommendation X.27. The DTE side can comply with either X.27 or another CCITT Recommendation, X.26. For synchronous operation at signaling rates above 9600 bps, interchange circuits at both the DTE and DCE sides of the interchange circuits must comply with X.27.

X.26 is defined in CCITT Standard V.10. It describes the electrical characteristics for unbalanced interchange circuits. X.26 calls for both a DTE and DCE common grounding arrangement. The maximum suggested cable length is 1,000 meters, and the maximum data rate is 100K bps.

X.27 is defined by CCITT Standard V.11, which describes the electrical characteristics for balanced operation. Maximum suggested cable length is 1,000 meters, and the maximum data rate is 10M bps.

Mechanical Characteristics

The mechanical characteristics for X.21 are outlined in the ISO Standard 4903, approved by the International Organization for Standardization (ISO). The standard, entitled *Data Communication—15-pin DTE/DCE Interface Connector and Pin Assignments*, was published in June 1980.

ISO 4903 assigns connector pin numbers to a 15-pin interface between DTE and DCE equipment. Table 4 presents a chart of these X.21 pin assignments as they relate to the X.26 and X.27 standards.

X.21 Bis

Although X.21 is the specified interface for X.25, alternative interfaces also exist. One of these is X.21 bis.

CCITT Recommendation X.21 bis, the physical and functional equivalent to CCITT V.24, defines 25 interchange circuits between DTEs and DCEs. CCITT V.24 is compatible with EIA Standard RS-232-C. The X.21 bis recommendation, accepted as the interim interface for X.25, will be gradually replaced by X.21 as more equipment is manufactured to meet X.21 specifications.

Recommendation X.25

The development of Recommendation X.25 was stimulated by the need for a standard interface between the packet-switching networks already developed or being developed by many industrial nations and by the requirement that no terminal equipment be denied access to packet switched services.

X.25 is a dynamic standard with many variations in the U.S. and abroad. Currently, X.25-based packet switched networks exist in Australia, Austria, Belgium, Canada, France, Ireland, Germany, Hong Kong, Italy, Japan, Mexico, the Netherlands, Portugal, Singapore, the Soviet Union, South Africa, Spain, Switzerland, the United Kingdom, and the United States. Since X.25 is a dynamic standard with many extensions and optional features, these networks are not totally compatible with one another. Those located in Europe have the highest level of mutual compatibility.

Since the establishment of X.25, additional user-level protocols have been developed. These protocols provide the interfaces between different types of terminals and the X.25 interface. X.3, X.28, and X.29, informally called the Interactive Terminal Interface (ITI), were the first of the protocols to interface to X.25. They relate to the support of asynchronous, low-speed terminals by packet switched networks. These are logical complements to X.25 because they permit specific sets of terminals to interface to the packet networks using the X.25 interface.

The X.25 interface standard provides for the connection of terminals and computers to public packet-switching networks. X.25 outlines three layers of operation: the Physical Layer, the Link Layer, and the Packet Layer. These layers parallel the bottom three layers of the ISO Reference Model for Open Systems Interconnection. The Physical Layer calls for CCITT X.21 as the physical and electrical interface but accepts X.21 bis, a functional equivalent of RS-232-C, as an interim standard. The Link Layer uses the procedures of the HDLC protocol standard. The Packet Layer defines procedures for constructing and controlling a data packet.

The 1984 revision of Recommendation X.25 added specifications for X.21 access and expanded the potential of packet operations, allowing users to actively gain access to the X.25 port, identify themselves, and validate their connection through passwords. This change reoriented the X.25 standard toward switched access through both X.21 facilities and the public telephone network. It now supports X.32 with regard to the public switched telephone network or a circuit switched public data network, dial-in

Table 3. X.21 States: Names, Signalling, and Transitions

State Number	State Name	Phase of Operation	Signals on T,C and R,I Circuits: T	C	R	I	Transitions*: DTE to state number	DCE to state number
1	Ready	Q	1	OFF	1	OFF	2,13S,14,24	8,13R,18
2	Call request	CC	0	ON	1	OFF	—	3,15
3	Proceed-to-select	CC	0	ON	+	OFF	4,15	—
4	Selection signal	CC	IA5	ON	+	OFF	5	—
5	DTE Waiting	CC	1	ON	+	OFF	—	6A,11,12
6A	DCE Waiting	CC	1	ON	SYN	OFF	—	7,10,11,12
6B	DCE Waiting	CC	1	ON	SYN	OFF	—	10 *bis*, 11,12
7	Call progress signal	CC	1	ON	IA5	OFF	—	6A,10,11,12
8	Incoming call	CC	1	OFF	BEL	OFF	15,9	—
9	Call accepted	CC	1	ON	BEL	OFF	—	6B,11,12
10	DCE provided information	CC	1	ON	IA5	OFF	—	6A,11,12
10 *bis*	DCE provided information	CC	1	ON	IA5	OFF	—	6B,11,12
11	Connection in progress	CC	1	ON	1	OFF	—	12
12	Ready for data	CC	1	ON	1	ON	—	13
13	Data transfer	DT	D	ON	D	ON	13R	13S,DCE not ready
13R	Receive data	DT	1	OFF	D	ON	13	1
13S	Send data	DT	D	ON	1	OFF	7	13
14	DTE Controlled not ready, DCE ready	Q	01	OFF	1	OFF	1,24	23
15	Call collision	CC	0	ON	BEL	OFF	—	3
16	DTE Clear request	C	0 (see Note)	OFF	X	X	—	17
17	DCE Clear confirmation	C	0	OFF	0	OFF	—	21
18	DTE Ready, DCE Not ready	Q	1	OFF	0	OFF	22	1
—	DCE Not ready	Q	D	ON	0	OFF	—	1,13,13S
19	DCE Clear indication	C	X (see Note)	X	0	OFF	20	—
20	DTE Clear confirmation	C	0	OFF	0	OFF	—	21
21	DCE Ready	C	0	OFF	1	OFF	1	—
22	DTE Uncontrolled not ready, DCE not ready	Q	0	OFF	0	OFF	18	24
23	DTE Controlled not ready, DCE not ready	Q	01	OFF	0	OFF	18,22	14
24	DTE Uncontrolled not ready, DCE ready	Q	0	OFF	1	OFF	1	22
Any state (see Note)			X	X	X	X	16	19

**All other transitions are considered invalid.*
Note: DCE Clear indication or DTE Clear request may be entered from any state except Ready.

Key to Table:

Q—Quiescent Phase
CC—Call Control Phase
DT—Data Transfer Phase
T—Transmit interchange circuit
C—Control interchange circuit
R—Receive interchange circuit
I—Indication interchange circuit

0 and 1—Steady binary conditions
01—Alternate binary 0 and binary 1
X—Any value
OFF—Continuous off (binary 1)
ON—Continuous on (binary 0)
IA5—Characters from CCITT Alphabet #5
+—IA5 character 2/11
BEL—IA5 character 0/7
SYN—IA5 character 1/6

and dial-out access, backup for leased line connections, long-distance access to the network, and teletex.

Datagram was deleted in 1984, while the following packet-level services were made available as options:

- ***Registered Private Operating Agent (RPOA) Selection*** permits the use of one or more networks to route a call to its destination. If the user selects only one network, either the basic or extended format of the RPOA Selection can be used; if more than one network is chosen, the extended format is used.
- ***Call Redirection*** permits the rerouting of calls if the first tried route fails.
- ***Call Redirection Notification*** informs the recipient of the forwarded call that the call has been redirected.
- ***Called Line Address Modified Notification*** tells the caller, within a call confirmation packet, that the call has been redirected.
- ***Hunt Group*** distributes incoming calls that have an address associated with the hunt group.
- ***Charging Information*** gives the caller information on time and charges and requires a new field in the call-clearing packet format.
- ***Local Charging Prevention*** is a security facility that prevents reverse or third-party call charges.
- ***Network User Identification*** accommodates user ID, billing, and on-line facilities registration. This permits users to communicate directly with the packet data network to change the parameters of their subscriptions.

The packet level is an octet-oriented (eight bits per octet) structure. Packet sizes can vary from 1,024 to 2,048 octets, but only within a network. Network-to-network exchange is limited to 128 octets. Closed user group facilities can accommodate very large private-packet networks, although the number of closed user groups to which a DTE can belong is network dependent.

Link-level changes implemented in 1984 created a clear separation between the Link Access Procedure (LAP) and the Link Access Procedure Balanced (LAPB). Multilink procedures for a single interface were also implemented. LAPB underwent an alignment with the single-link procedure of X.75. An extended numbering option (modulo 128) was added to LAPB to enable the sequencing of 127 frames and the use of satellite facilities. In addition, the 1984 revisions to X.25 refined the procedure for the implementation of the D-bit, polished technical accuracy, and defined the rules for new fields and formats.

X.25 Communications

X.25 is titled *Interface Between Data Terminal Equipment (DTE) and Data Circuit-Terminating Equipment (DCE) for Terminals Operating in the Packet Mode on Public Data Networks.* It provides a precise set of procedures for communications between DTE and DCE for terminal equipment operating in a packet environment. The DCE in this case is a node processor that serves as an entry/exit point on the packet network side of the user/network interface.

The Data Terminal Equipment (DTE) is a programmable device on the user side of the user/network interface. The DTE is located at the user site when the on-site equipment supports X.25; at such installations, the DTE can be either a computer, a front-end processor, or an intelligent terminal, as shown in Figure 2. The DTE can be a group of intelligent terminals (multiplexed to avoid the use of multiple lines) that transmit data over the packet network to a remotely located host. It can also be a processor acting on calls received from multiple locations that communicate over the packet network.

Regardless of the device or application, all DTEs present standard formatted data and control information to the DCE over standard communications facilities. Devices operate over the network in the virtual circuit mode. Essentially, the user causes the network to establish a logical circuit connection with the receiving station for the transmission of multiple contiguous packets. (The actual physical circuit over which individual packets are transmitted can vary during a session, but the logical circuit ensures presentation of each packet to the receiving station in the proper order.) Information delivery is so rapid that the user appears to have an end-to-end, dedicated channel.

Users who do not support X.25 can access the public data network for packet data transmission; however, they cannot transmit directly to a DCE or network node. They must transmit to a special network-operated PAD, discussed earlier in this report. Terminal transmissions are stored in a buffer at the PAD. There they are assembled into packets and sent to the device at the other end of the virtual circuit. Packets arriving at the PAD from the network are reassembled into the appropriate format before they are sent on to the terminal. The PAD is programmed and configured to interface properly with the protocol and physical characteristics of the user's device. Data presented to the PAD is reformatted into X.25 format and forwarded to the DCE.

Recommendation X.25 is divided into those specifications required for a device or network to comply and those that are optional. Approximately one third are required; the remaining two thirds of the specifications are optional.

The excess throughput capacity inherent in the X.25 standard allows for future network growth and technological progress. For example, a single X.25 interface can theoretically handle 4,095 virtual channels, packet sizes up to 2048 bytes each, and packet sequencing up to 128 packets per logical channel. Most network suppliers' nodal processors are too small to handle this much traffic through a single interface. Therefore, in practice, the support offered over each interface is limited to the current capacity of the network's access node.

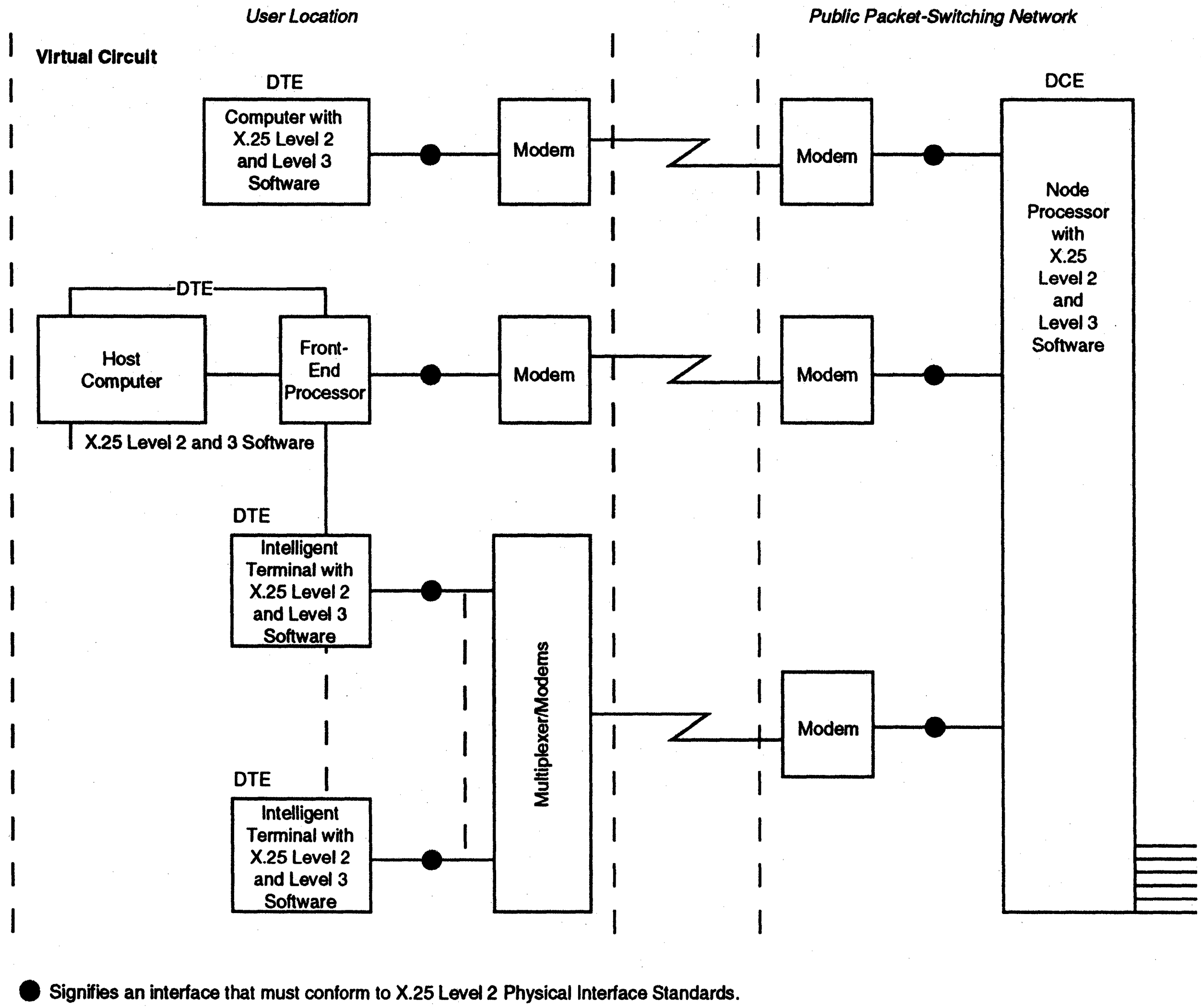
Functional Layers

Recommendation X.25 defines three functional layers: the Physical Layer (Level 1), the Link Layer (Level 2), and the Packet Layer (Level 3). These are consistent with the first three layers of the ISO Reference Model for Open Systems Interconnection (OSI). (Although OSI labels its third layer the Network Layer, its function parallels that of the Packet Layer. Both provide the means to establish, maintain, and terminate connections.)

Level 1: Physical Level—outlines the physical, functional, and electrical characteristics of the DTE/DCE interface. X.21 uses the transmission of coded character strings across a 15-pin connector to define standard interface functions, e.g., Transmit Data. Its specifications are defined in CCITT Recommendation X.21.

Although X.21 is the recommended physical-level interface for X.25, the availability of data communications equipment with X.21 capabilities is limited, especially in the United States. As a result, the CCITT has accepted an interim recommendation, X.21 bis, as the X.25 physical

Figure 2.
A Sample User Terminal Configuration for Operating on a Public Data Network (PDN) in Packet Mode, with X.25 as the Interface to the Network



interface. X.21 bis is functionally equivalent to EIA RS-232-C, which assigns a separate function to each pin across a 25-pin connector.

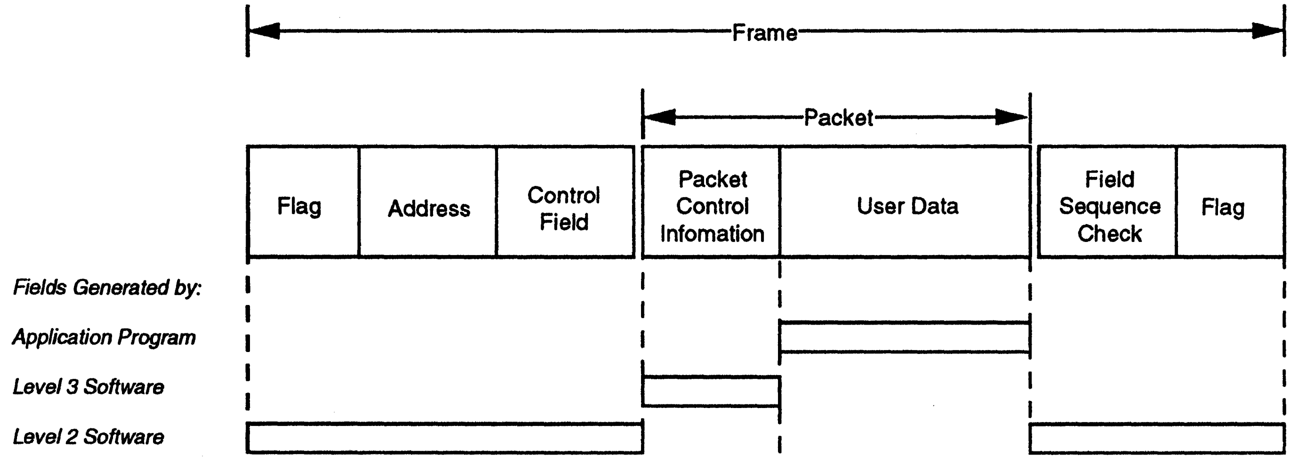
Level 2: Link Level—describes the link access procedures used for data interchange between a DCE and a DTE. In the CCITT Recommendation X.21, *International User Classes of Service in Public Data Networks,* X.25 specifies that the DTE and DCE must operate in the following user classes of service: class 8 (2400 bps), class 9 (4800 bps), class 10 (9600 bps), or class 11 (48K bps). The procedure calls for a full-duplex facility so that the DTE and DCE can conduct two-way, simultaneous, independent transmissions. The procedures use the principles and terminology of the High-level Data Link Control (HDLC) protocol specified by the International Organization for Standardization.

Level 2 comprises three procedures: the Link Access Procedure (LAP), the Link Access Procedure Balanced (LAPB), and the Multilink Procedure (MLP). The original X.25 data link control procedure embraced LAP, which is similar to the HDLC Asynchronous Response Mode (ARM). Due to some incompatibilities with some elements of procedures, Level 2 of the X.25 Recommendation was revised to incorporate LAPB. Similar to the Asynchronous Balanced Mode (ABM) of HDLC, it provides for a "balanced" configuration; that is, each side of the link consists of a combined primary/secondary station. The Multilink Procedure is used for data transmission on one or more single links. Each link conforms to the X.25-defined frame structure and to the elements of procedure described in LAPB.

Software in both DTE and DCE performs Level 2 processing. This software appends control information onto packets that are ready for transmission, maintains control of the transmissions, performs transmission error checking, and strips a successfully received frame down to a packet. The *packet* consists of packet control information and (optionally) user data; packets are discussed in detail later in this report.

HDLC specifies certain control fields that must be appended to both ends of a packet, resulting in a transmission format called a *frame.* Appended in front of a packet are a beginning Flag field, an Address field, and a Control

Figure 3.
Frame Formats for Packet Mode Transmission

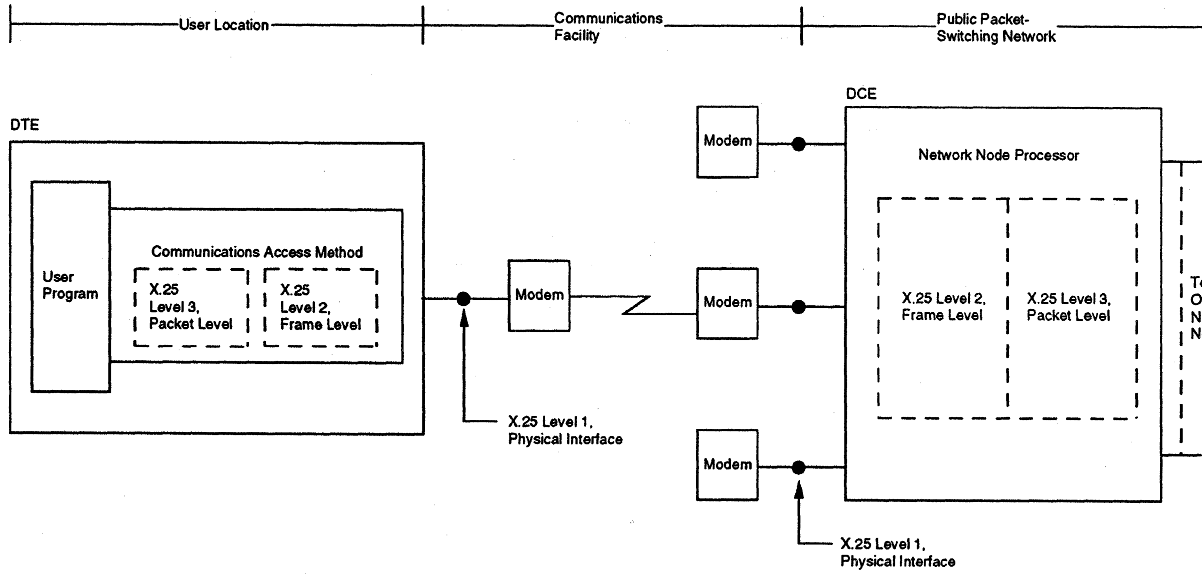


Field	Size, bits	Description
Flag	8	Value is 01111110.
Address	8	Value for DTE to DCE command frame is "10000000". Value for DTE to DCE response frame is "11000000". Value for DCE to DTE command frame is "11000000". Value for DCE to DTE response frame is "10000000".
Control	8	I Frame: Bit 1 is "0". Bits 2, 3, 4, are N(S) (transmitter send sequence count). Bit 5 is P/F (Poll/Final) bit. Bits 6, 7, 8 are N(R) (transmitter receive sequence count). S Frame: Bit 1 is "1". Bit 2 is "0". Bits 3, 4 identify Supervisory Command. Bit 5 is P/F (Poll/Final) bit. Bits 6, 7, 8 are N(R) (transmitter receiver sequence count). U Frame: Bit 1 is 1. Bit 2 is 1. Bits 3, 4 are *first* part of Unnumbered Frame Command identifier. Bit 5 is P/F (Poll/Final) bit. Bits 6, 7, 8 are second part of Unnumbered Frame Command identifier.
Packet Control	24	Control information.
User Data	1,024	1,024 data bits are normal maximum; exceptional maximum is 2,040 data bits.
Field Sequence Check	16	Check bits for user data.
Flag	8	Value is "01111110".

field. Appended behind the packet are a Frame Check Sequence field and a closing Flag field. Figure 3 gives the size and description of each field. The receiving device uses the two *Flag* fields to ascertain the beginning and ending of a frame. A single Flag field can be used as the closing flag for one frame and the opening flag of the next frame. The *Address* field, under HDLC, is used to identify the station(s) for which the command is intended in command frames or to identify the station sending the response in response frames.

The *Control* field identifies the type of frame and supplies control information pertinent to that type of frame. A frame can be either an Information Frame (I-Frame), a Supervisory Frame (S-Frame), or an Unnumbered Frame (U-Frame). See Table 5 for the encoding of this field.

Figure 4.
X.25 User and Network Software Relationships



An Information Frame contains a user packet. The Control field of the I-Frame contains the N(S) transmitter Send Sequence Count, the N(R) transmitter Receive Sequence Count, and the Poll/Final (P/F) bit. N(S) is the sequence number of this frame sent from this transmitter to this receiver. N(R) is the sequence number of the next frame this transmitter expects to get from the receiver when the receiver becomes a transmitter. The Poll/Final bit indicates whether a transmission acknowledgment is required or when the final frame in a stream has been transmitted.

The Supervisory Frame transmits one of three supervisory commands and cannot contain user data. The Control field of the S-Frame contains the command, the P/F bit, and an N(R). Table 6 summarizes the commands and responses possible in the Control field.

The Unnumbered Frame extends the number of link control functions, without incrementing the sequence counts at either the sending or receiving station.

A U-Frame control field contains the Unnumbered command and the P/F bit. One of the U-Frame commands initializes the DTE/DCE network to the Asynchronous Response Mode (ARM) of operation, which permits both DTE and DCE to initiate transmission to each other.

The Frame Check Sequence (FCS) field contains a 16-bit check pattern created at framing time by generating check bits based upon the binary value of the data in the packet. The receiving device performs the same calculation and compares its results with the value that the sending device had placed in the FCS field. If these values do not agree, the frame has a transmission error and is discarded. Discarding causes the receiving device to send an S-Frame with the Reject Recovery command. This S-Frame contains the frame numbered N(R), thus acknowledging receipt of all frames numbered N(R)-1 and below, and initiates retransmission of frames N(R) and above.

In effect, Level 2 envelops the packet in control information and prescribes procedures that ensure a high degree of transmission accuracy and detection of lost frames during transmission.

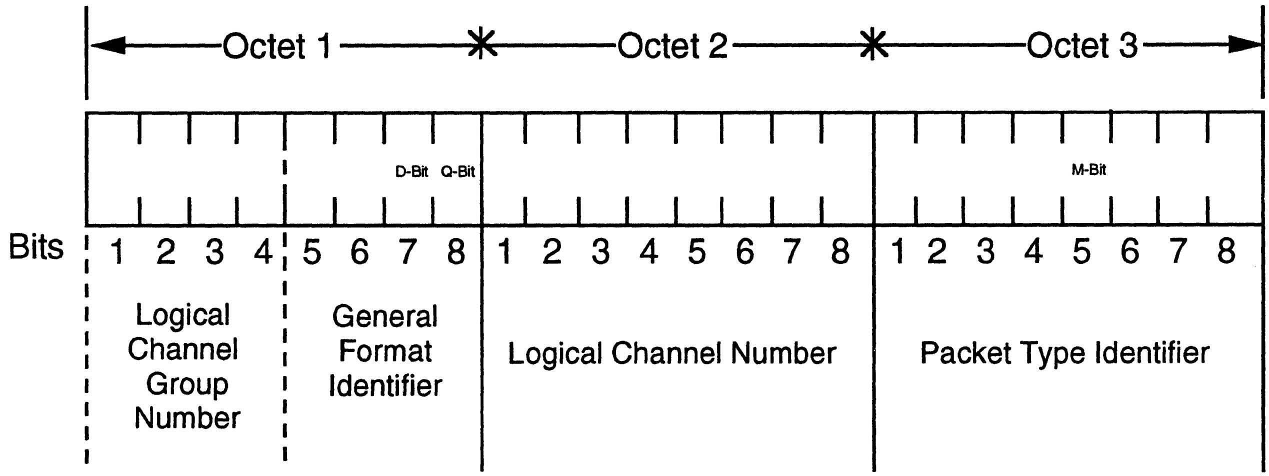
Level 3*: *Packet Level—describes the packet format and control procedures for the exchange of packets between the DTE and the DCE. In addition to the user data packet format, there are several formats for DTE/DCE administrative messages.

The software for formatting packets and controlling packet exchange is the Level 3 software resident in both the DTE and the DCE. Figure 4 shows the relationship of Level 3 and Level 2 software operating in the DTE and the DCE. In the DTE, a user application program normally presents the data to be transmitted to the operating system's communications access method. The access method invokes Level 3 software to append the packet header information, then invokes Level 2 software to create the frame. Packet header formats are discussed below.

Once the frame is created, it is ready for transmission. Upon receiving the frame, the receiving DCE invokes Level 2 software to perform error detection and sequence checking and to strip the accepted frame down to a packet. The packet is presented to Level 3 software for packet-level processing and to prepare the packet for transmission to the destination DCE. The physical address of the destination DTE, derived from the call initiation, is inserted into the packet during Level 3 processing. At the network destination DCE, Level 3 software reformats the packet control information and presents the resulting packet to Level 2 software; Level 2 software includes the packet in a frame for transmission to the destination DTE (user). At the destination DTE (user), Level 2 software performs error detection and sequence checking and strips accepted frames down to the packet. Level 3 software is then applied to the packet to strip the header information from the packet and pass the user information to the appropriate application program via the communications access method. Table 7 summarizes the types of packets exchanged between terminals.

The Packet Header consists of three octets. In Octet 1, the first four bits represent the Logical Channel Group

Figure 5.
X.25 Packet Header Format



Number, and the final four bits represent the General Format Identifier. Octet 2 represents the Logical Channel Number, and Octet 3 represents the Packet Type Identifier. See Figure 5.

The *Logical Channel Group Number* and the *Logical Channel Number* provide the routing information that directs the packet over one of the logical channels. The numbering system for the logical channels is dynamic and refers to a switched data path within the packet network.

The *General Format Identifier* indicates the general format of the rest of the header. Specific bit patterns are established for the following: call setup packets; clearing, flow control, interrupt, reset, restart, and diagnostic packets; and data packets.

The *Packet Type Identifier* establishes the packet's function. Examples of functions include call setup, priorities, and data. If applicable, it may identify the packet's place in sequence. See Table 7 for the various packet types.

Packet-Level Procedures

X.25 Level 3 defines procedures for call initiation, data transfer, interrupts, reset, restart, and clearing. Some of these procedures are summarized below.

Call Initiation: The Level 3 software in a DTE initiates a transmission by sending a Call Request packet. This packet enables the calling DTE to request the opening of a logical channel. The calling DTE designates the channel number based upon the original assignments that were made when the user subscribed to the network. The Call Request packet also informs the network of the calling DTE's address and of the called DTE's address. Until the call is disconnected, the network retains the addresses of both devices associated with the logical channel number. Therefore, each data packet that is transmitted needs to contain only the logical channel number. The network appends the destination address just before routing the packet. At the time the Call Request is issued, the logical channel indicated by the calling DTE must be in a Ready state, that is, not being used to handle another call. Upon receipt of the Call Request by the called DTE, the specified logical channel is designated as being in the DTE Waiting state. The packet is then transmitted to the destination DCE.

The destination DCE transmits an Incoming Call packet to the originating DTE and places the logical channel in the DCE Waiting state.

The called DTE indicates its willingness to accept the call by transmitting a Call Accepted packet across the DTE/DCE interface. The Call Accepted packet specifies the same logical channel that is indicated by the Incoming Call packet. This places the specified logical channel in the Data Transfer state. (The logical channel at the calling DCE is still in the Wait state.)

A Call Connected packet is then sent by the DCE to the calling DTE and sets the logical channel status to the Data Transfer state; the logical channel is then ready for transfer of data packets. This applies only for virtual circuit connections; for permanent virtual circuit connections, the assigned logical channels are always in the Data Transfer state.

It is possible for a DCE to receive a Call Request (from a DTE) and an Incoming Call (from the network) simultaneously, with both messages specifying the same logical channel. This is called a call collision; when a collision occurs, the DCE cancels the Incoming Call and proceeds to process the Call Request.

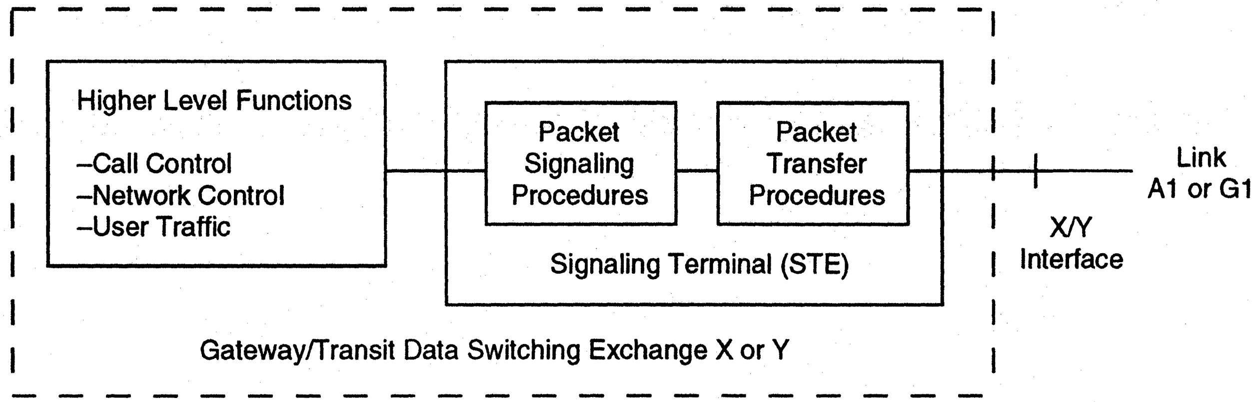
Data Transfer: Once the logical channel is in the Data Transfer state, data, flow control, or reset information packets can be transmitted.

The Data packet format includes the packet send and receive sequence numbers. The calling DTE can transmit up to a predetermined number of packets before requiring a response. This number is referred to as the window. All packet networks must accommodate a lower window edge of at least eight, permitting at least seven packets to be outstanding before an acknowledgment is required. The upper window value (the maximum number of outstanding packets) may not exceed 127 (modulo 128).

Upon receipt of an authorized packet, the receiving device can either authorize additional transmission by transmitting a Receive Ready packet to the sending device or deny authorization to transmit by issuing a Receive Not Ready packet.

When transmitting Data packets, the Interrupt packet can bypass flow control (authorization procedures). A DTE can transmit an Interrupt packet to another DTE. To avoid swamping the receiver with Interrupt packets, the

Figure 6.
Basic System Structure of X.75 Signaling and Data Transfer Procedures



sender cannot send a second Interrupt packet until the first Interrupt packet is acknowledged by an Interrupt Confirmation packet.

While Data packets or Interrupt packets are being transmitted, issuing a Reset Request packet can reset the call. A DCE initiates a reset by issuing a Reset Indication packet. In either case, the logical channel is placed in the Data Transfer state. Any Data, Interrupt, Receive Ready (RR), or Receive Not Ready (RNR) packets in the network at the time of reset are ignored. If a DTE and DCE transmit Reset packets simultaneously, a reset collision occurs. The net effect is to place the logical channel in the Data Transfer state, ready for Data and Interrupt packets.

A DTE or a DCE initiates a request for clearing (disconnecting) a logical channel. Upon confirmation by the other device, the logical channel is placed in the Ready state.

Error Handling (Packet Level): When an error occurs, the DCE transmits Reset, Clear, and Restart indication packets to the DTE. *Reset* reinitializes a virtual call or permanent virtual circuit. Reset removes all Data and Interrupt packets on the logical channel and resets the lower window edge to zero. It affects only one logical channel number (one user). Reset procedures, which apply only in the Data Transfer state, handle specific error events, such as local procedure error, remote procedure error, network congestion, incompatible destination, network out of order, etc. *Clear* affects only one logical channel number (one user). It clears a session when, for example, the host or host link crashes. In this case, the network initiates Clear procedures on the terminal link. It effectively logs off the terminal user. Clear resets the lower window edge to 0. *Restart* affects all users (all logical channels on a given link) and clears all calls on that link. Restart is used when a failed link returns to service; it makes sure that all calls were cleared when the link went down. Restart also is used when either side (DTE or DCE) reports error conditions at the packet level; the good side initiates the restart procedures.

In some networks, a *diagnostic* packet indicates unusual error conditions. A diagnostic packet from the DCE provides information on events that are considered unrecoverable at the packet level; the information permits the DTE to analyze and initiate recovery by higher levels. No confirmation is required on receipt of a diagnostic packet.

Implementation Considerations for Users

X.25 recognizes that DTEs differ in their degree of sophistication. A simple DTE may have fixed packet formats and built-in parameter values, while a sophisticated DTE may work with varying packet formats and provide variable parameters to take advantage of the many network functions and signaling capabilities offered.

At the physical level, the transmission rate DTE uses to access an X.25 network should be governed by the throughput and response time requirements of the user.

Table 4. X.21 Pin Assignments

Pin Number	Employing X.26	Employing X.27
1	See Note *(3)*	See Note *(3)*
9	Ga	T(B)
2	T	T(A)
10	Ga	C(B)
3	C	C(A)
11	R(B)	R(B)
4	R(A)	R(A)
12	I(B)	I(B)
5	I(A)	I(A)
13	S(B)	S(B)
6	S(A)	S(A)
14	B(B)	B(B)
7	B(A)	B(A)
15	Reserved for future use	Reserved for future use
8	G	G

Notes:
(1) X.21 pin assignments are defined by ISO 4903-1980.
(2) Where balanced ciruits are, the associated pairs are designated "A" and "B."
(3) Pin 1 is reserved for connection of the shield or shielded interconnecting cable.

Table 5. X.25 Level 2 Commands and Responses

Format	Commands (1)		Responses		Encoding of Control Field 1	2	3	4	5	6	7	8
Information transfer	I	(information)			0	├──	N(S)	──┤	P	├──	N(R)	──┤
Supervisory	RR *(3)*	(receive ready)	RNR	(receive not ready)	1	0	0	0	P/F		N(R)	
	RNR *(3)*	(receive not ready)	RNR	(receive not ready)	1	0	1	0	P/F		N(R)	
	REJ *(3)*	(reject)	REJ	(reject)	1	0	0	1	P/F		N(R)	
Unnumbered	SARM *(2,3)*	(set asynchronous response mode)	DM *(2)*	(disconnected mode)	1	1	1	1	P/F	0	0	0
	SABM *(2)*	(set asynchronous balanced mode)			1	1	1	1	P	1	0	0
	DISC	(disconnect)			1	1	0	0	P	0	1	0
			UA	(unnumbered acknowledgment)	1	1	0	0	F	1	1	0
			CMDR FRMR	(command reject) (frame reject)	1	1	1	0	F	0	0	1

(1) The need for, and use of, additional commands and responses are for further study.
(2) DTEs do not have to implement both SARM and SABM; furthermore, DM and SABM need to be used if SARM only is used.
(3) RR, RNR, and REJ supervisory command frames are not used by the DCE when SARM is used (LAP).

Factors to consider include the maximum number of virtual circuits operating simultaneously and traffic characteristics of throughput-critical and response-time-critical virtual circuits.

At the link level, Link Access Procedures (LAPs) and Link Access Procedures Balanced (LAPBs) are defined. A DTE might implement only LAPB. Parameters that are part of the LAPB procedures can be set to constants for all network connections. For example, a timer (T1) may be set according to the slowest required line speed; a constant such as three seconds may be used. Also, the maximum permitted number of unacknowledged I-Frames (information frames) may be determined. The network provider must agree to this. All networks support a window of at least seven I-Frames. The maximum packet size (number of bits) of the I-Frame must also be established.

If the DTE handles certain character sizes (octets), the frame level should be capable of accommodating any number of bits correctly (generate acknowledgment, calculate frame check sequence). How such a properly received frame is processed depends on the individual system and may include actions such as discarding the frame, padding it, clearing the call, or resetting.

Connections Between Packet Switched Data Networks

CCITT Recommendation X.75 describes the procedures for the interconnection of packet switched networks. Many public packet switched data networks support X.75 procedures, including AT&T Accunet, TransCanada's Datapac, Graphnet Freedom Network II, US Sprint's SprintNet, and WangPac networks.

X.75 is similar to X.25 in that it specifies procedures for the physical, link, and packet levels. Signal Terminal Equipment (STE), which acts as a bridge node between networks, implements X.75 procedures. A related standard, CCITT X.121, defines the international numbering plan for public data networks.

Recommendation X.75

Recommendation X.75, *Terminal and Transmit Call Control Procedures and Data Transfer System on International Circuits Between Packet-Switched Data Networks*, provides the rules for transmitting data between different data networks. The basic system structure is made up of communicating elements that function independently. These elements include the physical circuits, which comprise links A1 or G1 (as defined in X.92), and a set of mechanical, electrical, functional, and procedural interface characteristics; packet transfer procedures, which operate over the physical circuits and provide for the transport of packets between STEs; and packet signaling procedures, which use the packet data transfer procedures and provide for the exchange of call control information and user traffic between STEs. Figure 6 shows the basic system structure of the signaling and data transfer procedures. The international link is assumed to be data link A1 and/or data link G1 as defined in Recommendation X.92. The international link should be capable of supporting full-duplex operation.

Link-level packet transfer procedures between STEs consist of the Single Link Procedure (SLP) and the Multilink Procedure (MLP). The SLP is used for data interchange over a single physical circuit between two STEs. When multiple physical circuits are used in parallel, the SLP is used independently on each circuit. The MLP is used for data interchange over multiple parallel links. The MLP may be used over a single link when the communicating parties agree to this procedure. Transmissions are full duplex. SLP is based upon the Link Access Procedure Balanced (LAPB) as described in X.25 and uses the principle and terminology of the International Organization for Standardization's (ISO's) High-level Data Link Control (HDLC). For SLP, either modulo 8 (nonextended mode) or the modulo 128 (extended mode) may be used. The MLP is based on the multilink procedures specified by the ISO and performs the functions of distributing packets across available SLPs.

Three channel states are defined: the link channel state, which provides transmission in one direction; the active

Table 6. Summary of Packets Exchanged Between Terminals During a Virtual Call

Events	Activity at Calling DTE	Activity at Called DTE
Call Initiation	Call Request packet is sent	Incoming Call packet is received Call Accepted packet is sent
	Call Connected packet is received	
Data Transfer	Data packet sent	Data packet received Ready Receive packet sent
	Ready Receive packet received Data packet A sent* Data packet B received*	Data packet B sent* Data packet A received*
Disconnect	Clear Request packet sent	Clear Indication packet received Clear Confirmation packet sent
	Clear Confirmation packet received	

**Two-way (full-duplex) transmission of data packets between terminal equipment.*

channel state, which means that the incoming or outgoing channel is receiving or transmitting a frame; and the idle channel state, which means that the incoming or outgoing channel is receiving or transmitting at least 15 contiguous 1 bits.

Data is transmitted in frames. Each frame must contain an Opening Flag (8 bits), an Address field (8 bits), a Control field (8 bits), a Frame Check Sequence (FCS) field (16 bits), and a Closing Flag (8 bits). An Information field of an unspecified number of bits, which follows the Control field, is optional.

The Control field contains a command or response, and sequence numbers if applicable. Control field formats may be one of three types: numbered information transfer (I format), numbered supervisory functions (S format), and unnumbered control functions (U format). The I format performs information transfer functions. The S format performs link supervisory control functions, such as acknowledging I frames, requesting transmission of I frames, and requesting a temporary suspension of transmission of I frames. The U format provides additional link control functions.

Each I frame is numbered sequentially. The send state variable V(S) represents the sequence number of the next in-sequence I frame to be transmitted. The value of the V(S) is incremented by one with each successive I frame transmission but cannot exceed N(R) of the last received I or S format frame by more than the maximum number of outstanding frames. The send sequence number N(S), contained only in I frames, is set equal to the value of V(S). The receive state variable V(R) represents the sequence number of the next in-sequence I frame expected to be received. The value of V(R) is incremented by one when an error-free, in-sequence I frame whose N(S) equals V(R) is received. Both I frames and S frames contain the receive sequence number N(R). N(R) is the expected send sequence number of the next received I frame. When the STE transmits N(R), it indicates that all I frames numbered up to and including N(R)-1 have been received correctly.

All frames contain the Poll/Final (P/F) bit, which is referred to as the P bit in command frames and the F bit in response frames. The STE solicits a response from another STE by setting the P bit to 1; the answering STE responds by setting the F bit to 1. The following commands and responses are supported:

- ***Information (I) command***—transfers sequentially numbered frames that contain an information field;
- ***Receive ready (RR) command and response***—used by the STE to indicate that it is ready to receive an I frame or to acknowledge a previously received I frame;
- ***Receive not ready (RNR) command and response***—used by the STE to indicate a busy condition;
- ***Reject (REJ) command and response***—used by the STE to request retransmission of I frames beginning with frame numbered N(R);
- ***Set asynchronous balanced mode (SABM) command***—an unnumbered command used to set the addressed STE in the asynchronous balanced mode information transfer phase; all command/response control fields are one octet (eight bits);
- ***Set asynchronous balanced mode extended (SABME) command***—an unnumbered command used to set the addressed STE in the asynchronous balanced mode information transfer phase; all numbered command/response control fields are two octets; all unnumbered command/response control fields are one octet;
- ***Disconnect (DISC) command***—terminates the previously set mode; DISC indicates that the STE transmitting DISC is suspending operation;
- ***Unnumbered acknowledge (UA) response***—used by the STE to acknowledge mode-setting commands;
- ***Disconnected mode (DM) response***—reports STE status when it is logically disconnected from the link and is in the disconnected phase; and
- ***Frame reject (FRMR) response***—indicates an error condition that is not recoverable by retransmission of the frame.

Packet-level signaling procedures relate to the transfer of packets at the STE-X/STE-Y (X/Y) interface. Recommendation X.75 specifies signaling procedures for virtual call

Table 7. Packet Types and Their Use in Various Functions

Function	Packet Type: From DCE to DTE	Packet Type: From DTE to DCE	Service: Switched Virtual Circuit	Service: Perm. Virtual Circuit
Call Setup and Cleaning	In Incoming Call	Call Request	X	
	Call Connected	Call Accepted	X	
	Clear Indication	Clear Request	X	
	DCE Clear Confirmation	DTE Clear Confirmation	X	
Data and Interrupt	DCE Data	DTE Data	X	X
	DCE Interrupt	DTE Interrupt	X	X
	DCE Interrupt Confirmation	DTE Interrupt Confirmation	X	X
Flow Control and Reset	DCE RR (Receive Ready)	DTE RR	X	X
		DTE RNR	X	X
	DCE RNR (Receive Not Ready)	DTE REJ*	X	X
		Reset Request	X	X
	Reset Indication			
	DCE Reset Confirmation	DTE Reset Confirmation	X	X
Restart	Restart Indication	Restart Request	X	X
	DCE Restart Confirmation	DTE Restart Confirmation	X	X
Diagnostics	Diagnostics		X	X

setup and clearing, for permanent virtual circuit service, for data and interrupt transfer, for flow control, and for reset.

Logical channels are used to complete simultaneous virtual calls and/or permanent virtual circuits. A logical channel group number and a logical channel number (in the range 0 to 15 inclusive and 0 to 255 inclusive, respectively) are assigned to each virtual call and permanent virtual circuit. The logical channel group number and the logical channel number are contained in each packet type, except restart packets.

The procedures for virtual call setup and clearing are used only when a logical channel is in the *packet-level ready* (RL) state. If call setup is possible, and no call or call attempt exists, the logical channel is in the *ready* (PL) state (within the RL state). Call setup is initiated when the STE sends a *call request* packet across the X/Y interface. The call request packet specifies a logical channel in the PL state. The logical channel is then placed in the call request state. The called STE indicates acceptance by the called DTE by sending a *call connected* packet across the X/Y interface. It specifies the same logical channel as that requested by the call request packet. The logical channel is then placed in the *flow control ready* (DL) state within the *data transfer* (P4) state.

A logical channel (in any state) can be cleared when the STE sends a *clear request* packet, which specifies the logical channel, across the X/Y interface. Upon receipt of a clear request packet, STE-X or STE-Y frees the logical channel and transmits a *clear confirmation* packet that specifies the same channel. This places the logical channel in the ready state within the RL state. Permanent virtual circuits require no call setup or clearing.

Data transfer procedures apply independently to each logical channel at the X/Y interface. In the *data transfer* (P4) state, *data, interrupt, flow control*, and *reset* packets may be sent and received by the STE. The data transfer state exists within the packet-level ready state of a logical channel. Each data packet contains a sequence number called the packet send sequence number P(S); only data packets contain the P(S).

The procedures for flow control and reset apply only in the data transfer state. Flow control applies to data packets. A window is defined for each direction of transmission at the X/Y interface. The lowest number in the window is called the lower window edge. The maximum window edge does not exceed modulo 8 or 128, is unique to each logical channel, and is reserved for a period of time. For a particular call, two window sizes, one for each direction of transmission, may be selected. The packet receive sequence number P(R) (modulo 8 or 128) conveys information from the receiver for the transmission of data packets. The P(R) becomes the lower window edge when transmitted across the X/Y interface, thereby authorizing additional data packets to cross the X/Y interface.

Reset procedures are used to reinitialize a single call and apply only in the data transfer state. The STE sends a *reset request* packet that specifies the logical channel to indicate a request for reset. The logical channel is placed in the reset request state. The requested STE confirms by sending a *reset confirmation* packet, which places the logical channel in the *flow control ready* state.

Restart procedures are used to clear all calls simultaneously. When the STE sends a *restart request* packet, the X/Y interface for each logical channel is placed in the restart request state. In this state all packets, except restart request and restart confirmation packets, are discarded by the X/Y interface. An STE confirms by sending a *restart confirmation* packet, which places all channels in the ready state.

Packet formats are based on the general structure of packets as defined in X.25.

Trends in Packet Switching

X.25 packet switching is widely supported in existing data processing and data communications equipment. All major host computer and communications processor vendors, for example, have incorporated X.25 interfaces into their products. This is part of an overall trend in accepting international standards and the increasing availability of products conforming to these standards.

The CCITT published revisions to the X Series standards in 1984 and in 1989. Since that time, the ratification and publication of revisions has become a continuous, ongoing process. Since the major building blocks for X.25 were laid by 1984, all subsequent changes have been, and will continue to be, relatively minor. Some post-1984 changes have revolved around efforts to make CCITT X Series standards compatible with those of the International Organization for Standardization (ISO). Currently, discussions on how to provide greater interoperability between various X.25 networks is taking place. Major developments in packet switching today, however, center not around X.25, but around the development of new ISDN-related technologies, such as frame relay and Broadband ISDN, which provide much higher throughput through simplified packetization and routing schemes. This section discusses post-1984 changes to X.25 and its relationship to ISDN.

Major Changes in 1988 Revisions

In the 1988 revised standards, there were no changes at the physical and link levels. At the packet level, however, a new facility for redirecting calls, *Call Deflection*, was established. In 1984, the CCITT had made available a new Call Redirection facility, allowing the network to redirect *all* calls destined for a given address. This redirection could occur when the destination was out of order or busy, or it could be based on time of day or other criteria. The 1988 facility extended this capability, allowing the destination subscriber to clear incoming calls to another party on a call-selective basis. The Clear Request packet contains the Call Deflection information that profiles the desired alternate party.

Relationship Between CCITT and ISO Efforts

CCITT X.25 packet-level protocol specifies a virtual circuit service; the ISO has issued a compatible version of the packet standard, ISO 8208. In recent years, CCITT and ISO organizations have worked on standards to carry longer addresses in the DTE field to facilitate interworking with ISDN (E.164).

In 1988, the CCITT also modified the Address Extension facilities to be consistent with ISO address length. Previously, a provisional 32-decimal/16-octet field had been recommended; this address length was increased to 40 decimals/20 octets. The ISO also added these address recommendations to Addendum 2 of ISO 8348 (Connection-Mode Network Service); the CCITT adoption is X.213.

Connectionless Issues: Relationships With ISO Efforts

At any layer of the Open Systems Interconnection (OSI) Reference Model, two basic forms of operation are possible: connection oriented and connectionless. Connection-oriented service involves a connection establishment phase, a data transfer phase, and a connection termination phase. A logical connection is set up between end entities prior to exchanging data. In a connectionless service, typical of local area networks, each packet is independently routed to the destination. No connection establishment activities are required since each data unit is independent of the previous or subsequent one. Each transmission mode has a niche where it represents the best approach. For example, file transfers may benefit from a connection-oriented service, while point-of-sale inquiries may be best served by a connectionless service.

Traditionally, the CCITT has pursued a connection-oriented philosophy, while ISO has shown interest in connectionless. While the original OSI standard, ISO 7498, is connection oriented, ISO saw the need to provide connectionless service by issuing an addendum to that protocol, ISO 7498/DAD1. ISO has issued a standard for connection-mode network service (ISO 8348), while the CCITT has issued an identical service, X.213. In regard to X.25 itself, however, ISO has decided not to pursue the connectionless service, formerly known as "datagram" service. X.75 is also a connection-oriented service; ISO has shown considerable interest in a connectionless internetworking protocol (IP) and has developed the ISO 8473 to accommodate it.

Packet Switching in ISDN

The goal of the Integrated Services Digital Network (ISDN) is to provide an end-to-end digital path over a set of standardized user interfaces, giving the user the capability to signal the network through an out-of-band channel. (In contrast, in X.25, the user signals the network in-band fashion by issuing packets such as CALL REQUEST, CALL ACCEPTED, etc.)

Currently, different types of interfaces to the telephone network exist for different services. These interfaces include two-wire switched, two-wire dedicated, four-wire dedicated, DDS, and so forth. ISDN will provide a small set of interfaces that can be used for multiple applications. The CCITT has defined the following interfaces for ISDN:

- 2B+D—two 64K bps channels and a 16K bps packet/signaling channel (also called the Basic Rate Interface).
- 23B+D—twenty-three 64K bps channels and a 64K bps packet/signaling channel (also called the Primary Rate Interface).
- 3H0+D—three 384K bps channels and one 64K bps packet/signaling channel.
- H11—nonchannelized 1.536M bps.
- H12—nonchannelized 1.920M bps.
- Multislotted—multiples of 64K bps channels (up to 1.536M bps) under the customer's control.
- Broadband—high data rates, based on an approach called synchronous optical network (SONET), building on multiplex of 51.84M bps. SONET standards negotiations began in 1986. The CCITT approved phase I of the standards in 1988 and phase II in 1989. This architecture has been called Broadband ISDN, in contrast to the other interfaces that have been considered part of Narrowband ISDN.

With the exception of Broadband ISDN, all of the above interfaces could be carried on unloaded copper loops. Using fiber has also been considered, as it would make the local loop more robust. Out-of-band signaling makes possible a new class of services. In addition, the 16K bps D-channel will be connected directly to the BOC's packet switched network, providing the subscriber with the data multiplexing advantages packet switching offers. A major effort is under way in Europe to bring the system to market. In the United States, several trials have been undertaken, and limited ISDN service is already available.

CCITT ISDN Standards

ISDN provides a specific protocol that users can employ to signal the network. Currently, a three-layer protocol suite is defined. At the Basic Rate, the Physical Layer manages a 192K bps, full-duplex bit stream using time-compression techniques and time division methods to recover the two B-channels and one D-channel. The remaining 48K bps stream is used for Physical Layer control information. The defined standards are I.420 (Basic Rate Interface Definition), I.430 (Basic Rate Interface Layer 1), I.421 (Primary Rate Interface Definition), and I.431 (Primary Rate Interface Layer 1).

The Data Link Layer is not defined for transparent B-channels used for circuit switched voice or data, but it is defined for the D-channel. For Narrowband ISDN, the D-channel employs a LAP-D Link Layer protocol, which is a subset of the ISO HDLC Data Link protocol, as specified in CCITT Recommendations Q.920 (I.440) and X.921 (I.441). It provides statistical multiplexing for three channel types: signaling information for the management of the B-channels; packet switched service over the D-channel; and optional channels, used for telemetry of other applications.

The Network Layer protocol for the signaling channel is specified in CCITT's Q.930 (I.450) and Q.931 (I.451) specifications. It provides the mechanism for establishing and terminating connections on the B-channels and other network control functions. For the packet switched service over the D-channel, the Network Layer protocol is X.25. CCITT will define Layer 3 protocols for the optional channels in the future, or they will be specified as national options.

A technique is required for specifying whether user-to-network signaling, user packet data, or user telemetry data is being sent over the D-channel. This technique involves the use of a **service access point identifier (SAPI)**.

Each layer in the OSI Reference Model communicates with the layers above and below it across an interface. The interface is through one or more service access points (SAPs). SAPs have a number of uses, including subaddressing for internetworking situations, Transport Layer applications, and for user data packet service over an ISDN D-channel.

Considering the applications to the Transport Layer, one should note that two general types of addressing in a communications architecture are available. Each host on the network must have a network address, allowing the network to deliver data to the proper computer. Each process within a host must have an address that is unique within the host; this allows the Transport Layer to deliver data to the proper process. These process addresses are identified using SAPs. A similar approach is followed for ISDN.

LAP-D, the data link standard for ISDN, specifies the link access protocol used on the D-channel. LAP-D is based on **LAP-B**, which is based on HDLC. LAP-D must deal with two levels of multiplexing. First, at a subscriber location, multiple-user devices may be sharing the same physical interface. Second, each user device may support multiple types of traffic, including packet switched data and signaling. To accomplish this type of multiplexing, LAP-D employs a two-part address consisting of a terminal endpoint identifier (TEI) and a SAPI. Typically, each user terminal is given a distinguishing TEI. The SAPI identifies the traffic type and the Data Link Layer services directed to Layer 3. For example, the SAPI value of 0 directs the frames to Layer 3 for call-control procedures; a SAPI value of 16 indicates a packet communication procedure. See Figure 7.

Frame Relay

Frame relay is a rapidly emerging, standards-based addressing technique that has great potential in LAN/WAN networking and other interactive applications requiring high-throughput, low-delay transmission. Frame relay is based on the CCITT Layer 2 protocol developed for ISDN, Link Access Protocol D (LAPD). Unlike conventional X.25 packet switching, frame relay uses variable packet lengths and performs error checking only at the remote end of transmission. Any errors occurring between intermediate network nodes are assumed caught and corrected by higher-layer protocols. Thus, intermediate nodes simply forward packets (called frames) without processing the datastream. In addition, frames must be received in the order in which they were sent, unlike some X.25 networks, which involves considerably less machine processing at the opposite end of transmission. These efficiencies result in superior performance, with data rates up to T1/E1 levels.

Vendors from several different networking disciplines have established themselves as frame relay equipment providers. These include traditional packet switched equipment suppliers such as Northern Telecom, US Sprint, BBN Communications, BT North America, Hughes Network Systems, and Netrix Corp.; T-carrier nodal processor vendors such as General DataComm, Newbridge Networks, Network Equipment Technologies, StrataCom, and Timeplex; LAN internetworking (bridge and router) vendors; and communications carriers.

Most commercial frame relay products are based on ISDN recommendations contained in the following American National Standards Institute (ANSI) specifications:

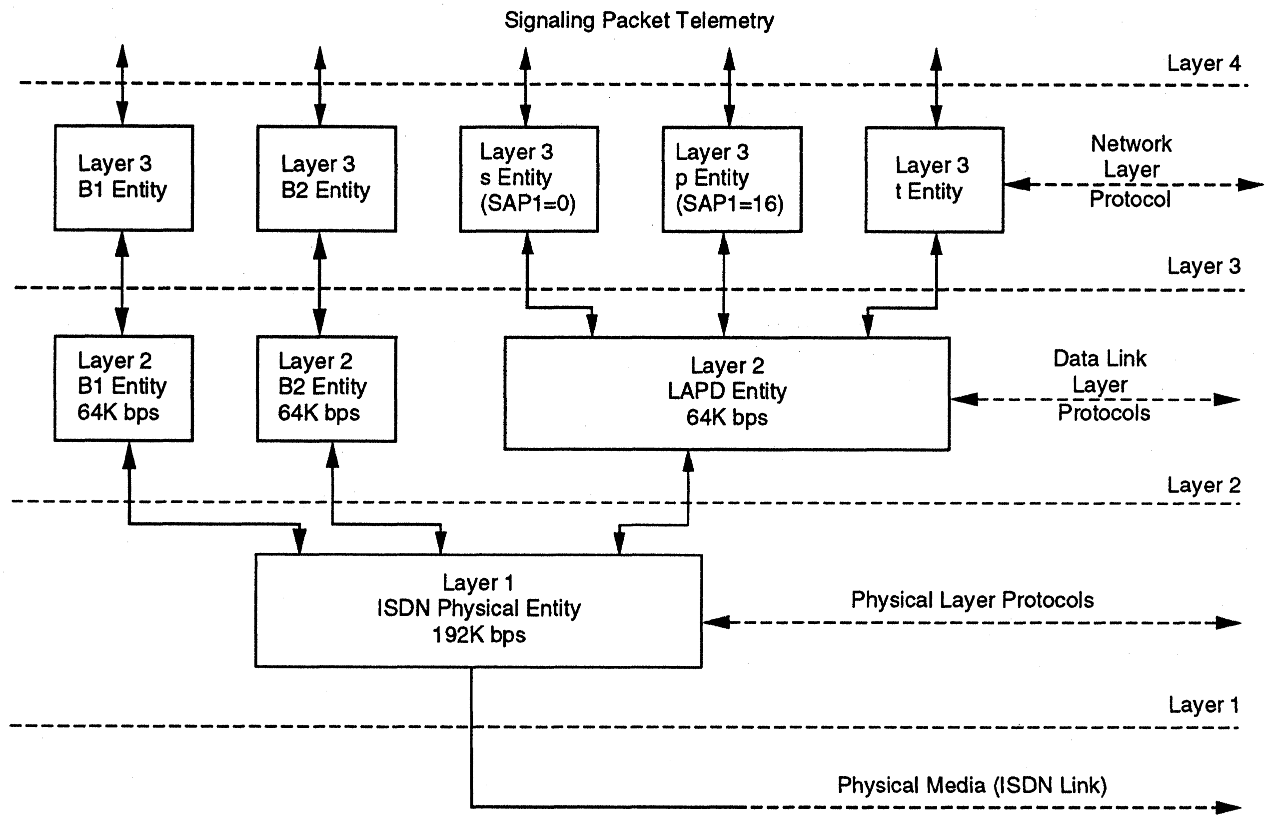
- *T1.606:* Frame Relaying Bearer Service—Architectural Framework and Service Description (T1S1/88-225)
- *Addendum to T1.606:* Frame Relaying Bearer Service—Architectural Framework and Service Description (T1S1/90-175)
- *T1.6ca:* Core Aspects of Frame Protocol for Use with Frame Relay Bearer Service (T1S1/90-214)

The CCIII has released frame-relay specification *I.122*, entitled "Framework for Providing Additional Packet Mode Bearer Services." Currently, only one packet service has been specified in ISDN standards: "Support of Packet Mode Terminal Equipment by an ISDN," CCITT *I.462 (X.31)*.

Broadband ISDN and Cell Relay

Broadband ISDN (BISDN) is the blueprint for public networks in the mid-1990s (1994 and beyond). It is being developed to support switched (on demand), semipermanent, and permanent broadband connections for both point-to-point and point-to-multipoint applications. Channels operating at 155M bps and 622M bps will be

Figure 7.
SAPI Action for a Basic Rate D-Channel



available under BISDN, allowing transmission of data, video, and digitized voice.

Broadband services are aimed at both business applications and residential subscribers. Connections will support both circuit mode and packet mode services of a single media, mixed-media, and multimedia. BISDN's foundation is cell relay, and particularly the international standard supporting it: Asynchronous Transfer Mode (ATM).

Cell relay is a high-bandwidth, low-delay switching and multiplexing technology in which information is packetized into fixed-size slots called cells. A cell consists of an information field that is transported transparently by the network and a header containing routing information. With simplified protocols and cells with a fixed, short length (53 bytes), cell relay will make very high data rates possible.

The CCITT has issued several Broadband ISDN specifications in its I-Series recommendations. *I.361,* the *BISDN ATM Layer Specification,* defines the ATM cell structure and coding, including header formats and coding at both the User-Network Interface (UNI) and Network Node Interface (NNI). It also defines ATM protocol procedures. *I.311,* entitled *BISDN General Network Aspects,* describes networking techniques, signaling principles, traffic control, and resource management for BISDN. It defines ATM virtual section, virtual path, and virtual channel concepts.

Off-the-shelf ATM products for BISDN are expected by 1995; some ATM products are available already and a great deal of work continues world-wide. In 1990, Fujitsu announced a commercial BISDN switch. It switches 512 by 512 150M bps lines. Major trials are planned for 1992 and beyond; a trial scheduled in Belgium in 1992 follows 1991 trials in the U.S. and Japan. Several high-speed switching trials in the past two-to-three years have been undertaken in the U.S. and in Germany. NYNEX is planning a trial in Boston while BellSouth plans one in North Carolina. MCI Communications Corp. plans an early deployment of Siemens Stromberg-Carlson ATM switches to provide broadband interLATA services in the U.S. These services are expected for the 1992-93 time frame. In late 1991, Southern Bell Telephone installed what was hailed as the "first broadband ISDN switch in a U.S. CO." The switch, which supports the 622M bps UNI, will be used by the University of North Carolina, as part of the VISTA-NET undertaking.

A number of cell switch vendors have efforts underway to develop ATM-based equipment for frame relay applications, rather than for mixed-media CO applications. It appears that, in the U.S., the route to frame relay will be via cell relay switches; these support frame relay interfaces on the access side and cell relay on the backbone side. Examples of this type of equipment include AT&T's BNS-1000 and BNS-2000, and Stratacom IPX products. StrataCom supports a 24-octet cell (with 4 octets of overhead); AT&T supports a 16-octet cell on the BNS-1000. Other early ATM equipment or service entrants include: Fujitsu Network Switching, ASCON Timeplex (TIMEPATH/Esprit), Network Equipment Technologies, Ungermann-Bass Inc., BBN (Emerald), and Siemens Stomberg-Carlson (Metropolitan Area Network Switching System). Several of these switches support both voice and data. ■

CCITT Packet Switched Networking Standards X Series

In this report:

Synopsis

Editor's Note
In 1984, CCITT published Red Books on wide-ranging topics, including the X.25 packet-switching standards. A set of revisions to the X Series, the Blue Books, was published in 1989. Since that time, standards ratification and publication have been ongoing, continuous processes. Each future addition or revision to the X Series standards will be made available, as soon as they are finalized, in individual grey booklets. Since the major building blocks of the X standards were completed by 1984, all post-1984 technical changes are relatively minor; they are discussed in this report, however.

Major developments in packet switching center around the development of ISDN-related technologies, such as fast packet switching and frame relay, which provide integration of voice, video, and data, and support much higher throughput than traditional X.25 networks. ISDN's relationship with traditional X.25 packet switching is also discussed.

Report Highlights
A packet switched network permits a user's data terminal equipment (i.e., a PC, host computer, or terminal) to communicate with the equipment of other geographically dispersed users. Data must be presented to the network in a prescribed manner, however. A packet assembler/ disassembler (PAD), also referred to as data circuit-terminating equipment (DTE), serves as a network entry/exit point, packetizing and depacketizing data according to the rules specified by the X.3, X.28, X.29, X.21, X.25, and X.75 recommendations of the CCITT.

—By Martin Dintzis
Assistant Editor

Analysis

In the early days of packet switching, each Public Data Network (PDN) defined its own network access protocol, which permitted an appropriately equipped computer to communicate with other devices on the network through a physical connection to the PDN. Each of these protocols used a multiplexing technique that enabled a computer to establish and maintain one or more virtual circuits to other network communicating equipment. No industry standard for packet switching existed, however, and most computer manufacturers were reluctant to provide the necessary software to handle the variety of network access protocols.

With the adoption of the X Series Recommendations by the CCITT in 1976, the PDNs could offer a standard network access protocol. The recommendations are continually fine-tuned.

Table 1. CCIT Recommendations—X Series

CCITT Recommendation	Description
X.1	International user classes of service in public data networks: class 8 (2400 bps); class 9 (4800 bps); class 10 (9600 bps); or class 11 (48,000 bps)
X.2	International user facilities in public data networks
X.3	Packet assembly/disassembly (PAD) facility in a public data network; lists options and defaults for interactive asynchronous terminal connection to X.25 packet networks
X.4	General structure of signals of International Alphabet No. 5 (IA5) code for data transmission over public data networks (IA5 is described in CCITT V.3)
X.20	Interface between data terminal equipment (DTE) and data circuit-terminating equipment (DCE) for async transmission services on public data networks
X.20 bis	V.21-compatible interface between DTE and DCE for async transmission services on public data network
X.21	General-purpose interface between DTE and DCE for synchronous operation on public data networks
X.21 bis	For use on public data networks by DTE that are designed to interface to synchronous V-Series modems
X.24	List of definitions of interchange circuits between DTE and DCE on public data networks
X.25	Interface between DTE and DCE for terminals operating in the packet mode on public data networks
X.26	Electrical characteristics for unbalanced double-current interchange circuits for data communications equipment
X.27	Electrical characteristics for balanced double-current interchange circuits for data communications equipment
X.28	DTE/DCE interface for asynchronous device access to the PAD facility of a public data network in the same country
X.29	Procedure for the exchange of control information and user data between a packet mode DTE and a PAD facility
X.32	Procedure for communications between users and packet networks through the switched telephone network and through circuit switched public data networks
X.75	Expanded X.25 recommendation for internetwork communications between packet switched networks; interface is defined between two STEs (Signaling Terminal Equipments) that are a part of ISDEs (International Data Switching Exchanges), with expanded support for wideband links, extended sequencing, and an expanded network utility field for international call establishment
X.92	Hypothetical reference connections for public synchronous data networks
X.95	Network parameters in public data networks
X.96	Call progress signals in public data networks
X.121	International numbering scheme for multinetwork communications containing a 4-digit DNIX (Data Network Identification Code), 3-digit area code, 5-digit host identification, a 0- to 2-digit subaddress

Revised editions are published at four-year intervals; the 1989 draft incorporates the latest revisions and recommendations. The next published revision will be available in 1992.

This report focuses on Recommendations X.3, X.28, and X.29 (informally called the Interactive Terminal Interface [ITI] standards); X.21; X.25; and X.75.

Packet Assembly/Disassembly

Recommendations X.3, X.28, and X.29 define the procedures by which asynchronous terminals, computers, and other devices, often referred to as data terminal equipment (DTE), communicate with other devices via a packet switched network. Packet assemblers/disassemblers, also referred to as DTE, commonly serve as network entry/exit points.

X.3 defines the basic and user-selectable functions of a packet assembler/disassembler (PAD). It also lists 22 parameters necessary to characterize a specific device (e.g., bit rate, the escape character, and flow control technique). The proper setting of these values enables the PAD to correctly interpret the communicating device and vice versa.

X.28, a related standard, defines the procedures for character interchange and service initialization, the exchange of control information, and the exchange of user data between an asynchronous terminal device and a PAD. X.29 defines the procedures for the exchange of PAD control information and the manner in which user data is transferred between a packet mode DTE and a PAD or between two PADS.

Recommendation X.3

CCITT Recommendation X.3, *Packet Assembly/ Disassembly Facility in a Public Data Network*, outlines the procedures for packet assembly/ disassembly in asynchronous transmissions. These functions can be programmed and built into a microprocessor-based "black box" that is placed between the terminal and the X.25 network at either the customer's premises or the entry point of the network node.

The PAD performs a number of functions, some of which allow it to be configured, by either an asynchronous terminal device or another (remote) PAD, so that its operation is adapted to the asynchronous terminal's characteristics. The PAD's basic functions include:

- The assembly of characters into packets;
- The disassembly of the user data field;
- Virtual call setup, clearing, resetting, and interrupt procedures;
- Generation of service signals;
- A mechanism for forwarding packets when the proper conditions exist;
- A mechanism for transmitting data characters, including start, stop, and parity elements;
- A mechanism for handling a break signal from an asynchronous terminal;
- Editing of PAD command signals;
- A mechanism for setting and reading the current value of PAD parameters;
- A mechanism for the selection of a standard profile (optional);
- Automatic detection of data rate, code, parity, and operational characteristics (optional); and
- A mechanism for the remote DTE to request a virtual call between an asynchronous terminal and another DTE (optional).

The PAD's operation depends on the selectable values of internal variables called PAD parameters. A set of parameters exists independently for each asynchronous terminal. The current value (the binary representation of the decimal value) of each PAD parameter delimits the operational characteristics of the related function. The initial value of each parameter is set according to a predetermined set of values, the initial standard profile. Twenty-two PAD parameters have been standardized by the CCITT. They are as follows:

- ***PAD recall using a character***—allows an asynchronous terminal to initiate an escape from the *data transfer state* or the *connection-in-progress state* in order to send PAD command signals. This parameter has the following selectable values: not possible, possible by character 1/0 (DLE), or possible by a user-defined graphics character.
- ***Echo***—enables characters received from the asynchronous terminal to be interpreted by the

PAD and transmitted back to the asynchronous terminal. Selectable values are no echo (0) and echo (1).

- ***Selection of data forwarding characters***—allows the asynchronous terminal to send defined sets of characters, which the PAD recognizes as an indication to complete the packet assembly and to forward a complete packet sequence as defined in X.25. The basic functions of this parameter are encoded and represented by a decimal value. The functions include no data forwarding character (represented by decimal 0); alphanumeric characters A-Z, a-z, and 0-9 (decimal 1); CR (decimal 2); ESC, BEL, ENQ, and ACK (decimal 4); DEL, CAN, and DC2 (decimal 8); ETX and EOT (decimal 16); HT, LF, VT, and FF (decimal 32); and all other characters in columns 0 and 1 of International Alphabet No. 5 (IA5) not included in the above (decimal 64).
- ***Selection of idle timer delay***—permits the selection of the duration of a time interval between successive characters. When data received from the asynchronous terminal exceeds this interval, the PAD terminates the assembly of a packet and forwards it as defined in the X.25 protocol.
- ***Ancillary control***—defines flow control between the PAD and the asynchronous terminal. Decimal 0 represents no use of X-on (DC1) and X-off (DC3); decimal 1 represents use of X-on/X-off (data transfer); and decimal 2 represents the use of X-on/X-off (data transfer and command).
- ***Control of PAD service signals***—provides the asynchronous terminal with the capability to decide whether and in what format PAD service signals are transmitted.
- ***Selection of operation of the PAD on receipt of the break signal***—after receiving a break signal from the asynchronous terminal, the PAD may do nothing, send an *interrupt packet* to a packet mode DTE or another PAD, reset, or send an *indication of break* PAD message to a packet mode DTE or another PAD.
- ***Discard output***—permits a PAD to discard the content of user sequences in packets rather than disassembling and transmitting them to the asynchronous terminal. Selections include normal data delivery or discard output.
- ***Padding after carriage return***—permits the PAD to automatically insert padding characters in the character stream sent to the asynchronous terminal after the occurrence of a carriage return character. This enables the asynchronous terminal printing device to perform the carriage return function correctly. A value between 0 and 255 indicates the number of padding characters the PAD will generate.
- ***Line folding***—permits the PAD to automatically insert appropriate format effectors in the character stream sent to the asynchronous terminal. No line folding or a predetermined maximum number of graphics characters per line may be selected.
- ***Binary speed***—a read-only parameter that neither DTE can change. It enables the packet mode DTE to access a characteristic (known by the PAD) of the asynchronous terminal device. Speeds from 50 bps to 64K bps are represented.
- ***Flow control of the PAD by the start/stop mode DTE***—governs flow control between the asynchronous terminal and the PAD. The asynchronous terminal transmits special characters to indicate whether it is ready to accept characters from the PAD. In IA5, these special characters switch an ancillary transmit device on and off. Decimal 0 represents no use of X-on (DC1) and X-off (DC3); decimal 1 represents use of X-on/X-off.
- ***Line-feed insertion after carriage return***—permits the PAD to automatically insert a line-feed character in the character stream sent to or received from the asynchronous terminal or after echo of each carriage return character. This function applies only in the data transfer state.
- ***Line-feed padding***—permits the PAD to automatically insert padding characters in the character stream transmitted to the asynchronous terminal after the occurrence of a line-feed character. This enables the asynchronous terminal printing mechanism to perform the line-feed operation correctly. This function applies only in the data transfer state.
- ***Editing***—enables character delete, line delete, and line display editing capabilities. During the *PAD command state*, the editing function is always available; use or nonuse of the editing function in the *data transfer state* is selectable.

- ***Character delete, line delete,*** and ***line display***—all editing functions represented by one user-selectable character from IA5.
- ***Editing PAD service signals***—enable the asynchronous terminal to edit PAD service signals for printing devices and display terminals; also used for editing via one character from IA5. Editing is not selectable.
- ***Echo mask***—when echo is enabled, echo mask designates that selected defined groups of characters sent by the asynchronous terminal are not transmitted back. The following may be selected: no echo mask; no echo of CR; no echo of LF; no echo of VT, HT, and FF; no echo of BEL and BS; no echo of ESC and ENQ; no echo of ACK, NAK, STX, SOH, EOT, ETB, and ETX; no echo of editing characters; or no echo of all other characters.
- ***Parity treatment***—permits the PAD to check parity in the datastream from the asynchronous terminal and/or generate parity in the datastream to the asynchronous terminal. No parity checking or generation, parity checking, or parity generation are selectable.
- ***Page wait***—allows the PAD to suspend transmission of additional characters to the asynchronous terminal after the PAD has transmitted a specified number of line-feed characters.

Recommendation X.28

CCITT Recommendation X.28, titled *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*, describes the interfacing procedures that allow the PAD to be connected to an asynchronous terminal. X.28 covers four areas:

- Procedures to establish an access information path between an asynchronous terminal and a PAD;
- Procedures for character interchange and service initialization between an asynchronous terminal and a PAD;
- Procedures for the exchange of control information between an asynchronous terminal and a PAD; and
- Procedures for the exchange of user data between an asynchronous terminal and a PAD.

Modems standardized for use on public switched or leased line facilities establish the procedures for providing an access path (DTE/DCE interface). Procedures for both V and X Series interfaces are defined.

Transmission speeds up to 1200 bps are specified for V-Series interfaces; they are in accordance with either the V.21, V.22, or V.23 standard, depending on facility type and speed. The V-Series specifications define the procedures for setting up and disconnecting the access information path by both the DTE and the PAD.

X-Series interfaces also are used with switched or leased line facilities. The physical characteristics for the DTE/DCE interface are specified in X.20 or X.20 bis. Procedures for setting up and disconnecting the path by both the DTE and the PAD are defined.

X.28 specifies procedures for character interchange and service initialization between an asynchronous terminal and a PAD. Characters sent and received must conform to IA5. The PAD transmits and expects to receive only eight-bit characters. The eighth bit, the last bit preceding the stop element, is used for parity checking.

X.28 describes the action the PAD takes when the value of parameter 21 (X.3, parity treatment) is set to 0, 1, 2, or 3. If parameter 21 is set to 0, the PAD inspects only the first seven bits and ignores the eighth bit. When parameter 21 is set to 1, the PAD treats the eighth bit of the character as a parity bit and checks this bit against the type of parity—odd, even, space (0), or mark (1)—used between the PAD and the asynchronous terminal. If it is set to 2, the PAD replaces the eighth bit of the characters to be sent to the terminal with the bit that corresponds to the type of parity used between the PAD and terminal. When the value is set to 3, the PAD checks the parity bit for characters received from the asynchronous terminal *and* generates the parity bit for characters to be sent to the asynchronous terminal (as in values 1 and 2).

Once the access information path is established, the asynchronous terminal and the PAD exchange binary 1 across the interface. This places the interface in the *active link state* (state 1). When the interface is in the active link state, the DTE transmits a sequence of characters that indicates *service request* (state 2) and initializes the PAD. The service request permits the PAD to detect the data rate, code, and parity used by the asynchronous terminal (DTE) and to select the initial profile of the PAD. The service request may be bypassed, if the terminal is connected to the PAD via a leased line and the PAD knows the speed, code, and initial profile of the terminal or if a default value is used. After the request service signal is transmitted, the DTE transmits binary 1, which places the interface in the *DTE waiting state* (state 3A). If parameter 6 (X.3, control of PAD service signals) is set to 0, the interface immediately enters the *PAD waiting state* (state 5) after receipt of service request. If parameter 6 is set to other than 0, the PAD transmits the *PAD identification PAD service* signal (indicates PAD and port identity; is network dependent), and the interface enters the *service ready state* (state 4). The DTE then transmits a *selection PAD command* signal (state 6), and the PAD transmits an *acknowledgment PAD service* signal, followed by binary 1, which places the interface in the *connection-in-progress* state (state 7).

If parameter 6 is 0, the PAD will not transmit PAD service signals. In this case, the interface is placed in the connection-in-progress state after receipt of a valid selection PAD command signal.

Once the DTE receives the PAD service signal (state 8) or a sequence of signals in response to a PAD command signal, the interface is placed in either the PAD waiting state (state 5) or the data transfer state (state 9).

A *fault condition* exists if a valid service request signal is not received by the PAD within a selectable number of seconds after the transmission of binary 1. If a fault condition occurs, the PAD performs clearing by disconnecting the access information path.

The procedures for the exchange of control information between an asynchronous terminal and a PAD include *PAD command* signals, *PAD service* signals, *break* signals, and *prompt PAD service* signals. PAD command signals flow from the DTE to the PAD; they set up and clear a virtual call, select a standard profile (PAD parameters) that is either CCITT or network defined, request current values of PAD parameters, send an interrupt requesting circuit status, and reset a virtual call. PAD service signals flow from the PAD to the DTE; they transmit call progress signals, acknowledge PAD command signals, and transmit operating information of the PAD to the terminal. Either the PAD or the terminal can transmit the *break* signal. It provides signaling without losing character transparency. The *prompt PAD service* signal indicates the PAD's readiness to receive a PAD command signal.

The temporary storage of characters in an editing buffer provides editing functions in the PAD. These functions permit the asynchronous terminal to edit characters input to the PAD before the PAD processes them. They include character delete, line delete, and line display. Character delete removes the last character in the editing; line delete removes the contents of the editing buffer. Line display causes the PAD to send a format effector followed by the contents of the editing buffer to the terminal.

Procedures for the exchange of user data between an asynchronous terminal and a PAD apply during the data transfer state. The values of the parameters set in X.3 determine which characters are transmitted during the data transfer state. For example, if parameters 1 (PAD recall using a character), 12 (flow control of the PAD by the start/stop mode DTE), 15 (editing), and 22 (page wait) are set to 0, any character sequence may be transmitted by the asynchronous terminal for delivery to the remote DTE during the data transfer state.

User data is sent to the asynchronous terminal in octets (eight-bit characters) at the appropriate transmission rate for the asynchronous terminal; the start/stop bits are added to the data characters. Octets are assembled into packets (see X.25) and forwarded when enough data has been received to fill a packet, when the maximum assembly timer delay period has elapsed, when a data forwarding character is transmitted, or when a break signal is transmitted (parameter 7 is set to other than 0).

Recommendation X.29

CCITT Recommendation X.29, titled *Procedures for the Exchange of Control Information and User Data Between a Packet Assembly/Disassembly Facility (PAD) and a Packet Mode DTE or Another PAD*, provides the final step. X.29 describes the interfacing procedures that allow the PAD to communicate with the X.25 network. It defines the procedures for the exchange of PAD control information and the manner in which user data is transferred between a packet mode DTE and a PAD or between two PADS.

Recommendation X.29 specifies that control information and user data are exchanged between a PAD and a packet mode DTE or between PADs using the data fields described in X.25. Interface characteristics—mechanical, electrical, functional, and procedural—are also defined as in X.25.

X.29 specifies that the *call user data* field of an *incoming call* or *call request* packet going to/from the PAD or the packet mode DTE must consist of protocol identifier and call data fields. A call request packet need not contain a call user data field to be accepted by the PAD. If the call user data field is present, the PAD transmits it, unchanged, to its destination.

A call data field's octets consist of user characters sent from the DTE to the PAD during the call establishment phase. This field is limited to 12 octets. The octet's bits are numbered 8 to 1; bit 1, the low order bit, is transmitted first.

Bits 8, 7, 6, and 5 of octet 1 of a user data field of complete packet sequences are the control identifier field. This field, which consists of four octets, identifies the facility to be controlled. The control identifier field coding for messages to control a PAD for an asynchronous terminal is 0000. When the control identifier field is set to 0000, bits 4, 3, 2, and 1 of octet 1 are defined as the message code field, which is used to identify specific types of PAD messages.

User sequences perform data exchange. They are transferred in the user data fields of complete packet sequences with the Q bit set to 0. Only one user sequence exists per complete packet sequence. The PAD transmits all data packets with the D bit set to 0. The DTE sends a data packet to the PAD with the D bit set to 1. When the PAD *receives* a data packet with the D bit set to 1, it sends the corresponding acknowledgment. The PAD may reset the virtual call, if it does not support the D bit procedure.

Control information is exchanged via *PAD messages*, which contain a control identifier field and a message code field that may be followed by a parameter field. PAD messages are transferred in the user data fields of complete packet sequences with the Q bit set to 1. Only one PAD message exists per complete packet sequence. The PAD *sends* all data packets with the D bit set to 0. The DTE may send data packets to the PAD with both the D bit and the Q bit set to 1. When the PAD *receives* a data packet with both the Q and D bits set to 1, the corresponding acknowledgment is transmitted. The PAD may reset the virtual call if it does not support the D bit procedure. (Figure 5 shows the bit positions for the Q and D bits.)

The PAD forwards a data packet when a *set*, *read*, or *set and read* PAD message is received or when any of the conditions listed in X.28 exist (e.g., enough data has been received to fill a packet, the maximum assembly timer delay period has elapsed, or a data forwarding character is transmitted). The PAD never forwards an empty data packet.

By sending a *set, read,* or *set and read* message to the PAD, one can read and change the current values of PAD parameters. Upon receipt of one of these messages, the PAD delivers to the DTE any previously received data before it acts on the PAD message. The PAD responds to a *read* or *set and read* PAD message by sending a *parameter indication* PAD message, which contains a parameter field listing parameter references and current values. *Set* allows the changing of parameters.

X.29 also discusses *invitation to clear* procedures, which are used to request that the virtual call be cleared by the PAD; *interrupt and discard* procedures, which are used to indicate that the asynchronous terminal has requested that the PAD discard received user sequences; *reset* procedures, as defined in X.25; *error handling procedures by the PAD,* which define the actions to be taken by the PAD when errors are detected; and *procedures for inviting the PAD to reselect the called DTE* (optional), which are used by a packet mode DTE to request that the PAD clear the virtual call.

X.21 Interface Specifications

The trends in communications engineering lean toward all-digital networks and the integration of voice and data. Prospective users of these digital, integrated networks are concerned about an interface that can provide access to voice, data, video teleconferencing, and related services. Currently, a wide variety of connectors, electrical standards, and user procedures for various services and networks exists—leading to almost insurmountable technical and economical problems. Therefore, it is likely that standards organizations will develop a *universal service access interface*. Although it would require certain extensions, X.21 is currently the most likely to become a future standard for a universal interface in distributed system implementations.

CCITT Recommendation X.21, *Interface Between Data Terminal Equipment (DTE) and Data Circuit-terminating Equipment (DCE) for Synchronous Operation on Public Data Networks*, defines the physical characteristics and control procedures for an interface between DTEs and DCEs.

X.21 is the designated interface for CCITT Recommendation X.25, a packet-switching protocol. X.21 can also be used in a non-packet switched environment. At least two X.21-based public data circuit switched networks are currently implemented, one in Scandinavia and one in Japan.

The X.21 standard has not gained wide acceptance in the United States. The reluctance in the U.S. to embrace the X.21 standard is due in part to the firm entrenchment of RS-232-C. Another factor is the cost of implementing X.21. Since X.21 transmits and interprets coded character strings, more intelligence must be built into the interface, at a higher cost than traditional pin-per-function interfaces.

Certain characteristics of X.21 should ensure a more widespread acceptance in the coming years. One immense advantage X.21 has over traditional interfaces is its capability to assign an almost unlimited number of functions, because there are no functional boundaries associated with connector size. Also, X.21 offers a much more sophisticated level of control over the communications process. Another important feature of X.21 is its inherent dialing functions, including the provision for reporting the reasons why a call was not completed. This eliminates the need for a separate data call interface, such as RS-232-C's companion RS-366-A, and in switched facilities, results in improved response times.

Another important aspect is its relationship to X.25. As the packet-switching technique becomes more widely implemented, the demand will be greater for equipment to meet the X.21 standard. Internationally, the combination of X.21, the ISO HDLC protocol, and X.25 has been used to form an effective communications path. Another boost for X.21 is IBM's recognition.

X.21 has some shortcomings. It does not permit the transmission of control information during data transfer. Also, it precludes the insertion of data encryption hardware between the DTE and the DCE. Another drawback is the need to modify the DTE/DCE master/slave protocol techniques and to supply special crossover cables to facilitate DTE-to-DTE or DCE-to-DCE interconnection.

X.21 uses a different interfacing technique than that which is normally associated with physical-level interfaces. Instead of assigning each function a specific pin on the connector (e.g., CCITT V.24 and EIA RS-232-C), X.21 assigns coded character strings to each function.

The following is a summary of the X.21 standard, including the functional descriptions of the interchange circuits, phases of operation, electrical characteristics, and mechanical characteristics.

Functional Descriptions of Interchange Circuits

Four types of X.21 interchange circuits are defined: Ground, Data Transfer, Control, and Timing. These circuits, outlined in Table 2, are described below.

Ground and Common Return Circuits—include two types of common return circuits, DTE Common Return and DCE Common Return, and one ground circuit, Signal Ground.

Signal Ground (Circuit G) establishes the common reference potential for unbalanced double-current interchange circuits. If required, it reduces environmental signal interference.

Lowering signaling rates may require two common return conductors. In this case, two circuits, *DTE Common Return (Circuit Ga)* and *DCE Common Return (Circuit Gb)*, are necessary. For a further explanation of these circuits, see the Electrical Characteristics section of this report.

Data Transfer Circuits—include two Transmit and Receive data transfer circuits.

Transmit (Circuit T) transfers signals from the DTE to the DCE during the data transfer phase. It also transfers call control signals to the DCE during call establishment and other call control phases.

Receive (Circuit R) receives signals transmitted by the DCE from a remote DTE during the data transfer phase. This circuit also transfers call control signals from the DCE during the call establishment and other call control phases.

Control Circuits—include Control and Indication circuits.

Control (Circuit C) transmits signals that control the DCE for a particular signaling process. The representation of this signal requires additional coding of the Transmit circuit, as specified for the procedural characteristics of the interface. During the data phase, Circuit C remains in the ON condition.

Indication (Circuit I) indicates the call control process to the DTE. The representation of this signal requires additional coding of the Receive circuit. When Circuit I is on, it signifies that signals on the Receive circuit contain information from the remote DTE. When Circuit I is off, it signifies a control signaling condition, defined by the Circuit R bit patterns, as specified by the procedural characteristics of the interface.

Timing Circuits—includes Signal Element Timing and Byte Timing.

Signal Element Timing (Circuit S) provides the DTE with signal element timing information. For this function, Circuit S turns on and off for nominally equal periods of time.

X.21 defines different roles for the DTE and DCE in regard to signal element timing. During the off-to-on transition, the DTE presents a binary signal on Circuit T and a condition on Circuit C. The DCE presents a binary signal on Circuit R and a condition on Circuit I during the off-to-on transition. The DCE transfers the signal element timing across the interface as long as the timing source is capable of generating this information.

Byte Timing (Circuit B) provides the DTE with eight-bit timing information for synchronous transmission. Use of this circuit is not mandatory. Circuit B turns off whenever Circuit S is in the ON condition, indicating the last bit of the eight-bit byte. At all other times within the period of the eight-bit byte, Circuit B remains on.

Phases of Operation

The X.21 standard defines four phases of operation: the Quiescent Phase, the Call Control Phase, the Data Transfer Phase, and the Clearing Phase.

Each step of the operational phases places the DTE and DCE in a certain state. See Table 3 for a listing of these states and their associated signals on the interchange circuits.

Table 2. CCITT X.21 Interchange Circuits

Interchange Circuit	Name	Direction: to DCE	Direction: from DCE	Circuit Type
G	Signal ground or common return			
Ga	DTE common return	X		Ground
Gb	DCE common return		X	
T	Transmit	X		Data Transfer
R	Receive		X	
C	Control	X		
I	Indication		X	Control
S	Signal element timing		X	
B	Byte timing		X	Timing

Quiescent Phase—the quiescent phase is the period during which the DTE and the DCE signal their capability to enter the call control phase or the data transfer phase. It is characterized by the appearance of basic quiescent signals from the DTE and DCE. Various combinations of these quiescent signals result in different interface states, or quiescent states.

There are three DTE quiescent signals. *DTE Ready* indicates the readiness of the DTE to enter the other operational phases. *DTE Uncontrolled Not Ready* indicates the DTE is unable to enter certain operational phases, usually due to an abnormal condition. *DTE Controlled Not Ready* indicates that although the DTE is operational, it is temporarily unable to accept incoming calls for circuit switched service.

There are two DCE quiescent signals: DCE Ready and DCE Not Ready. *DCE Ready* indicates the DCE is ready to enter operational phases. *DCE Not Ready* indicates that no service is available; it is also signaled whenever possible during network fault conditions and during the period when test loops are activated.

Table 3. X.21 States: Names, Signalling, and Transitions

State Number	State Name	Phase of Opera-tion	T	C	R	I	DTE to state number	DCE to state number
			Signals on T,C and R,I Circuits				Transitions*	
1	Ready	Q	1	OFF	1	OFF	2,13S,14,24	8,13R,18
2	Call request	CC	0	ON	1	OFF	—	3,15
3	Proceed-to-select	CC	0	ON	+	OFF	4,15	—
4	Selection signal	CC	IA5	ON	+	OFF	5	—
5	DTE Waiting	CC	1	ON	+	OFF	—	6A,11,12
6A	DCE Waiting	CC	1	ON	SYN	OFF	—	7,10,11,12
6B	DCE Waiting	CC	1	ON	SYN	OFF	—	10 *bis*, 11,12
7	Call progress signal	CC	1	ON	IA5	OFF	—	6A,10,11,12
8	Incoming call	CC	1	OFF	BEL	OFF	15,9	—
9	Call accepted	CC	1	ON	BEL	OFF	—	6B,11,12
10	DCE provided information	CC	1	ON	IA5	OFF	—	6A,11,12
10 *bis*	DCE provided information	CC	1	ON	IA5	OFF	—	6B,11,12
11	Connection in progress	CC	1	ON	1	OFF	—	12
12	Ready for data	CC	1	ON	1	ON	—	13
13	Data transfer	DT	D	ON	D	ON	13R	13S,DCE not ready
13R	Receive data	DT	1	OFF	D	ON	13	1
13S	Send data	DT	D	ON	1	OFF	7	13
14	DTE Controlled not ready, DCE ready	Q	01	OFF	1	OFF	1,24	23
15	Call collision	CC	0	ON	BEL	OFF	—	3
16	DTE Clear request	C	0 (see Note)	OFF	X	X	—	17
17	DCE Clear confirmation	C	0	OFF	0	OFF	—	21
18	DTE Ready, DCE Not ready	Q	1	OFF	0	OFF	22	1
—	DCE Not ready	Q	D	ON	0	OFF	—	1,13,13S
19	DCE Clear indication	C	X (see Note)	X	0	OFF	20	—
20	DTE Clear confirmation	C	0	OFF	0	OFF	—	21
21	DCE Ready	C	0	OFF	1	OFF	1	—
22	DTE Uncontrolled not ready, DCE not ready	Q	0	OFF	0	OFF	18	24
23	DTE Controlled not ready, DCE not ready	Q	01	OFF	0	OFF	18,22	14
24	DTE Uncontrolled not ready, DCE ready	Q	0	OFF	1	OFF	1	22
Any state (see Note)			X	X	X	X	16	19

**All other transitions are considered invalid.*
Note: DCE Clear indication or DTE Clear request may be entered from any state except Ready.

Key to Table:

Q—Quiescent Phase
CC—Call Control Phase
DT—Data Transfer Phase
T—Transmit interchange circuit
C—Control interchange circuit
R—Receive interchange circuit
I—Indication interchange circuit

0 and 1—Steady binary conditions
01—Alternate binary 0 and binary 1
X—Any value
OFF—Continuous off (binary 1)
ON—Continuous on (binary 0)
IA5—Characters from CCITT Alphabet #5
+—IA5 character 2/11
BEL—IA5 character 0/7
SYN—IA5 character 1/6

There are six quiescent states:

- Ready
- DTE Controlled Not Ready, DCE Ready
- DTE Ready, DCE Not Ready
- DTE Uncontrolled Not Ready, DCE Not Ready
- DTE Controlled Not Ready, DCE Not Ready
- DTE Uncontrolled Not Ready, DCE Ready

See Figure 1 for a diagram of the quiescent states and the transitions that are allowed between these states.

Call Control Phase—the call control phase for circuit switched service contains many elements and procedures. Characters used for call control are selected from IA5, a seven-bit plus parity international code outlined in CCITT Recommendation V.3. Each call control sequence to and from the DCE is preceded by two or more continuous SYN characters. For error checking of call control characters, odd parity is specified.

The following elements of the call control procedure are outlined in X.21: events of call control procedures, unsuccessful call, call collision, direct call, and facility registration/cancellation procedure. These elements are summarized below.

The events of the call control procedures include the following:

- *Call Request*, signaled by the DTE to indicate a request for a call.
- *Proceed to Select*, used when the network is prepared to receive selection information. It is transmitted by the DCE to the DTE within three seconds of the call request signal.
- *Selection Signal Sequence*, transmitted by the DTE. A selection sequence consists of a facility request block, an address block, a facility request block followed by an address block, or a facility registration/cancellation block. A facility request block comprises one or more facility request signals, which consist of a facility request code containing one or more facility parameters. An address block contains one or more address signals. Address signals consist of either a full address signal or an abbreviated address signal.
- *DTE Waiting.*
- *Incoming Call*, indicated by the DCE. In response, the DTE signals Clear Request, DTE Uncontrolled Not Ready, or DTE Controlled Not Ready.
- *DCE Waiting.*
- *Call Progress Signal Sequence* is transmitted by the DCE to the calling DTE to indicate that circumstances have arisen to prevent the connection from being established, to report the progress made toward establishing the call, or to signal that problems have been detected and that the call needs to be cleared and reset.
- *DCE-Provided Information Sequence*, transmitted from the DCE to the calling DTE. It consists of DCE-provided information blocks, such as line identification and charging information. Line Identification is transmitted by the DCE to the calling DTE during the DCE-Provided Information state immediately after all call progress signals, if any, are transmitted. Both calling and called line identification are optional. Line identification consists of the international data number, as assigned in CCITT Recommendation X.121, *International Numbering Plan for Public Data Networks.* The DCE transmits Charging Information during the DCE-Provided Information state. It informs the subscriber of either the monetary charges for a call, the duration of the call, or the number of units used during the call.
- *Connection-In-Progress*, indicated by the DCE.
- *Ready for Data*, transmitted by the DCE when the connection is available for data transfer between DTEs.

An unsuccessful call occurs when a required connection cannot be established. In this case, the DCE indicates the failure and its reason to the calling DTE through a call progress signal.

A *call collision* can occur in one of two ways: a DTE detects a call collision when it receives Incoming Call in response to Call Request. A DCE detects a call collision when it receives Call Request in response to Incoming Call. When the DCE detects a call collision, it will indicate Proceed to select and cancel the incoming call.

The DTE indicates a request for a direct call by signaling DTE Waiting after receiving the Proceed to Select signal. If necessary, the DTE may choose an addressed call by presenting the correct Selection signal.

The facility registration/cancellation procedure is optional. A facility registration/cancellation signal consists of up to four elements in order: facility request code, indicator, registration parameter, and address signal. Not all of these elements are required in the facility registration/cancellation signal. Also, a number of these signals may be linked to form a block. In response to acceptance or rejection of the facility registration/cancellation action, the network provides the appropriate Call Progress Signal.

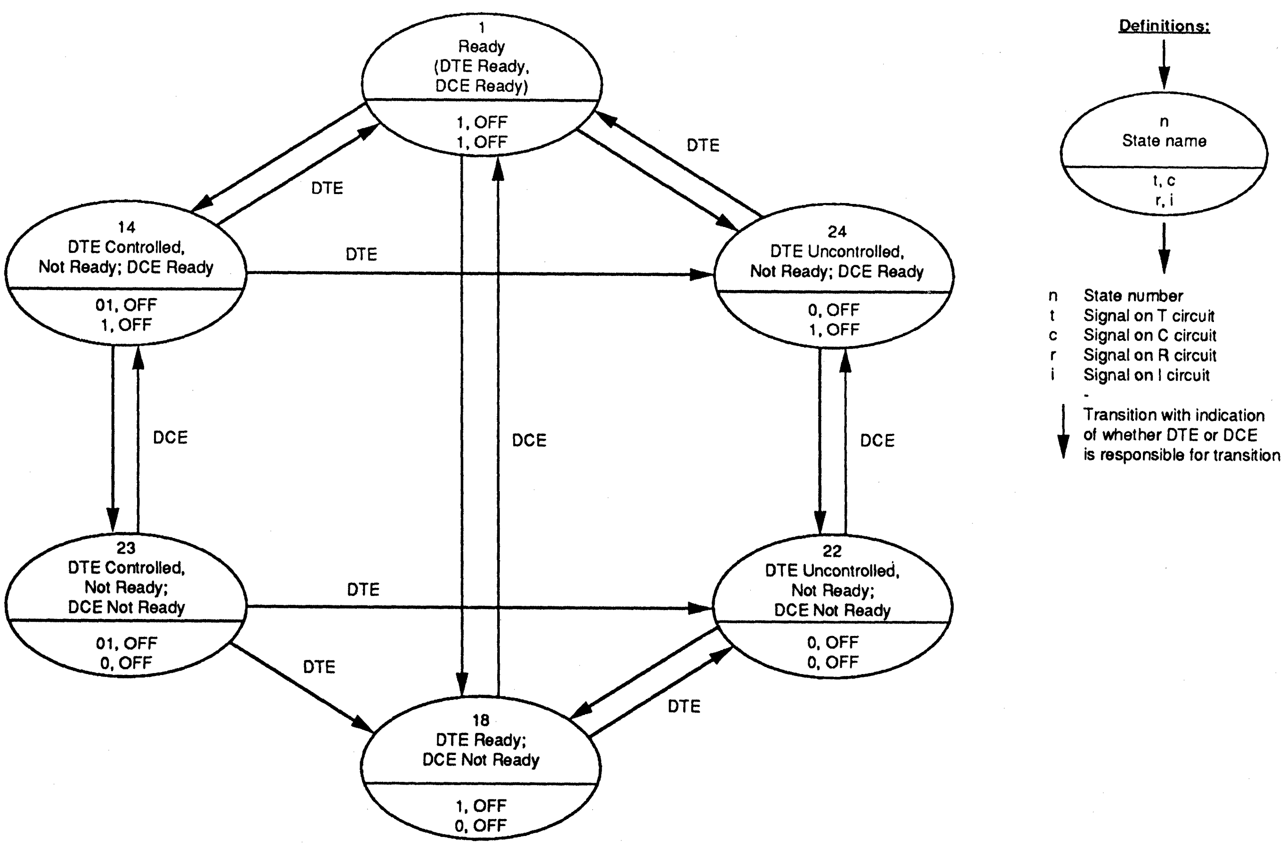
Data Transfer Phase—when the DTE is in the data transfer phase, any bit sequence may be transmitted. X.21 defines the data transfer phase for three types of connections: switched; leased, point to point; and leased, centralized multipoint.

For operation over switched facilities, the DTE may send bits to a corresponding DTE after receiving the Ready for Data signal. During data transfer, control and interchange circuits are in the ON condition, and data is transmitted over the transmit and receive circuits. Data transfer may be terminated by *clearing*, which is defined below.

Two basic signals are used for operation over leased, point-to-point facilities. Send Data transmits data by the DTE on Circuit T; the remote DTE's Receive Data signal receives data over Circuit R. To terminate the data transfer, the DTE signal places its transmit circuit in the binary 1 condition. The DCE indicates termination of data transfer by placing its receive circuit in the binary 1 condition, its control circuit in the OFF condition, and its indications circuit in the OFF condition.

Both the central and remote DTEs use the Send Data and Receive Data signals for operation over leased, multipoint facilities. The central DTE

Figure 1.
Quiescent States



The above diagram indicates transitions that are allowed in X.21 networks. Other transitions are possible and may be allowed in some networks. See Table 3 for a listing of possible transitions.

delivers data transmitted to all remote DTEs; remote DTEs (one at a time) transmit data to the central DTE. A remote DTE may send data to the central DTE while the central DTE is sending to all remote DTEs.

Clearing Phase—either the DTE or the DCE may initiate clearing. The DTE indicates its desire to enter the clearing phase by transmitting DTE *Clear Request.* The DCE responds by signaling DCE *Clear Confirmation*, followed by DCE *Ready.*

Clearing by the DCE takes place when it transmits DCE *Clear Indication.* The DTE responds with the DTE *Clear Confirmation* signal, followed by the DCE signaling *DCE Ready.*

Electrical Characteristics

X.21 uses two types of electrical characteristics, each for different system requirements.

For synchronous operation at 9600 bps and below, the interchange circuits at the DCE side of the interface must comply with CCITT Recommendation X.27. The DTE side can comply with either X.27 or another CCITT Recommendation, X.26. For synchronous operation at signaling rates above 9600 bps, interchange circuits at both the DTE and DCE sides of the interchange circuits must comply with X.27.

X.26 is defined in CCITT Standard V.10. It describes the electrical characteristics for unbalanced interchange circuits. X.26 calls for both a DTE and DCE common grounding arrangement. The maximum suggested cable length is 1,000 meters, and the maximum data rate is 100K bps.

X.27 is defined by CCITT Standard V.11, which describes the electrical characteristics for balanced operation. Maximum suggested cable length is 1,000 meters, and the maximum data rate is 10M bps.

Mechanical Characteristics

The mechanical characteristics for X.21 are outlined in the ISO Standard 4903, approved by the International Organization for Standardization (ISO). The standard, entitled *Data Communication—15-pin DTE/DCE Interface Connector and Pin Assignments*, was published in June 1980.

ISO 4903 assigns connector pin numbers to a 15-pin interface between DTE and DCE equipment. Table 4 presents a chart of these X.21 pin assignments as they relate to the X.26 and X.27 standards.

X.21 Bis

Although X.21 is the specified interface for X.25, alternative interfaces also exist. One of these is X.21 bis.

CCITT Recommendation X.21 bis, the physical and functional equivalent to CCITT V.24, defines 25 interchange circuits between DTEs and DCEs. CCITT V.24 is compatible with EIA Standard RS-232-C. The X.21 bis recommendation, accepted as the interim interface for X.25, will be gradually replaced by X.21 as more equipment is manufactured to meet X.21 specifications.

Recommendation X.25

The development of Recommendation X.25 was stimulated by the need for a standard interface between the packet-switching networks already developed or being developed by many industrial nations and by the requirement that no terminal equipment be denied access to packet switched services.

X.25 is a dynamic standard with many variations in the U.S. and abroad. Currently, X.25-based packet switched networks exist in Australia, Austria, Belgium, Canada, France, Ireland, Germany, Hong Kong, Italy, Japan, Mexico, the Netherlands, Portugal, Singapore, the Soviet Union, South Africa, Spain, Switzerland, the United Kingdom, and the United States. Since X.25 is a dynamic standard with many extensions and optional features, these networks are not totally compatible with one another. Those located in Europe have the highest level of mutual compatibility.

Since the establishment of X.25, additional user-level protocols have been developed. These protocols provide the interfaces between different types of terminals and the X.25 interface. X.3, X.28, and X.29, informally called the Interactive Terminal Interface (ITI), were the first of the protocols to interface to X.25. They relate to the support of asynchronous, low-speed terminals by packet switched networks. These are logical complements to X.25 because they permit specific sets of terminals to interface to the packet networks using the X.25 interface.

The X.25 interface standard provides for the connection of terminals and computers to public packet-switching networks. X.25 outlines three layers of operation: the Physical Layer, the Link Layer, and the Packet Layer. These layers parallel the bottom three layers of the ISO Reference Model for Open Systems Interconnection. The Physical Layer calls for CCITT X.21 as the physical and electrical interface but accepts X.21 bis, a functional equivalent of RS-232-C, as an interim standard. The Link Layer uses the procedures of the HDLC protocol standard. The Packet Layer defines procedures for constructing and controlling a data packet.

The 1984 revision of Recommendation X.25 added specifications for X.21 access and expanded the potential of packet operations, allowing users to actively gain access to the X.25 port, identify themselves, and validate their connection through passwords. This change reoriented the X.25 standard toward switched access through both X.21 facilities and the public telephone network. It now

Table 4. X.21 Pin Assignments

Pin Number		Employing X.26	Employing X.27
1		See Note *(3)*	See Note *(3)*
	9	Ga	T(B)
2		T	T(A)
	10	Ga	C(B)
3		C	C(A)
	11	R(B)	R(B)
4		R(A)	R(A)
	12	I(B)	I(B)
5		I(A)	I(A)
	13	S(B)	S(B)
6		S(A)	S(A)
	14	B(B)	B(B)
7		B(A)	B(A)
	15	Reserved for future use	Reserved for future use
8		G	G

Notes:
(1) X.21 pin assignments are defined by ISO 4903-1980.
(2) Where balanced ciruits are, the associated pairs are designated "A" and "B."
(3) Pin 1 is reserved for connection of the shield or shielded interconnecting cable.

supports X.32 with regard to the public switched telephone network or a circuit switched public data network, dial-in and dial-out access, backup for leased line connections, long-distance access to the network, and teletex.

Datagram was deleted in 1984, while the following packet-level services were made available as options:

- ***Registered Private Operating Agent (RPOA) Selection*** permits the use of one or more networks to route a call to its destination. If the user selects only one network, either the basic or extended format of the RPOA Selection can be used; if more than one network is chosen, the extended format is used.
- ***Call Redirection*** permits the rerouting of calls if the first tried route fails.
- ***Call Redirection Notification*** informs the recipient of the forwarded call that the call has been redirected.
- ***Called Line Address Modified Notification*** tells the caller, within a call confirmation packet, that the call has been redirected.
- ***Hunt Group*** distributes incoming calls that have an address associated with the hunt group.
- ***Charging Information*** gives the caller information on time and charges and requires a new field in the call-clearing packet format.
- ***Local Charging Prevention*** is a security facility that prevents reverse or third-party call charges.
- ***Network User Identification*** accommodates user ID, billing, and on-line facilities registration. This permits users to communicate directly with the packet data network to change the parameters of their subscriptions.

The packet level is an octet-oriented (eight bits per octet) structure. Packet sizes can vary from 1,024 to 2,048 octets, but only within a network. Network-to-network exchange is limited to 128 octets. Closed user group facilities can accommodate very large private-packet networks, although the number of closed user groups to which a DTE can belong is network dependent.

Link-level changes implemented in 1984 created a clear separation between the Link Access Procedure (LAP) and the Link Access Procedure Balanced (LAPB). Multilink procedures for a single interface were also implemented. LAPB underwent an alignment with the single-link procedure of X.75. An extended numbering option (modulo 128) was added to LAPB to enable the sequencing of 127 frames and the use of satellite facilities. In addition, the 1984 revisions to X.25 refined the procedure for the implementation of the D-bit, polished technical accuracy, and defined the rules for new fields and formats.

X.25 Communications

X.25 is titled *Interface Between Data Terminal Equipment (DTE) and Data Circuit-terminating Equipment (DCE) for Terminals Operating in the Packet Mode on Public Data Networks.* It provides a precise set of procedures for communications between DTE and DCE for terminal equipment operating in a packet environment. The DCE in this case is a node processor that serves as an entry/exit point on the packet network side of the user/network interface.

The Data Terminal Equipment (DTE) is a programmable device on the user side of the user/network interface. The DTE is located at the user site when the on-site equipment supports X.25; at such installations, the DTE can be either a computer, a front-end processor, or an intelligent terminal, as shown in Figure 2. The DTE can be a group of intelligent terminals (multiplexed to avoid the use of multiple lines) that transmit data over the packet network to a remotely located host. It can also be a processor acting on calls received from multiple locations that communicate over the packet network.

Regardless of the device or application, all DTEs present standard formatted data and control information to the DCE over standard communications facilities. Devices operate over the network in the virtual circuit mode. Essentially, the user causes the network to establish a logical circuit connection with the receiving station for the transmission of multiple contiguous packets. (The actual physical circuit over which individual packets are transmitted can vary during a session, but the logical circuit ensures presentation of each packet to the receiving station in the proper order.) Information delivery is so rapid that the user appears to have an end-to-end, dedicated channel.

Users who do not support X.25 can access the public data network for packet data transmission; however, they cannot transmit directly to a DCE or network node. They must transmit to a special network-operated PAD, discussed earlier in this report. Terminal transmissions are stored in a buffer at the PAD. There they are assembled into packets and sent to the device at the other end of the virtual circuit. Packets arriving at the PAD from the network are reassembled into the appropriate format before they are sent on to the terminal. The PAD is programmed and configured to interface properly with the protocol and physical characteristics of the user's device. Data presented to the PAD is reformatted into X.25 format and forwarded to the DCE.

Recommendation X.25 is divided into those specifications required for a device or network to comply and those that are optional. Approximately one third are required; the remaining two thirds of the specifications are optional.

The excess throughput capacity inherent in the X.25 standard allows for future network growth and technological progress. For example, a single X.25 interface can theoretically handle 4,095 virtual channels, packet sizes up to 2,048 bytes each, and packet sequencing up to 128 packets per logical channel. Most network suppliers' nodal processors are too small to handle this much traffic through a single interface. Therefore, in practice, the support offered over each interface is limited to the current capacity of the network's access node.

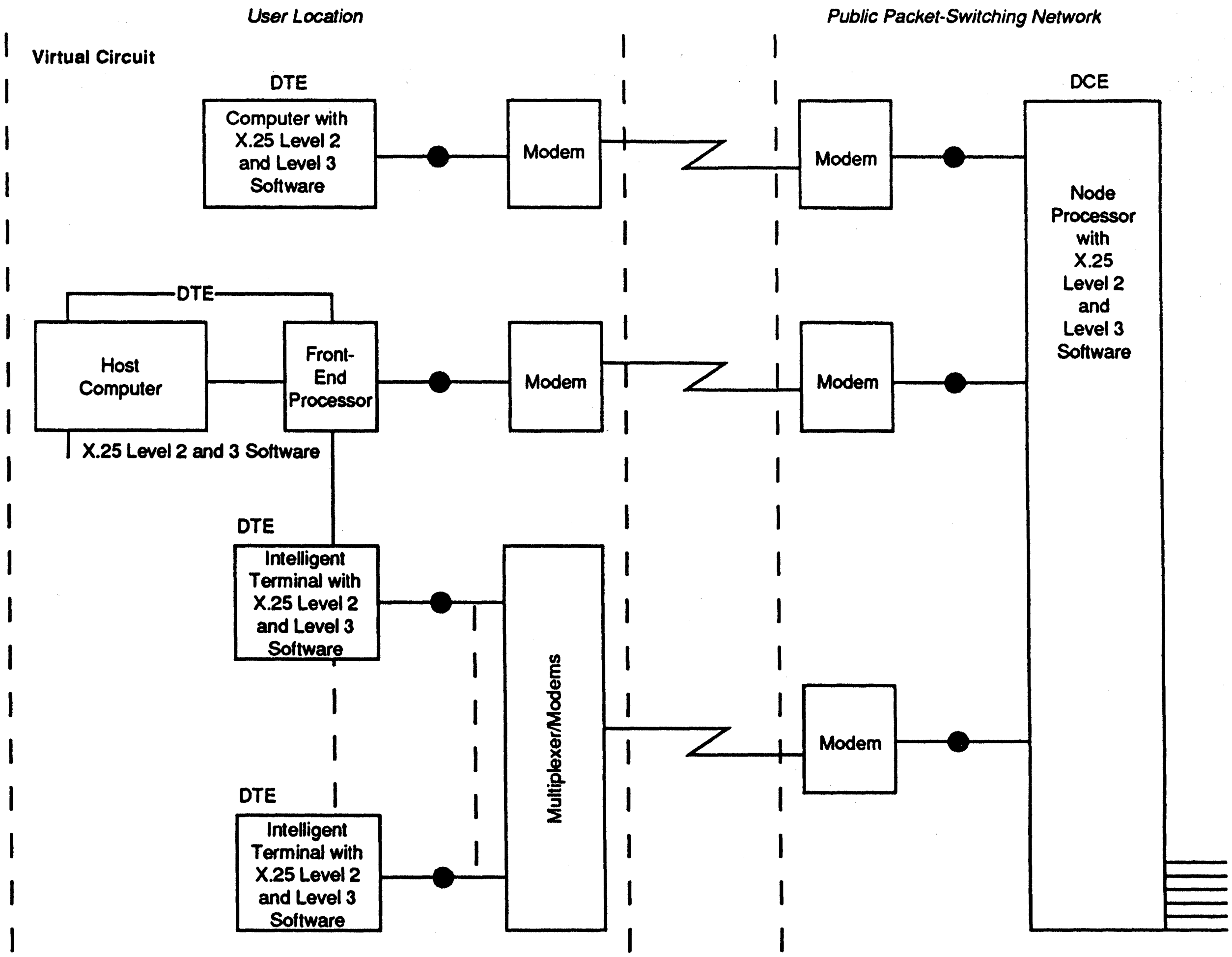
Functional Layers

Recommendation X.25 defines three functional layers: the Physical Layer (Level 1), the Link Layer (Level 2), and the Packet Layer (Level 3). These are consistent with the first three layers of the ISO Reference Model for Open Systems Interconnection (OSI). (Although OSI labels its third layer the Network Layer, its function parallels that of the Packet Layer. Both provide the means to establish, maintain, and terminate connections.)

Level 1: Physical Level—outlines the physical, functional, and electrical characteristics of the DTE/DCE interface. X.21 uses the transmission of coded character strings across a 15-pin connector to define standard interface functions, e.g., Transmit Data. Its specifications are defined in CCITT Recommendation X.21.

Although X.21 is the recommended physical-level interface for X.25, the availability of data communications equipment with X.21 capabilities

Figure 2.
A Sample User Terminal Configuration for Operating on a Public Data Network (PDN) in Packet Mode, with X.25 as the Interface to the Network



● Signifies an interface that must conform to X.25 Level 2, Physical Interface Standards.

is limited, especially in the United States. As a result, the CCITT has accepted an interim recommendation, X.21 bis, as the X.25 physical interface. X.21 bis is functionally equivalent to EIA RS-232-C, which assigns a separate function to each pin across a 25-pin connector.

Level 2*: *Link Level—describes the link access procedures used for data interchange between a DCE and a DTE. In the CCITT Recommendation X.21, *International User Classes of Service in Public Data Networks,* X.25 specifies that the DTE and DCE must operate in the following user classes of service: class 8 (2400 bps), class 9 (4800 bps), class 10 (9600 bps), or class 11 (48K bps). The procedure calls for a full-duplex facility so that the DTE and DCE can conduct two-way, simultaneous, independent transmissions. The procedures use the principles and terminology of the High-level Data Link Control (HDLC) protocol specified by the International Organization for Standardization.

Level 2 comprises three procedures: the Link Access Procedure (LAP), the Link Access Procedure Balanced (LAPB), and the Multilink Procedure (MLP). The original X.25 data link control procedure embraced LAP, which is similar to the HDLC Asynchronous Response Mode (ARM). Due to some incompatibilities with some elements of procedures, Level 2 of the X.25 Recommendation was revised to incorporate LAPB. Similar to the Asynchronous Balanced Mode (ABM) of

HDLC, it provides for a "balanced" configuration; that is, each side of the link consists of a combined primary/secondary station. The Multilink Procedure is used for data transmission on one or more single links. Each link conforms to the X.25-defined frame structure and to the elements of procedure described in LAPB.

Software in both DTE and DCE performs Level 2 processing. This software appends control information onto packets that are ready for transmission, maintains control of the transmissions, performs transmission error checking, and strips a successfully received frame down to a packet. The *packet* consists of packet control information and (optionally) user data; packets are discussed in detail later in this report.

HDLC specifies certain control fields that must be appended to both ends of a packet, resulting in a transmission format called a *frame*. Appended in front of a packet are a beginning Flag field, an Address field, and a Control field. Appended behind the packet are a Frame Check Sequence field and a closing Flag field. Figure 3 gives the size and description of each field. The receiving device uses the two *Flag* fields to ascertain the beginning and ending of a frame. A single Flag field can be used as the closing flag for one frame and the opening flag of the next frame. The *Address* field, under HDLC, is used to identify the station(s) for which the command is intended in command frames or to identify the station sending the response in response frames.

The *Control* field identifies the type of frame and supplies control information pertinent to that type of frame. A frame can be either an Information Frame (I-Frame), a Supervisory Frame (S-Frame), or an Unnumbered Frame (U-Frame). See Table 5 for the encoding of this field.

An Information Frame contains a user packet. The Control field of the I-Frame contains the N(S) transmitter Send Sequence Count, the N(R) transmitter Receive Sequence Count, and the Poll/Final (P/F) bit. N(S) is the sequence number of this frame sent from this transmitter to this receiver. N(R) is the sequence number of the next frame this transmitter expects to get from the receiver when the receiver becomes a transmitter. The Poll/Final bit indicates whether a transmission acknowledgment is required or when the final frame in a stream has been transmitted.

The Supervisory Frame transmits one of three supervisory commands and cannot contain user data. The Control field of the S-Frame contains the command, the P/F bit, and an N(R). Table 6 summarizes the commands and responses possible in the Control field.

The Unnumbered Frame extends the number of link control functions, without incrementing the sequence counts at either the sending or receiving station.

A U-Frame control field contains the Unnumbered command and the P/F bit. One of the U-Frame commands initializes the DTE/DCE network to the Asynchronous Response Mode (ARM) of operation, which permits both DTE and DCE to initiate transmission to each other.

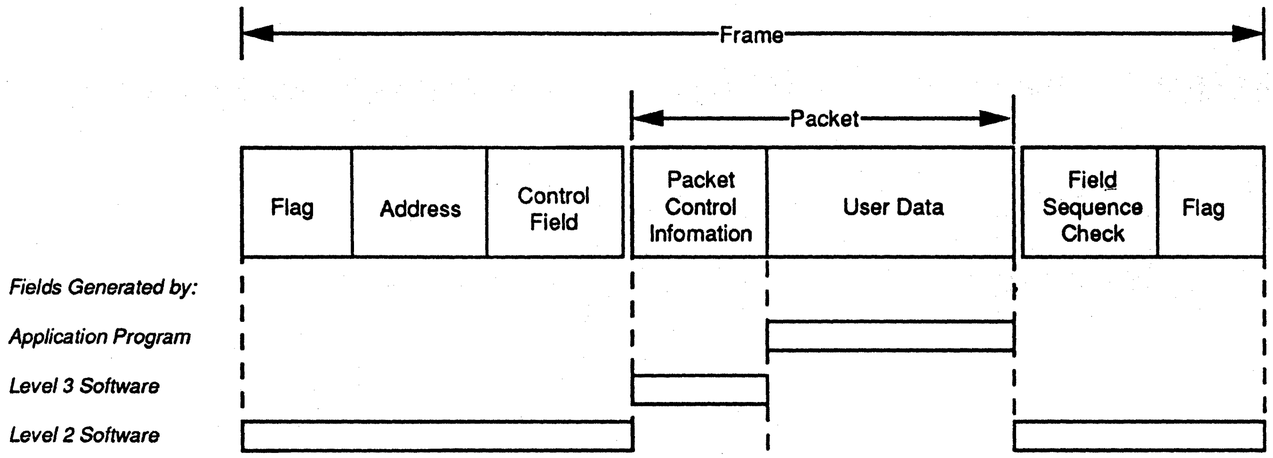
The Frame Check Sequence (FCS) field contains a 16-bit check pattern created at framing time by generating check bits based upon the binary value of the data in the packet. The receiving device performs the same calculation and compares its results with the value that the sending device had placed in the FCS field. If these values do not agree, the frame has a transmission error and is discarded. Discarding causes the receiving device to send an S-Frame with the Reject Recovery command. This S-Frame contains the frame numbered N(R), thus acknowledging receipt of all frames numbered N(R)-1 and below, and initiates retransmission of frames N(R) and above.

In effect, Level 2 envelops the packet in control information and prescribes procedures that ensure a high degree of transmission accuracy and detection of lost frames during transmission.

Level 3*: *Packet Level—describes the packet format and control procedures for the exchange of packets between the DTE and the DCE. In addition to the user data packet format, there are several formats for DTE/DCE administrative messages.

The software for formatting packets and controlling packet exchange is the Level 3 software resident in both the DTE and the DCE. Figure 4 shows the relationship of Level 3 and Level 2 software operating in the DTE and the DCE. In the DTE, a user application program normally presents the data to be transmitted to the operating system's communications access method. The access method invokes Level 3 software to append the packet header information, then invokes Level

Figure 3.
Frame Formats for Packet Mode Transmission



Field	Size, bits	Description
Flag	8	Value is 01111110.
Address	8	Value for DTE to DCE command frame is "10000000". Value for DTE to DCE response frame is "11000000". Value for DCE to DTE command frame is "11000000". Value for DCE to DTE response frame is "10000000".
Control	8	I Frame: Bit 1 is "0". Bits 2, 3, 4, are N(S) (transmitter send sequence count). Bit 5 is P/F (Poll/Final) bit. Bits 6, 7, 8 are N(R) (transmitter receive sequence count). S Frame: Bit 1 is "1". Bit 2 is "0". Bits 3, 4 identify Supervisory Command. Bit 5 is P/F (Poll/Final) bit. Bits 6, 7, 8 are N(R) (transmitter receiver sequence count). U Frame: Bit 1 is 1. Bit 2 is 1. Bits 3, 4 are *first* part of Unnumbered Frame Command identifier. Bit 5 is P/F (Poll/Final) bit. Bits 6, 7, 8 are second part of Unnumbered Frame Command identifier.
Packet Control	24	Control information.
User Data	1,024	1,024 data bits are normal maximum; exceptional maximum is 2,040 data bits
Field Sequence Check	16	Check bits for user data.
Flag	8	Value is "01111110".

2 software to create the frame. Packet header formats are discussed below.

Once the frame is created, it is ready for transmission. Upon receiving the frame, the receiving DCE invokes Level 2 software to perform error detection and sequence checking and to strip the accepted frame down to a packet. The packet is presented to Level 3 software for packet-level processing and to prepare the packet for transmission to the destination DCE. The physical address of

Table 5. X.25 Level 2 Commands and Responses

Format	Commands (1)		Responses		Encoding of Control Field 1	2	3	4	5	6	7	8
Information transfer	I	(information		0			N(S)		P		N(R)	
Supervisory	RR *(3)*	(receive ready)	RNR	(receive not ready)	1	0	0	0	P/F		N(R)	
	RNR *(3)*	(receive not ready)	RNR	(receive not ready)	1	0	1	0	P/F		N(R)	
	REJ *(3)*	(reject)	REJ	(reject)	1	0	0	1	P/F		N(R)	
Unnumbered	SARM *(2,3)*	(set asynchronous response mode)	DM *(2)*	(disconnected mode)	1	1	1	1	P/F	0	0	0
	SABM *(2)*	(set asynchronous balanced mode)			1	1	1	1	P	1	0	0
	DISC	(disconnect)			1	1	0	0	P	0	1	0
			UA	(unnumbered acknowledgment)	1	1	0	0	F	1	1	0
			CMDR FRMR	(command reject) (frame reject)	1	1	1	0	F	0	0	1

Note 1: The need for, and use of, additional commands and responses are for further study.
Note 2: DTEs do not have to implement both SARM and SABM, furthermore DM and SABM need to be used if SARM only is used.
Note 3: RR, RNR and REJ supervisory command frames are not used by the DCE when SARM is used (LAP).

the destination DTE, derived from the call initiation, is inserted into the packet during Level 3 processing. At the network destination DCE, Level 3 software reformats the packet control information and presents the resulting packet to Level 2 software; Level 2 software includes the packet in a frame for transmission to the destination DTE (user). At the destination DTE (user), Level 2 software performs error detection and sequence checking and strips accepted frames down to the packet. Level 3 software is then applied to the packet to strip the header information from the packet and pass the user information to the appropriate application program via the communications access method. Table 7 summarizes the types of packets exchanged between terminals.

The Packet Header consists of three octets. In Octet 1, the first four bits represent the Logical Channel Group Number, and the final four bits represent the General Format Identifier. Octet 2 represents the Logical Channel Number, and Octet 3 represents the Packet Type Identifier. See Figure 5.

Table 6. Summary of Packets Exchanged between Terminals during a Virtual Call

Events	Activity at Calling DTE	Activity at Called DTE
Call Initiation	Call Request packet is sent	Incoming Call packet is received Call Accepted packet is sent
	Call Connected packet is received	
Data Transfer	Data packet sent	Data packet received Ready Receive packet sent
	Ready Receive packet received Data packet A sent* Data packet B received*	Data packet B sent* Data packet A received*
Disconnect	Clear Request packet sent	Clear Indication packet received Clear Confirmation packet sent
	Clear Confirmation packet received	

**Two-way (full-duplex) transmission of data packets between terminal equipment.*

The *Logical Channel Group Number* and the *Logical Channel Number* provide the routing information that directs the packet over one of the logical channels. The numbering system for the logical channels is dynamic and refers to a switched data path within the packet network.

The *General Format Identifier* indicates the general format of the rest of the header. Specific bit patterns are established for the following: call setup packets; clearing, flow control, interrupt, reset, restart, and diagnostic packets; and data packets.

The *Packet Type Identifier* establishes the packet's function. Examples of functions include call setup, priorities, and data. If applicable, it may identify the packet's place in sequence. See Table 7 for the various packet types.

Packet-Level Procedures

X.25 Level 3 defines procedures for call initiation, data transfer, interrupts, reset, restart, and clearing. Some of these procedures are summarized below.

Call Initiation: The Level 3 software in a DTE initiates a transmission by sending a Call Request packet. This packet enables the calling DTE to request the opening of a logical channel. The calling DTE designates the channel number based upon the original assignments that were made when the user subscribed to the network. The Call Request packet also informs the network of the calling DTE's address and of the called DTE's address. Until the call is disconnected, the network retains the addresses of both devices associated with the logical channel number. Therefore, each data packet that is transmitted needs to contain only the logical channel number. The network appends the destination address just before routing the packet. At the time the Call Request is issued, the logical channel indicated by the calling DTE must be in a Ready state, that is, not being used to handle another call. Upon receipt of the Call Request by the called DTE, the specified logical channel is designated as being in the DTE Waiting state. The packet is then transmitted to the destination DCE.

The destination DCE transmits an Incoming Call packet to the originating DTE and places the logical channel in the DCE Waiting state.

The called DTE indicates its willingness to accept the call by transmitting a Call Accepted packet across the DTE/DCE interface. The Call Accepted packet specifies the same logical channel that is indicated by the Incoming Call packet. This places the specified logical channel in the Data Transfer state. (The logical channel at the calling DCE is still in the Wait state.)

Figure 4.
X.25 User and Network Software Relationships

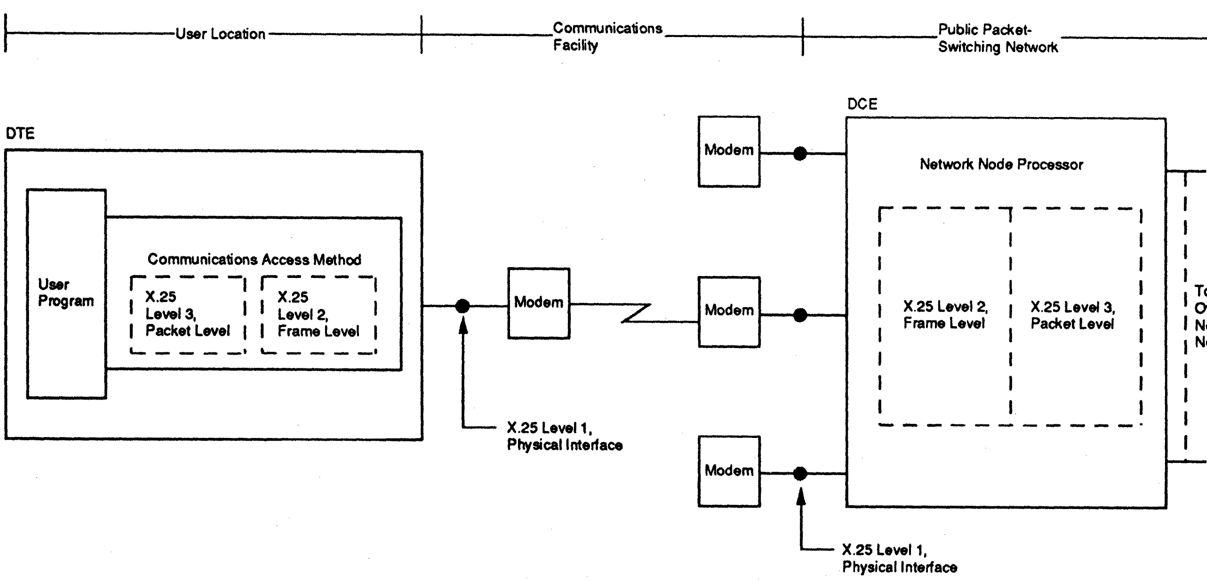
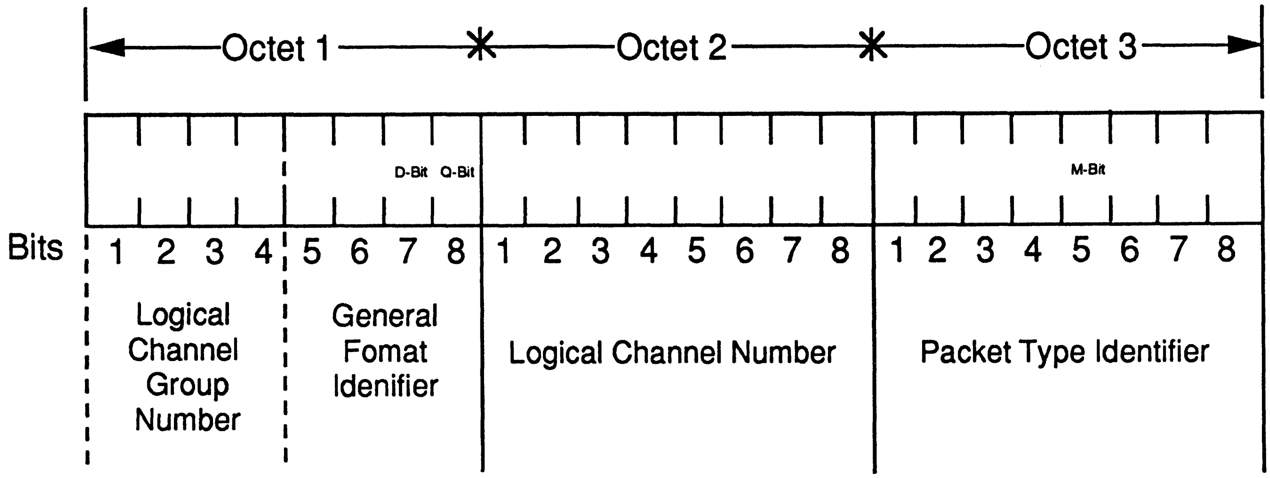


Figure 5.
X.25 Packet Header Format



A Call Connected packet is then sent by the DCE to the calling DTE and sets the logical channel status to the Data Transfer state; the logical channel is then ready for transfer of data packets. This applies only for virtual circuit connections; for permanent virtual circuit connections, the assigned logical channels are always in the Data Transfer state.

It is possible for a DCE to receive a Call Request (from a DTE) and an Incoming Call (from the network) simultaneously, with both messages specifying the same logical channel. This is called a call collision; when a collision occurs, the DCE cancels the Incoming Call and proceeds to process the Call Request.

Data Transfer: Once the logical channel is in the Data Transfer state, data, flow control, or reset information packets can be transmitted.

The Data packet format includes the packet send and receive sequence numbers. The calling DTE can transmit up to a predetermined number of packets before requiring a response. This number is referred to as the window. All packet networks must accommodate a lower window edge of at least eight, permitting at least seven packets to be outstanding before an acknowledgment is required. The upper window value (the maximum number of outstanding packets) may not exceed 127 (modulo 128).

Upon receipt of an authorized packet, the receiving device can either authorize additional transmission by transmitting a Receive Ready packet to the sending device or deny authorization to transmit by issuing a Receive Not Ready packet.

When transmitting Data packets, the Interrupt packet can bypass flow control (authorization procedures). A DTE can transmit an Interrupt packet to another DTE. To avoid swamping the receiver with Interrupt packets, the sender cannot send a second Interrupt packet until the first Interrupt packet is acknowledged by an Interrupt Confirmation packet.

While Data packets or Interrupt packets are being transmitted, issuing a Reset Request packet can reset the call. A DCE initiates a reset by issuing a Reset Indication packet. In either case, the logical channel is placed in the Data Transfer state. Any Data, Interrupt, Receive Ready (RR), or Receive Not Ready (RNR) packets in the network at the time of reset are ignored. If a DTE and DCE transmit Reset packets simultaneously, a reset collision occurs. The net effect is to place the logical channel in the Data Transfer state, ready for Data and Interrupt packets.

A DTE or a DCE initiates a request for clearing (disconnecting) a logical channel. Upon confirmation by the other device, the logical channel is placed in the Ready state.

Error Handling (Packet Level): When an error occurs, the DCE transmits Reset, Clear, and Restart indication packets to the DTE. *Reset* reinitializes a virtual call or permanent virtual

Table 7. Packet Types and Their Use in Various Functions

Function	Packet Type: From DCE to DTE	Packet Type: From DTE to DCE	Service: Switched Virtual Circuit	Service: Perm. Virtual Circuit
Call Setup and Cleaning	In Incoming Call	Call Request	X	
	Call Connected	Call Accepted	X	
	Clear Indication	Clear Request	X	
	DCE Clear Confirmation	DTE Clear Confirmation	X	
Data and Interrupt	DCE Data	DTE Data	X	X
	DCE Interrupt	DTE Interrupt	X	X
	DCE Interrupt Confirmation	DTE Interrupt Confirmation	X	X
Flow Control and Reset	DCE RR (Receive Ready)	DTE RR	X	X
		DTE RNR	X	X
	DCE RNR (Receive Not Ready)	DTE REJ*	X	X
		Reset Request	X	X
	Reset Indication			
	DCE Reset Confirmation	DTE Reset Confirmation	X	X
Restart	Restart Indication	Restart Request	X	X
	DCE Restart Confirmation	DTE Restart Confirmation	X	X
Diagnostics	Diagnostics		X	X

circuit. Reset removes all Data and Interrupt packets on the logical channel and resets the lower window edge to zero. It affects only one logical channel number (one user). Reset procedures, which apply only in the Data Transfer state, handle specific error events, such as local procedure error, remote procedure error, network congestion, incompatible destination, network out of order, etc. *Clear* affects only one logical channel number (one user). It clears a session when, for example, the host or host link crashes. In this case, the network initiates Clear procedures on the terminal link. It effectively logs off the terminal user. Clear resets the lower window edge to 0. *Restart* affects all users (all logical channels on a given link) and clears all calls on that link. Restart is used when a failed link returns to service; it makes sure that all calls were cleared when the link went down. Restart also is used when either side (DTE or DCE) reports error conditions at the packet level; the good side initiates the restart procedures.

In some networks, a *diagnostic* packet indicates unusual error conditions. A diagnostic packet from the DCE provides information on events that are considered unrecoverable at the packet level; the information permits the DTE to analyze and initiate recovery by higher levels. No confirmation is required on receipt of a diagnostic packet.

Implementation Considerations for Users

X.25 recognizes that DTEs differ in their degree of sophistication. A simple DTE may have fixed packet formats and built-in parameter values, while a sophisticated DTE may work with varying packet formats and provide variable parameters to take advantage of the many network functions and signaling capabilities offered.

At the physical level, the transmission rate DTE uses to access an X.25 network should be governed by the throughput and response time requirements of the user. Factors to consider include the maximum number of virtual circuits operating simultaneously and traffic characteristics of throughput-critical and response-time-critical virtual circuits.

At the link level, Link Access Procedures (LAPs) and Link Access Procedures Balanced (LAPBs) are defined. A DTE might implement only LAPB. Parameters that are part of the LAPB procedures can be set to constants for all network connections. For example, a timer (T1) may be set according to the slowest required line speed; a constant such as three seconds may be used. Also, the maximum permitted number of unacknowledged I-Frames (information frames) may be determined. The network provider must agree to this. All networks support a window of at least seven I-Frames.

The maximum packet size (number of bits) of the I-Frame must also be established.

If the DTE handles certain character sizes (octets), the frame level should be capable of accommodating any number of bits correctly (generate acknowledgment, calculate frame check sequence). How such a properly received frame is processed depends on the individual system and may include actions such as discarding the frame, padding it, clearing the call, or resetting.

Connections between Packet Switched Data Networks

CCITT Recommendation X.75 describes the procedures for the interconnection of packet switched networks. Many public packet switched data networks support X.75 procedures, including AT&T Accunet, TransCanada's Datapac, Graphnet Freedom Network II, US Sprint's SprintNet, and WangPac networks.

X.75 is similar to X.25 in that it specifies procedures for the physical, link, and packet levels. Signal Terminal Equipment (STE), which acts as a bridge node between networks, implements X.75 procedures. A related standard, CCITT X.121, defines the international numbering plan for public data networks.

Recommendation X.75

Recommendation X.75, *Terminal and Transmit Call Control Procedures and Data Transfer System on International Circuits Between Packet-Switched Data Networks*, provides the rules for transmitting data between different data networks. The basic system structure is made up of communicating elements that function independently. These elements include the physical circuits, which comprise links A1 or G1 (as defined in X.92), and a set of mechanical, electrical, functional, and procedural interface characteristics; packet transfer procedures, which operate over the physical circuits and provide for the transport of packets between STEs; and packet signaling procedures, which use the packet data transfer procedures and provide for the exchange of call control information and user traffic between STEs. Figure 6 shows the basic system structure of the signaling and data transfer procedures. The international link is assumed to be data link A1 and/or data link G1 as defined in Recommendation X.92. The international link should be capable of supporting full-duplex operation.

Link-level packet transfer procedures between STEs consist of the Single Link Procedure (SLP) and the Multilink Procedure (MLP). The SLP is used for data interchange over a single physical circuit between two STEs. When multiple physical circuits are used in parallel, the SLP is used independently on each circuit. The MLP is used for data interchange over multiple parallel links. The MLP may be used over a single link when the communicating parties agree to this procedure. Transmissions are full duplex. SLP is based upon the Link Access Procedure Balanced (LAPB) as described in X.25 and uses the principle and terminology of the International Organization for Standardization's (ISO's) High-level Data Link Control (HDLC). For SLP, either modulo 8 (non-extended mode) or the modulo 128 (extended mode) may be used. The MLP is based on the multilink procedures specified by the ISO and performs the functions of distributing packets across available SLPs.

Three channel states are defined: the link channel state, which provides transmission in one direction; the active channel state, which means that the incoming or outgoing channel is receiving or transmitting a frame; and the idle channel state, which means that the incoming or outgoing channel is receiving or transmitting at least 15 contiguous 1 bits.

Data is transmitted in frames. Each frame must contain an Opening Flag (8 bits), an Address field (8 bits), a Control field (8 bits), a Frame Check Sequence (FCS) field (16 bits), and a Closing Flag (8 bits). An Information field of an unspecified number of bits, which follows the Control field, is optional.

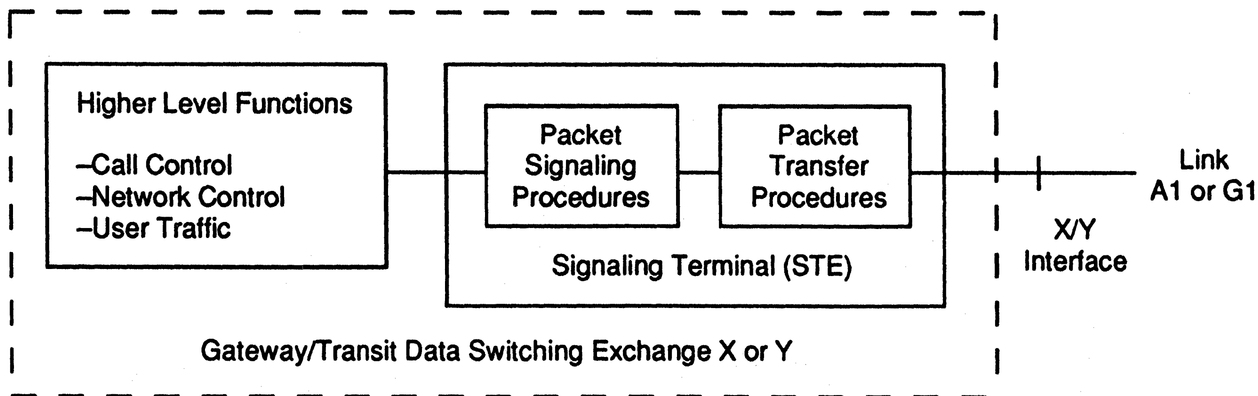
The Control field contains a command or response, and sequence numbers if applicable. Control field formats may be one of three types: numbered information transfer (I format), numbered supervisory functions (S format), and unnumbered control functions (U format). The I format performs information transfer functions. The S format performs link supervisory control functions, such as acknowledging I frames, requesting transmission of I frames, and requesting a temporary suspension of transmission of I frames. The U format provides additional link control functions.

Each I frame is numbered sequentially. The send state variable V(S) represents the sequence number of the next in-sequence I frame to be transmitted. The value of the V(S) is incremented by one with each successive I frame transmission but cannot exceed N(R) of the last received I or S format frame by more than the maximum number of outstanding frames. The send sequence number N(S), contained only in I frames, is set equal to the value of V(S). The receive state variable V(R) represents the sequence number of the next in-sequence I frame expected to be received. The value of V(R) is incremented by one when an error-free, in-sequence I frame whose N(S) equals V(R) is received. Both I frames and S frames contain the receive sequence number N(R). N(R) is the expected send sequence number of the next received I frame. When the STE transmits N(R), it indicates that all I frames numbered up to and including N(R)-1 have been received correctly.

All frames contain the Poll/Final (P/F) bit, which is referred to as the P bit in command frames and the F bit in response frames. The STE solicits a response from another STE by setting the P bit to 1; the answering STE responds by setting the F bit to 1. The following commands and responses are supported:

- ***Information (I) command***—transfers sequentially numbered frames that contain an information field;
- ***Receive ready (RR) command and response***—used by the STE to indicate that it is ready to receive an I frame or to acknowledge a previously received I frame;
- ***Receive not ready (RNR) command and response***—used by the STE to indicate a busy condition;
- ***Reject (REJ) command and response***—used by the STE to request retransmission of I frames beginning with frame numbered N(R);
- ***Set asynchronous balanced mode (SABM) command***—an unnumbered command used to set the addressed STE in the asynchronous balanced mode information transfer phase; all command/response control fields are one octet (eight bits);
- ***Set asynchronous balanced mode extended (SABME) command***—an unnumbered command used to set the addressed STE in the asynchronous balanced mode information transfer phase; all numbered command/response control fields are two octets; all unnumbered command/response control fields are one octet;
- ***Disconnect (DISC) command***—terminates the previously set mode; DISC indicates that the STE transmitting DISC is suspending operation;

Figure 6.
Basic System Structure of X.75 Signaling and Data Transfer Procedures



- ***Unnumbered acknowledge (UA) response***—used by the STE to acknowledge mode-setting commands;
- ***Disconnected mode (DM) response***—reports STE status when it is logically disconnected from the link and is in the disconnected phase; and
- ***Frame reject (FRMR) response***—indicates an error condition that is not recoverable by retransmission of the frame.

Packet-level signaling procedures relate to the transfer of packets at the STE-X/STE-Y (X/Y) interface. Recommendation X.75 specifies signaling procedures for virtual call setup and clearing, for permanent virtual circuit service, for data and interrupt transfer, for flow control, and for reset.

Logical channels are used to complete simultaneous virtual calls and/or permanent virtual circuits. A logical channel group number and a logical channel number (in the range 0 to 15 inclusive and 0 to 255 inclusive, respectively) are assigned to each virtual call and permanent virtual circuit. The logical channel group number and the logical channel number are contained in each packet type, except restart packets.

The procedures for virtual call setup and clearing are used only when a logical channel is in the *packet level ready* (RL) state. If call setup is possible, and no call or call attempt exists, the logical channel is in the *ready* (PL) state (within the RL state). Call setup is initiated when the STE sends a *call request* packet across the X/Y interface. The call request packet specifies a logical channel in the PL state. The logical channel is then placed in the call request state. The called STE indicates acceptance by the called DTE by sending a *call connected* packet across the X/Y interface. It specifies the same logical channel as that requested by the call request packet. The logical channel is then placed in the *flow control ready* (DL) state within the *data transfer* (P4) state.

A logical channel (in any state) can be cleared when the STE sends a *clear request* packet, which specifies the logical channel, across the X/Y interface. Upon receipt of a clear request packet, STE-X or STE-Y frees the logical channel and transmits a *clear confirmation* packet that specifies the same channel. This places the logical channel in the ready state within the RL state. Permanent virtual circuits require no call setup or clearing.

Data transfer procedures apply independently to each logical channel at the X/Y interface. In the *data transfer* (P4) state, *data, interrupt, flow control*, and *reset* packets may be sent and received by the STE. The data transfer state exists within the packet-level ready state of a logical channel. Each data packet contains a sequence number called the packet send sequence number P(S); only data packets contain the P(S).

The procedures for flow control and reset apply only in the data transfer state. Flow control applies to data packets. A window is defined for each direction of transmission at the X/Y interface. The lowest number in the window is called the lower window edge. The maximum window edge does not exceed modulo 8 or 128, is unique to each logical channel, and is reserved for a period of time. For a particular call, two window sizes, one for each direction of transmission, may be selected. The packet receive sequence number P(R) (modulo 8 or 128) conveys information from the receiver for the transmission of data packets. The P(R) becomes the lower window edge when transmitted across the X/Y interface, thereby authorizing additional data packets to cross the X/Y interface.

Reset procedures are used to reinitialize a single call and apply only in the data transfer state. The STE sends a *reset request* packet that specifies the logical channel to indicate a request for reset. The logical channel is placed in the reset request state. The requested STE confirms by sending a *reset confirmation* packet, which places the logical channel in the *flow control ready* state.

Restart procedures are used to clear all calls simultaneously. When the STE sends a *restart request* packet, the X/Y interface for each logical channel is placed in the restart request state. In this state all packets, except restart request and restart confirmation packets, are discarded by the X/Y interface. An STE confirms by sending a *restart confirmation* packet, which places all channels in the ready state.

Packet formats are based on the general structure of packets as defined in X.25.

Trends in Packet Switching

Support for packet switching has grown among U.S. manufacturers of data processing and data communications equipment in recent years. For example, nearly all major computer vendors have incorporated X.25 interfaces into their network architectures. This is part of an overall trend in accepting international standards and the increasing availability of products conforming to these standards.

The CCITT published revisions to the X Series standards in 1984 and in 1989. Since that time, the ratification and publication of revisions has become a continuous, ongoing process. Since the major building blocks for X.25 were laid by 1984, all subsequent changes have been, and will continue to be, relatively minor. Some post-1984 changes have revolved around efforts to make CCITT X Series standards compatible with those of the International Organization for Standardization (ISO). Currently, discussions on how to provide greater interoperability between various X.25 networks is taking place. Major developments in packet switching today, however, center not around X.25, but around the development of new ISDN-related technologies, such as fast packet switching and frame relay, which support the integration of voice, video, and data and much higher transmission speeds. This section discusses post-1984 changes to X.25 and its relationship to ISDN.

Major Changes in 1988 Revisions

In the 1988 revised standards, there were no changes at the physical and link levels. At the packet level, however, a new facility for redirecting calls, *Call Deflection*, was established. In 1984, the CCITT had made available a new Call Redirection facility, allowing the network to redirect *all* calls destined for a given address. This redirection could occur when the destination was out of order or busy, or it could be based on time of day or other criteria. The 1988 facility extended this capability, allowing the destination subscriber to clear incoming calls to another party on a call-selective basis. The Clear Request packet contains the Call Deflection information that profiles the desired alternate party.

Relationship between CCITT and ISO Efforts

CCITT X.25 packet-level protocol specifies a virtual circuit service; the ISO has issued a compatible version of the packet standard, ISO 8208. In recent years, CCITT and ISO organizations have worked on standards to carry longer addresses in the DTE field to facilitate interworking with ISDN (E.164).

In 1988, the CCITT also modified the Address Extension facilities to be consistent with ISO address length. Previously, a provisional 32-decimal/16-octet field had been recommended; this address length was increased to 40 decimals/20 octets. The ISO also added these address recommendations to Addendum 2 of ISO 8348 (Connection-Mode Network Service); the CCITT adoption is X.213.

Connectionless Issues: Relationships with ISO Efforts

At any layer of the Open Systems Interconnection (OSI) Reference Model, two basic forms of operation are possible: connection oriented and connectionless. Connection-oriented service involves a connection establishment phase, a data transfer phase, and a connection termination phase. A logical connection is set up between end entities prior to exchanging data. In a connectionless service, typical of local area networks, each packet is independently routed to the destination. No connection establishment activities are required since each data unit is independent of the previous or subsequent one. Each transmission mode has a niche where it represents the best approach. For example, file transfers may benefit from a connection-oriented service, while point-of-sale inquiries may be best served by a connectionless service.

Traditionally, the CCITT has pursued a connection-oriented philosophy, while ISO has shown interest in connectionless. While the original OSI standard, ISO 7498, is connection oriented, ISO saw the need to provide connectionless service by issuing an addendum to that protocol, ISO 7498/DAD1. ISO has issued a standard for connection-mode network service (ISO 8348), while the CCITT has issued an identical service, X.213. In regard to X.25 itself, however, ISO has decided not to pursue the connectionless service, formerly known as "datagram" service. X.75 is also a connection-oriented service; ISO has shown considerable interest in a connectionless internetworking protocol (IP) and has developed the ISO 8473 to accommodate it.

Packet Switching in ISDN

The goal of the Integrated Services Digital Network (ISDN) is to provide an end-to-end digital path over a set of standardized user interfaces, giving the user the capability to signal the network through an out-of-band channel. (In contrast, in X.25, the user signals the network in in-band fashion by issuing packets such as CALL REQUEST, CALL ACCEPTED, etc.)

Currently, different types of interfaces to the telephone network exist for different services. These interfaces include two-wire switched, two-wire dedicated, four-wire dedicated, DDS, and so forth. ISDN will provide a small set of interfaces that can be used for multiple applications. The CCITT has defined the following interfaces for ISDN:

- 2B+D—two 64K bps channels and a 16K bps packet/signaling channel (also called the Basic Rate Interface).
- 23B+D—twenty-three 64K bps channels and a 64K bps packet/signaling channel (also called the Primary Rate Interface).
- 3H0+D—three 384K bps channels and one 64K bps packet/signaling channel.
- H11—nonchannelized 1.536M bps.
- H12—nonchannelized 1.920M bps.
- Multislotted—multiples of 64K bps channels (up to 1.536M bps) under the customer's control.
- Broadband—high data rates, based on an approach called synchronous optical network (SONET), building on multiplex of 51.84M bps. SONET standards negotiations began in 1986. The CCITT approved phase I of the standards in 1988 and phase II in 1989. This architecture has been called Broadband ISDN, in contrast to the other interfaces that have been considered part of Narrowband ISDN.

With the exception of Broadband ISDN, all of the above interfaces could be carried on unloaded copper loops. Using fiber has also been considered, as it would make the local loop more robust. Out-of-band signaling makes possible a new class of services. In addition, the 16K bps D-channel will be connected directly to the BOC's packet switched network, providing the subscriber with the data multiplexing advantages packet switching offers. A major effort is under way in Europe to bring the system to market. In the United States, several trials have been undertaken, and limited ISDN service is already available.

CCITT ISDN Standards

ISDN provides a specific protocol that users can employ to signal the network. Currently, a three-layer protocol suite is defined. At the Basic Rate, the Physical Layer manages a 192K bps, full-duplex bit stream using time-compression techniques and time division methods to recover the two B-channels and one D-channel. The remaining 48K bps stream is used for Physical Layer control information. The defined standards are I.420 (Basic Rate Interface Definition), I.430 (Basic Rate Interface Layer 1), I.421 (Primary Rate Interface Definition), and I.431 (Primary Rate Interface Layer 1).

The Data Link Layer is not defined for transparent B-channels used for circuit switched voice or data, but it is defined for the D-channel. For Narrowband ISDN, the D-channel employs a LAP-D Link Layer protocol, which is a subset of the ISO HDLC Data Link protocol, as specified in CCITT Recommendations Q.920 (I.440) and X.921 (I.441). It provides statistical multiplexing for three channel types: signaling information for the management of the B-channels; packet switched service over the D-channel; and optional channels, used for telemetry of other applications.

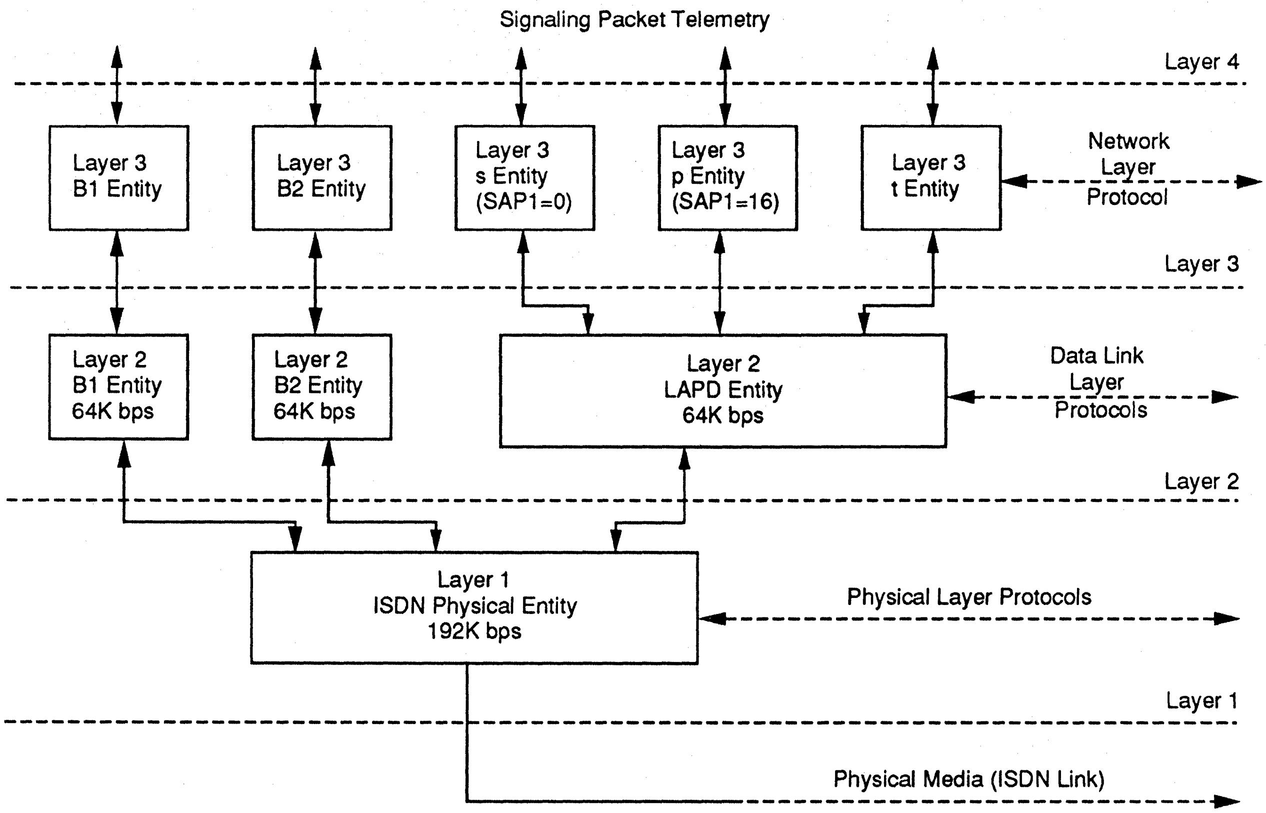
The Network Layer protocol for the signaling channel is specified in CCITT's Q.930 (I.450) and Q.931 (I.451) specifications. It provides the mechanism for establishing and terminating connections on the B-channels and other network control functions. For the packet switched service over the D-channel, the Network Layer protocol is X.25. CCITT will define Layer 3 protocols for the optional channels in the future, or they will be specified as national options.

A technique is required for specifying whether user-to-network signaling, user packet data, or user telemetry data is being sent over the D-channel. This technique involves the use of a **service access point identifier (SAPI).**

Each layer in the OSI Reference Model communicates with the layers above and below it across an interface. The interface is through one or more service access points (SAPs). SAPs have a number of uses, including subaddressing for internetworking situations, Transport Layer applications, and for user data packet service over an ISDN D-channel.

Considering the applications to the Transport Layer, one should note that two general types of

Figure 7.
SAPI Action for a Basic Rate D-Channel



addressing in a communications architecture are available. Each host on the network must have a network address, allowing the network to deliver data to the proper computer. Each process within a host must have an address that is unique within the host; this allows the Transport Layer to deliver data to the proper process. These process addresses are identified using SAPs. A similar approach is followed for ISDN.

LAP-D, the data link standard for ISDN, specifies the link access protocol used on the D-channel. LAP-D is based on **LAP-B**, which is based on HDLC. LAP-D must deal with two levels of multiplexing. First, at a subscriber location, multiple-user devices may be sharing the same physical interface. Second, each user device may support multiple types of traffic, including packet switched data and signaling. To accomplish this type of multiplexing, LAP-D employs a two-part address consisting of a terminal endpoint identifier (TEI) and a SAPI. Typically, each user terminal is given a distinguishing TEI. The SAPI identifies the traffic type and the Data Link Layer services directed to Layer 3. For example, the SAPI value of 0 directs the frames to Layer 3 for call-control procedures; a SAPI value of 16 indicates a packet communication procedure. See Figure 7.

Fast Packet Switching

Faster switches are required before packet-switching service is more widely used. Current packet switches can provide a throughput of up to 40,000 packets per second. The fast packet-switching technique has drawn considerable interest, since vendors of fast packet products promise up to 800,000 packets per second throughput. According to most sources, carriers throughout the world view fast packet technology as the technique of choice for future networks.

In the fast packet environment, voice, data signaling, video, mass-memory transfers, and high-speed LAN interconnections are combined and channeled through a common physical network. This technology provides continuously adaptive bandwidth management, allowing each user to acquire the requisite amount of transport capacity on an as-needed basis.

Data packets produced by the fast packet technique are like samples produced through pulse code modulation (PCM). Since X.25 data packets can contain data only, traditional packet switching is not compatible with fast packet technology. Proprietary solutions are available, however, from Stratacom and other vendors, for integrating both types of systems.

Frame Relay

Frame relay is an emerging, standards-based addressing technique that has great potential in fast packet swithing and internetworking of remote LANs. Frame relay is analogous to how X.25 relates to conventional packet-switching backbone networks. X.25 is a "network access method," or user-to-network interface. Frame relay provides user access to a higher speed network that is based on a transmission technology other than X.25.

Vendors have recently developed frame relay interfaces for conventional packet and circuit switched networks. LAN internetwork and WAN vendors are also teaming up to develop frame relay capabilities for remote bridges and routers, offering integrated LAN/WAN solutions to customers.

Frame relay is based on the CCITT Layer 2 protocol developed for ISDN, Link Access Protocol D (LAPD). Unlike conventional X.25 packet switching, frame relay uses variable packet lengths and performs error checking only at the remote end of transmission. Any errors occurring between intermediate network nodes are assumed caught and corrected by higher layer protocols. Thus, intermediate nodes simply forward packets (called frames) without processing the datastream. In addition, frames must be received in the order in which they were sent, unlike some X.25 networks, which involves considerably less machine processing at the opposite end of transmission. These efficiencies result in extremely higher throughput speeds—up to 2M bps.

Most commercial frame relay products are based on ISDN recommendations contained in CCITT I.122, entitled "Framework for Providing Additional Packet Mode Bearer Services," and/or in ANSI T1S1/88-2242, "Frame Relay Bearer Service—Architecture and Description." Currently, only one packet service has been specified in ISDN standards: "Support of Packet Mode Terminal Equipment by an ISDN," CCITT I.462 (X.31). More work is being accomplished during the 1989-1992 Study Period, however, to specify additional packet switched services.

Vendors from several different networking disciplines are trying to establish themselves as frame relay proponents. These include T-carrier nodal processor vendors; LAN internetwork vendors (bridges and routers); traditional packet switched network providers, such as Hughes Network Systems, Netrix, Telematics, and US Sprint; and communications carriers. Many have announced products or services that will be available in 1991. Stratacom is one vendor that has been instrumental in developing frame relay concepts (along with fast packet technology). ■