The service history of public data networks began in 1972. Since that time the number of such networks and the variety of services they offer has increased and continues to do so. In this paper, some of the networks, their characteristics, and the international network interface recommendations are briefly described.

Public data networks: Their evolution, interfaces, and status

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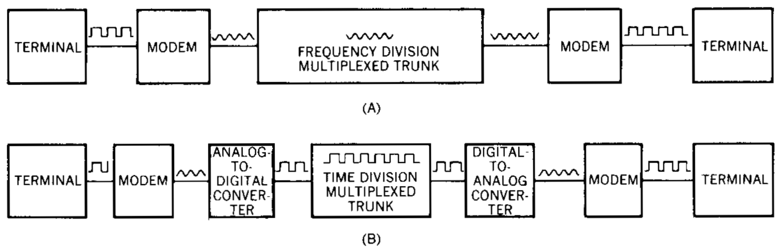
The first public data networks (PDNs) began commercial service in the late 1960s and early 1970s. More than 30 are planned to be operational worldwide by 1980. This paper outlines the evolution of PDNs and the characteristics of major network categories, reviews the CCITT (the International Telegraph and Telephone Consultative Committee) "X" series network interface recommendations, and provides summary charts of some existing and planned intranational networks. The paper is intended as a tutorial along with others on data communications, public data networks, and evolving interface and architecture standards that also appear in this issue.[1,2]

With the advent of data processing in telecommunications in the late 1950s, computer communication designers adapted the existing pervasive analog telephony facilities to data transmission. While these facilities continue to be widely available and used, factors including the accelerating growth of data transmission usage and a desire by carriers[3] to achieve maximum utilization and efficiency of their facilities, plus the advent of digital technology for transmission and switching, led to the development in the late 1960s and early 70s of public networks designed more specifically for data carriage.

Figure 1 Simplified schematic of early digital transmission evolution: (A) Prior to digital trunks, information was in analog form from modem to modem; (B) With the advent of digital trunks, information was converted to digital form for trunk transmission, then reconverted to analog form



PDN evolution

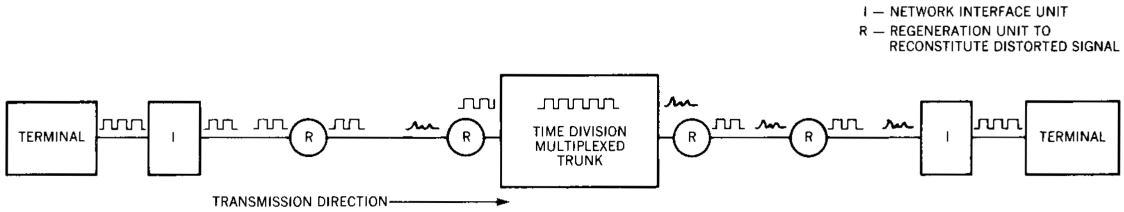
Among the earliest PDNs to be introduced were the Broadband Exchange Service and Multicom II in Canada and Caducee in France, which became available in 1967, 1971, and 1972, respectively. These networks offered a transparent, full-duplex, point-to-point switched service at speeds up to 4800 bits per second while providing low bit error rates which had previously only been generally available on private lines.

These early networks used conventional analog transmission techniques and modems and are representative of a category of PDNs sometimes referred to as interim circuit-switched, improved analog. Call setup is established by manual or automatic dialing in the same manner as on the conventional switched telephone network. By limiting the number of switching exchanges in these early PDNs, their designers helped minimize the time required to establish calls. For local calls, Multicom II aims for a period of one-half second between completion of dialing by the caller and commencement of ringing at the called party; for long-distance calls, two to three seconds are targeted for the establishment of a call, thus providing a significant improvement on public switched telephone network setup times. The provision of full-duplex circuit switching also increased data throughput by reducing the turnaround delays encountered in analog network half-duplex switches.

digital leased circuit

Coincident with this early period of PDN development, but separate from it, many of the world's carriers began using digital techniques within sections of their telephone networks as shown in Figure 1. Although this innovation had advantages for voice transmission, it was specially suited for data because, in time division multiplexed systems, more than 20 data streams of 2400 bits per second can be transmitted in the bandwidth assigned to one voice channel compared to a typically one-to-one relation-

Figure 2 Signals are maintained in digital form throughout a digital network



ship in an analog system. In 1973 the first digital leased-circuit PDNs, Dataroute and Infodat, were introduced in Canada. Dataroute and Infodat implement digital techniques throughout most of their network hierarchy, including the local access lines, and provide dedicated full-duplex circuits with multidrop capability.

As shown in Figure 2, data signals in a digital network are maintained in digital form. This contrasts to their treatment in an analog network where they are converted by the modem or dataset of the terminal[4] to an analog signal on entering the network and reconverted to a digital signal on exiting.

A major advantage of digital over analog transmission is the relative ease with which a true copy of the original digital signal may be successively regenerated and passed on through the network. Because of this characteristic, digital networks typically have a bit error rate objective of one in 10^7 compared to such usual analog circuit error rates as one in 10^5. An additional potential benefit for the user is that the unit required for interfacing a terminal to a digital network is generally less complex and therefore less costly than its analog counterpart, the modem.

Since 1973 additional digital leased-circuit PDNs have been introduced in the United States (Dataphone ® Digital Service), Brazil (Transdata), and Japan (Digital Data Circuit), and services are planned for other countries.

digital circuit switched

The next evolution in PDN development occurred with the introduction of digital circuit-switched services. These services typically provide point-to-point full-duplex circuits. Their major features are low error rates, fast call setup times (may be one second or less), and the billing structure of a switched network, i.e., charging for connected time only. Connect-time billing increments can be as small as one second.

User interaction with circuit-switched networks can be divided into three phases, which are analogous to a voice telephone call sequence. They are call establishment, data transfer, and call clearing.

One of the earliest digital circuit-switched PDNs was the Datran Data Dial service which became operational in the U.S.A. in 1974. Data Dial network design criteria included an average error rate no worse than one bit in 10^7 bits transmitted. The Data Dial service (now provided by Southern Pacific Communications Co.) offers transmission rates of 2.4, 4.8, and 9.6 kilobits per second. Billing usage is computed in one-second increments with a minimum of six seconds per call. Another example of circuit-switched digital PDNs is the recently introduced Infoexchange service in Canada.

packet switching

In a circuit-switched network, the terminal-to-terminal physical circuit is held for the duration of the call. As the user has this circuit dedicated to his use and not shared with other data traffic, transit time across the network is dependent only upon the transmission media and is therefore essentially constant.

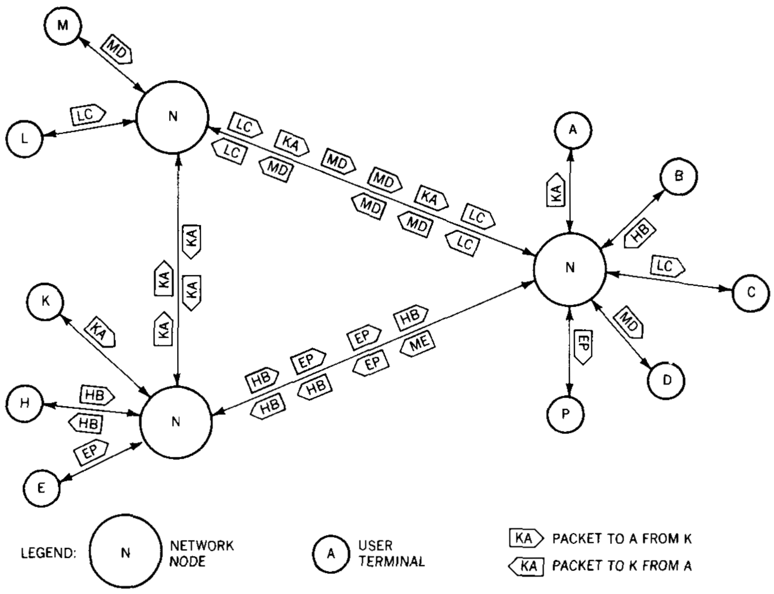
When messages are short and relatively infrequent, such as in inquiry and interactive applications, low line utilization results, raising the question of whether a different type of carrier network design could offer better utilization of transmission resources. This factor, plus others discussed initially by Paul Baran et al.[5] and expanded in terms of a public service by Davies[6] and Horton,[7] contributed to the development of packet-switched networks designed to meet the needs of some point-to-point, low-to-medium-volume data users while optimizing usage of the carrier's network resources.

Higher resource utilization is achieved by sharing network paths among multiple users. To enable path sharing, user data is transmitted across the network in blocks, or "packets," as shown in Figure 3. In currently implemented packet networks, maximum packet sizes at the user interface range from 16 to 1024 octets. Each packet contains a network-defined header in addition to user data to provide for system control of the packet through the network. If the arrival rate of packets at a network node momentarily exceeds the transmission capability of circuits leaving the node, packets may be queued in buffers and forwarded when a transmission time period is available.

Packet networks provide a "virtual circuit," that is, one that appears to be a point-to-point connection for a pair of terminals. Actually it is a circuit that is shared (in part) by many terminals through time division multiplexing techniques provided by the packet carrier.[8]

Packet networks typically offer users two basic communication facilities, (1) *virtual call*, where a temporary virtual circuit is established between terminals—logically equivalent to a circuit-

Figure 3 Path sharing within a packet network



switched call—or (2) *permanent virtual circuit*, where terminals are permanently associated via a virtual circuit—logically equivalent to a leased circuit.

The operational principles of packet networks vary, but the following example of a CCITT X.25-based (discussed in more detail later) network illustrates the general operation.

To make a virtual call, the calling terminal initiates a control packet interchange with the network. This interchange includes a "Call Request" packet that specifies the network terminal address to which subsequent data packets are to be delivered by the network. If a virtual circuit and the called terminal are available, a virtual circuit is then established to the called terminal (further control packets are passed between the switch and the called and calling terminals during this phase). When the calling terminal receives a "Call Accepted" packet from the network switch, the data transfer phase is entered. When data transfer is complete and the connection is no longer required, the calling or called terminal sends a "Clear Request," and the virtual circuit is deactivated. Call setup and clear packets are not required when the user has a permanent virtual circuit since the called and calling terminals are permanently associated. All data packets received on a permanent virtual circuit will have originated from the associated remote terminal.

Because of the store-and-forward nature of packet networks, they can be adapted to provide functions such as code, speed and protocol conversion, and device and error control. Some carriers offer users those value-added services.

Network attachment

Attachment of terminals to early PDNs was made by means of the long-established EIA RS232 or CCITT "V" series interfaces[9] which had been developed in the early 1960s for attachment to analog facilities. RS232 circuits and functions are generally equivalent to the CCITT V.24/V.28 interface recommendations. (In the remainder of this paper the V.24/V.28 recommendations are referred to as V.24.) To enable automatic call setup on circuit-switched networks, RS232 was supplemented by an "auto call" interface, RS366, and V.24 by V.25.

During the development of PDNs, a requirement evolved for terminal-to-network interface standards, and the CCITT has generated a family of recommended standards known as the "X" series for PDN implementation. Those most commonly referenced are summarized in Table 1. The recommendations[10] cover methods of terminal attachment, link control procedures, data transfer, and services for leased-circuit, circuit-switched, and packet-switched networks.

The X.21 recommendation defines a general-purpose interface between terminals and new synchronous public data networks that provide circuit-switched and leased-circuit services.

During 1979, the first networks (in Japan and the Nordic countries) to provide the X.21 interface are expected to become operational. The architectural compatibility of X.21 and IBM's Systems Network Architecture is described by Corr and Neal in this issue.[2] It is IBM's objective to provide X.21 attachment capability for some selected products.[11]

X.21 functionally replaces the terminal-to-modem and automatic calling interfaces EIA RS232C (CCITT V.24) and EIA RS366 (CCITT V.25) as shown in Figure 4. Some of the advantages X.21 offers over the older interfaces are:

1. Fewer interchange circuits and pins. A maximum of six interchange circuits[12] and one 15-pin connector are utilized, as compared to about 30 interchange circuits and two 25-pin connectors for RS232C/RS366 when these interfaces are used in an auto-call configuration. In X.21, terminal/network control signals are sent by code strings on the receive and transmit circuits rather than by discrete circuits as in RS232C or V.24.

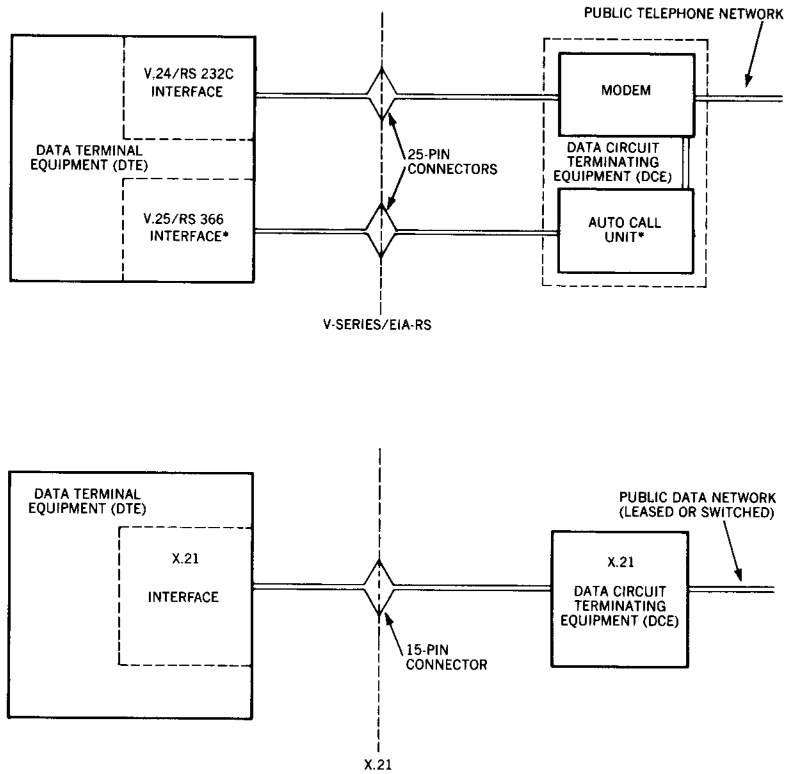
Table 1 Commonly referenced "X" series recommendations

Series	*Recommendations*
X.1	International user classes of service in PDNs
X.2	International user facilities in PDNs
X.3	Packet assembly/disassembly facility (PAD) in a PDN
X.20	Interface between data terminal equipment (DTE) and data circuit-terminating equipment (DCE) for start-stop transmission services on PDNs
X.20-bis	V.21-compatible interface between DTE and DCE for start-stop transmission services on PDNs
X.21	General-purpose interface between DTE and DCE for synchronous operation on PDNs
X.21-bis	Use on PDNs of DTEs that are designed for interfacing to synchronous Series V Recommendations modems
X.24	List of definitions for interchange circuits between DTE and DCE on PDNs
X.25	Interface between DTE and DCE for terminals operating in the packet mode on PDNs
X.26	Electrical characteristics for unbalanced double-current interchange circuits for general use with integrated circuit equipment in the field of data communications
X.27	Electrical characteristics for balanced double-current interchange circuits for general use with integrated circuit equipment in the field of data communications
X.28	DTE/DCE interface for a start-stop mode DTE accessing the packet assembly/disassembly facility in a PDN situated in the same country
X.29	Procedures for the exchange of control information and user data between a packet mode DTE and a packet assembly/disassembly facility

This factor permits the number of interchange circuits to be reduced and also provides for possible future extension of control signals.

2. Improved electrical characteristics. X.21 incorporates a provision in the physical interface for newly developed, LSI-compatible (large scale integration), balanced circuits, capable of operation up to 1000 meters, at bit rates up to 100 kilobits per second and up to 10 megabits per second at 10 meters. This operation is a major improvement over a typical RS232C or V.24 operation: 50 feet or less at bit rates below 20 kilobits per second.
3. Enhanced functional capability without sacrifice of data transparency. One of the unique features of public data networks utilizing the X.21 interface is the ability of the network to communicate detailed call-status information directly to the using terminal. Call-progress signals such as number busy, access

Figure 4 Comparisor of CCITT V-series/EIA-RS and X.21 interfaces



*NOT REQUIRED WHEN OPERATING WITH LEASED LINES (POINT-TO-POINT OR MULTIPOINT) OR WITH SWITCHED LINES RESTRICTED TO MANUAL CALL CAPABILITY.

barred, and changed number are passed from the network to the call-originating terminal to tell a user why a particular call was not completed. These signals also indicate call clearing due to network problems and normal completion.

The utility of circuit-switched networks using CCITT X series recommendations is further enhanced by their provision of a variety of additional facilities that are selectable by the user. Depending on the network implementation, activation of the desired facilities may be accomplished either when subscribing to the network service or when a facility registration request is entered into the network by means of the attached terminal. At this time, seven user facilities for circuit-switched services are included in the applicable CCITT Recommendation X.2 as described in Table 2.

Recommendation X.21 provides distinct separation of network signaling phases from the data transfer phase. In the data transfer phase, end-to-end data transparency[13] is maintained; the terminal is allowed to transmit any bit configuration. User-provided encryption is feasible during data transfer.

Table 2 X.2 user facilities for circuit-switched PDNs

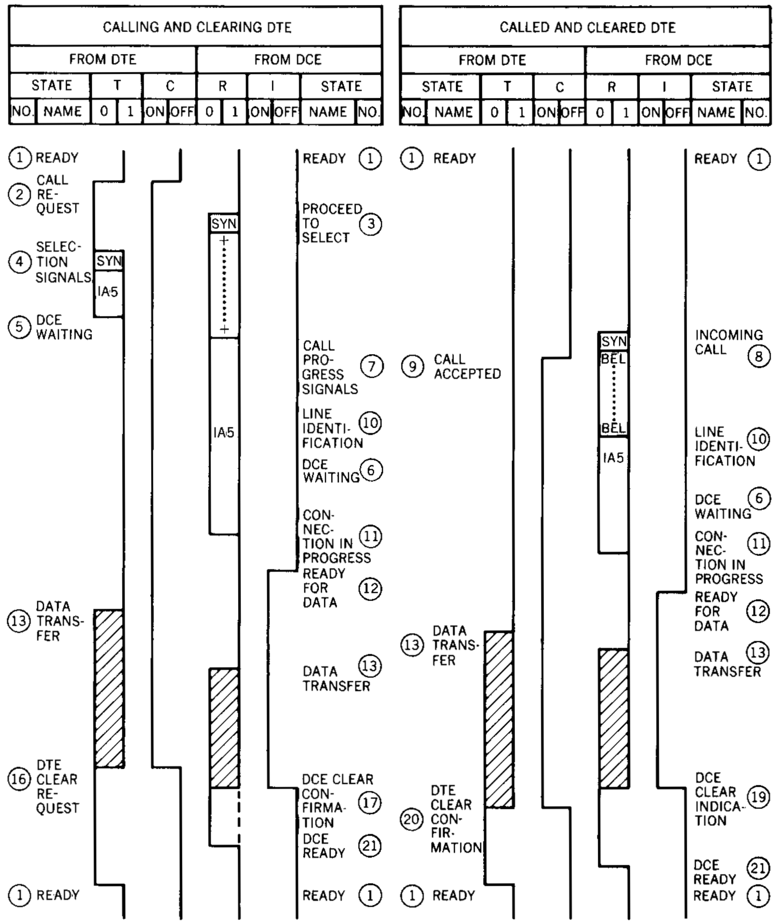
User facility	*Function*
Direct Call	Calling subscriber is connected to a predesignated subscriber. No selection (dial signals) needed.
Closed User Group	Subscriber will only accept calls from predesignated subscribers and can only make calls to predesignated subscribers.
Closed User Group with Outgoing Access	As Closed User Group but can call any subscriber.
Calling Line Identification	Network advises called subscribers of who is calling before data transfer phase is entered. Called subscriber can reject call.
Called Line Identification	Network confirms to calling subscriber the number of called subscriber with whom connection is about to be made.
Abbreviated Address Calling	Requires fewer characters than the full address when initiating a call. Network expands abbreviated address to full address.
Multiaddress Calling	Data is sent to multiple subscribers.

X.21 describes the recommended operation in four phases that are listed below. The network provides bit clocking to the terminal during all phases.

1. Quiescent Phase: Applicable to both circuit-switched and leased-circuit service, this is the nonactive phase during which the network and terminal indicate ready or not ready status.
2. Call Establishment Phase: To establish a circuit-switched connection, the terminal communicates with the network by way of the transmit and receive circuits using the characters of CCITT International Alphabet Number 5—IA5 is basically similar to ASCII. SYN characters are used to obtain and maintain character synchronization between the terminal and network during this phase.
3. Data Transfer Phase: Indicated by a unique state of the X.21 interface control circuits, a full-duplex transparent transmission path is maintained between user terminals for circuit-switched and leased-circuit services.
4. Clearing Phase: To release a circuit-switched connection, either the terminal or the network initiates a clear-request. The network will then clear the connection, and the interface will return to a quiescent state (Phase 1).

Figure 5 depicts an example of the sequence of events at the terminal (DTE) to network (DCE) interface for a call and clear operation on a circuit-switched network. T (Transmit), C (Control), R

Figure 5 X.21 interface signaling sequence diagram of call and clear operation (From CCITT Orange Book, VIII.2 (1977), International Telecommunications Union, Geneva, Switzerland)



(Receive), and I (Indication) are four of the six interchange circuits previously mentioned, and their binary states are shown during the operations. The circled numbers and titles beside them are X.21-defined states. The operational sequence flows down the diagram.

CCITT Recommendation X.21 bis[14] is an interim interface designed to allow terminals using RS232C and RS366 (CCITT V.24, V.25) to operate on the new X.21 networks with no changes in their design; however, they will not be able to take advantage of many new functions, such as call progress signals and facility requests, available with X.21. A network interface unit providing the X.21 bis interface converts V.24 (RS232C) signal sequences to sequences and waveforms compatible with the digital network.

Recommendation X.20 specifies the interface between start-stop terminals operating at speeds up to 300 bits per second on circuit-switched or leased-circuit public data networks. X.20 defines only two interchange circuits. Sequences are described in four phases in a similar manner to X.21, i.e., Quiescent, Call Establishment, Data Transfer, and Clearing.

X.20 bis provides a similar function to X.21 bis by specifying an interim interface to allow attachment of start-stop terminals using the RS232C or CCITT V.24 interfaces to circuit-switched services.

Packet-switched networks typically offer a range of interfaces to terminal equipment. The primary interface intended for packet networks is X.25. X.25 is structured to provide broad functional capability to support attachment of "intelligent" terminals as well as communications controllers and host processors. X.25 is a totally new interface. Equipment lacking it is not compatible and in many cases not easily upgradable to X.25; therefore, most packet networks offer compatibility interfaces to non-X.25 terminals.

Having recognized the fact that not all future terminals will contain the level of intelligence necessary to attach to the network by means of the X.25 interface in an economical manner, CCITT also developed a series of interface recommendations—X.3, X.28, and X.29—designed to support start-stop terminals. These recommendations are discussed below.

The interface to a packet network is inherently more complex than the interface to a leased- or circuit-switched network because of the structure of the network. Leased- and circuit-switched networks are generally referred to as transparent networks because the network itself does not place format constraints on the data stream but transmits data directly between user terminals. Terminal control functions (e.g., polling of terminals on a multipoint-based line) are performed directly by the user's equipment. The communications network treats each poll as data. In the case of an X.21 circuit switch, data is transmitted in a totally transparent manner when the circuit has been established.

The major difference with the packet network is that the data stream must be formatted into packets. This is true of both a virtual call and a permanent virtual circuit mode of configuration. All packets transmitted within the network have headers whose format is defined by the network. In the case of the X.25 interface, the user is responsible for formatting the headers prior to transmitting the data to the network. In the case of the compatibility interfaces for existing terminals and new terminals designed according to the X.3, X.28, and X.29 recommendations, additional function is provided within the network to convert terminal-defined message formats to the packet format required within the

Table 3 Overview of level function

Level	Function
1. Physical and electrical	Activate, maintain, and deactivate link between terminal and network
2. Link access procedure for data interchange	Framing, synchronization control, error detection, and connection between terminal and network node
3. Packet format and control procedures	Establish and clear virtual circuits and the transfer of user data between the terminal and the network

network. It becomes obvious from the above that specific function has to be provided by the network for each specific terminal or terminal protocol subset that the network supports.

Another effect of the network structure is that the user interacts indirectly via the network with the remote terminal in contrast to direct user control of the remote terminal in the case of a leased- or circuit-switched network. User end-to-end communication in a packet network consists of first, communication from the originating terminal to its access node, then, the network itself managing the flow of data from the entry access node to its destination node, and finally, an exchange across the interface from the destination node of the network to the user terminal. It is important to note that the concept of interface to a packet network is significantly more complex than it is to a leased- or circuit-switched network and involves considerably higher levels of function beyond the physical interface reflected in RS232, V.24, or X.21.

The X.25 recommendation for packet networks is structured into three "levels" as shown in Figure 6. A brief overview of level functions is outlined in Table 3. A full discussion of them is beyond the scope of this paper; Reference 15 provides a more complete review.

X.25 specifies a subset of the previously described X.21 recommendation for the provision of level 1 requirements. Two link access procedures, LAP and LAPB, are specified for level 2. LAPB is specified as "preferred"; it uses a subset of ISO HDLC (the X.25 data-link control protocol). Level 3 of the X.25 recommendation specifies a format of packets, e.g., Call Request, Call Accepted, and Call Connected, plus control procedures for virtual circuit establishment, information transfer, and circuit disconnection between the terminal and network. Note that call setup and clearing

Figure 6 X.25 levels

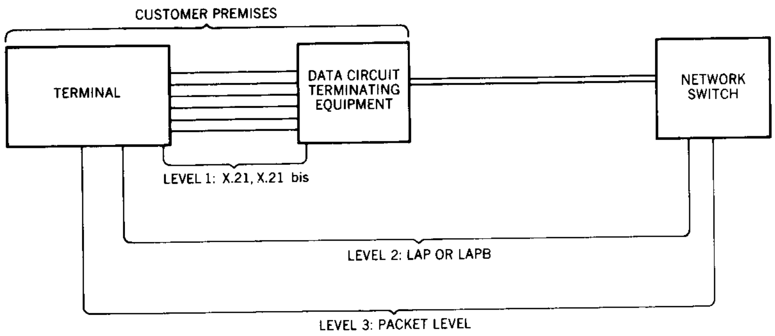
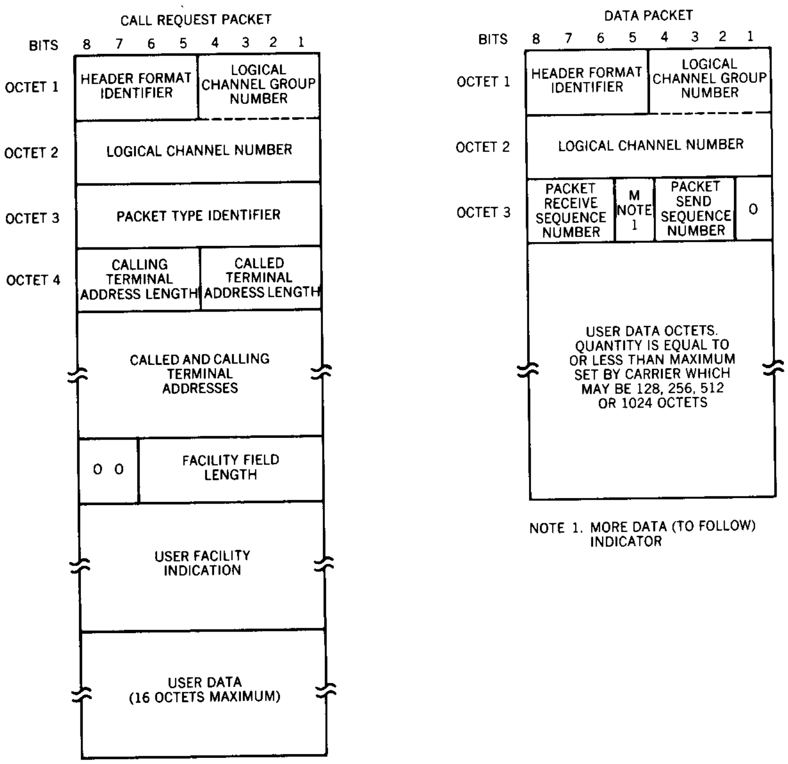


Figure 7 X.25 packet format examples



are effected by packets rather than the previously described method used by X.21 on circuit-switched networks. Some sample packet formats are shown in Figure 7. X.25 packets contain a logical channel identification in octets 1 and 2 that identifies the logical channel being used between the terminal and the network. This identification is assigned at subscription time for permanent virtual circuits and during call setup for virtual calls. Up to 4095 logical channels are available at each X.25 network interface, thus allowing, say, a host processor using one physical network access port to communicate simultaneously with multiple terminals.

Alternative ways to adapt IBM's Systems Network Architecture to X.25 are discussed by Corr and Neal.[2] Using one of these approaches, IBM announced product adaptations in 1977 for two X.25-based networks, Datapac in Canada and Transpac in France, that provide for the attachment of several SNA terminals and cluster controller products.

Recommendations X.3, X.28, and X.29 provide specifications for a packet assembly/disassembly (PAD) facility to enable attachment of start-stop character mode terminals to packet networks. While some existing start-stop terminals can be attached using these interfaces, they are primarily intended for the design of new start-stop terminals planned for use on packet networks. X.3 describes PAD functions and parameters that provide for the assembly of characters received from the terminal into packets for transmission to the network and disassembly of packet data fields received from the network into character mode for transmission to the terminal. X.3 provides for some PAD parameters to be programmed by the user. X.28 specifies the terminal-to-PAD protocol interface, including procedures for service initialization, character interchange, and control information exchange. X.29 describes procedures for the exchange of control information and user data between an X.25 terminal and a PAD.

Recommendation X.2 also specifies seven user facilities for packet-switched services. The facilities are Closed User Group, Closed User Group with Outgoing Access, Abbreviated Address Calling, Permanent Virtual Circuit, Packet Assembly and/or Disassembly, Datagram, and Virtual Call. The first three facilities are as described previously in Table 2. Permanent Virtual Circuit and Virtual Call have been outlined and the Packet Assembly/Disassembly facility has been described under X.3, X.28, and X.29. Datagram has not yet been defined by CCITT. In a proposed definition, messages are contained completely within one packet. The network may not deliver packets in the order they were put in and may not confirm delivery.[16]

PDN status

Tables 4, 5, and 6 contain a summary of available details of some existing or planned leased-circuit, circuit-switched, and packet-switched PDNs.

Table 4 Leased-circuit PDNs

Country	*Network or service name*	*Actual or planned commencement*	*Geographic access*	*Physical interface*	*Maximum access rate (bits/sec)*	*Multi-point • = yes*
Australia	DDN	1980	Initially, Sydney, Canberra, and Melbourne	X.20 bis	300	•
		1980		X.21 bis (V.24)	9600	•
		1980		X.21 bis (V.35)	48K	•
Austria	Leased Digital	1980		X.20	300	
		post 1981		X.21	9600	
Belgium	NDN	1979		V.24/V.28	9600	
		1979		V.35	64K	
Brazil	Transdata	1976	Sao Paulo, Rio de Janeiro in 1978	V.24/V.28	9600	•
Canada	Dataroute	1973	39 cities in 1978	RS232C	19.2K	•
		1973		WE303C	56K	
	Infodat	1973	39 cities in 1978	RS232C	9600	•
		1973		WE303C	56K	
		1973		V.35	56K	
France	Transplex	1974	25 cities in 1978	V.24/V.28	1200 (asynch only)	
	Transmic	1979	7 cities in 1979, 15 cities in 1981	V.24/V.28,	9600	
		1979		V.35	48K	
		1979		X.24/X.27	1024K	
		1979		(Special)	2048K	
Germany	HfD	1974	Countrywide	V.24/V.28	9600	
				V.35, V.36	48K	
Italy	Leased Digital	1979		X.21 bis	9600	•
		1980		V.35	48K	
		1980		X.21	48K	
Japan	Digital Data Circuit	1978	7 cities in 1978, 130 cities by 1982	X.21 bis (V.24)	9600	•
		1978		X.21 bis (V.35)	48K	•
		1978		X.20 bis (V.24)	1200	•
		1979		X.20	1200	•
		1979		X.21	48K	•
South Africa	Saponet	1979		V.24/V.28		
		1980		X.21		
Switzerland	Leased Digital	1979	Countrywide	V.24/V.28	9600	
		1979		V.35	64K	
United Kingdom	DDS	1983		X.21, X.21 bis	48K	
		1983			64K	
		1983			2048K	
United States	Dataphone® Digital Service	1974	47 cities in 1978	Data Service Unit	9600	•
				Channel Service Unit	9600	•
				Data Service Unit	56K	•
				Channel Service Unit	56K	•
				T1 Adapter	1544K	•

The information on which the tables are based was gathered from carrier publications. However, at the time this paper was written,

Table 5 Circuit-switched PDNs

Country	Network or service name	Actual or planned commencement	Geographic access	Physical interface	Maximum access rate (bits/sec)	Call setup time (sec)	Call clear downtime (sec)
Austria	Public Data Network	1979 1981	1 city in 1979	X.20 X.21	300 9600		
Canada	Infoexchange	1978	56 cities in 1978	RS232C	9600		
France	Caducee	1972 1974	Countrywide	V.24/V.28 V.35	19.2K 72K	2.5	1
	Hermes	1982		X.21	48K		
Germany	Datex	1976 1978 1979 1979 1981/82		V.24/V.28 X.21 bis X.21 bis X.20 X.21	200 300 9600 300 48K		
Italy	Datex	1980 1980		X.20, X.20 bis X.21 bis	 9600		
	Switched Digital	1980s		X.21	48K		
Japan	DDX	1979	4 cities in 1979, 7 cities in 1982	X.21 bis (V.24)	9600	<0.5	<0.1
		1979		X.21 bis (V.35)	48K	<0.5	<0.1
		1979		X.20	1200	<1.3	<0.1
		1979		X.20 bis	1200	<1.3	<0.1
		1979		X.21	48K	<0.5	<0.1
Netherlands	DN1*	1982 1982		X.20 X.21	300 48K		
Denmark, Finland, Norway, Sweden	Nordic Public Data Network	1979 1979		V.24/V.28 X.21	9600 9600	0.1	0.05
South Africa	Saponet	1979 1980		V.24/V.28 X.21			
Switzerland	EDW-A	1979	Countrywide	X.20 bis, X.20	300		
	EDW-S	1985		V.24/V.28, X.21	9600	1	
	IFS	1985			64K	<1	<1
United Kingdom	DDS	1983/ 1984		X.20, X.20 bis bis X.21, X.21 bis	300 48K		
United States	S.P.C. Data Dial	1974	28 cities in 1978	RS232C, RS366	9600	0.8	

*Under study

complete specifications were not available for some planned networks, and only minimal details were available for others. Thus, the most current information may not be reflected in the tables. Due to the need for brevity in the tables, interfaces and protocols have been broadly categorized as V.24/V.28, X.21, X.25, etc. Carriers have implemented various options of these interfaces such that network interfaces classed as, for example, X.21, may

Table 6 Packet-switched PDNs

Country	*Network or service name*	*Actual or planned commencement*	*Geographic access*	*Physical interface*					*Access protocol*					*Maximum packet size*	*User facilities*		
				X.21	X.21 bis (V.24/RS232)	X.21 bis (V.35)	X.20	X.20 bis	X.25	X.3 and/or X.28, X.29	HDLC	BSC	Start/Stop	* = characters † = bytes	Permanent Virtual Circuit	Virtual Call	PAD
Belgium	Packet Network	1980/81	Countrywide	•					•					128*	•	•	
	Packet Network	1980/81	Countrywide		•	•							•	128*	•	•	•
	Packet Network	1980/81	Countrywide				•	•					•	128*	•	•	•
Canada	Datapac	1977/78	55 cities in 1978		•				•					256†	•	•	
	Datapac	1977/78	55 cities in 1978		•					•		•	•	256†	•	•	•
	Infocall	1978	56 cities in 1978		•						•	•	•	268*		•	
	Infogram	1979	58 cities in 1979		•									268*			
France	Transpac	1978	Countrywide		•	•			•					128*	•	•	
	Transpac	1978	Countrywide		•					•				128*	•	•	•
	Transpac	1978	Countrywide					•					•	128*	•	•	•
Germany	Packet Network	1981	Countrywide	•	•				•		•	•		128*	•	•	
	Packet Network	1981	Countrywide				•			•			•	128*	•	•	•
Japan	DDX	1979	7 cities in 1979	•	•	•			•					256†	•	•	
	DDX	1979	7 cities in 1979				•	•					•	256†	•	•	•
	DDX	1979	7 cities in 1979	•	•						•			256†	•	•	•
Netherlands	DN1—Phase 1	1980	Countrywide						•								
Spain	RETD	1971	Countrywide		•							•	•	256†			
	CTNE (X.25)	1980							•								
Switzerland	EDW (P)	1981/82							•								
United Kingdom	E.P.S.S.	1977	Experimental—40 users		•												
	N.P.S.S.	1979/80	Countrywide	•					•	•					•	•	•
United States	AT&T's ACS		48 cont. states		•	•			•			•	•			•	•
	Graphnet	1976	49 cities in 1978		•								•	100*			
	Telenet	1975	81 cities in 1978		•					•		•	•	1024†		•	•
	Telenet	1979	81 cities in 1979		•	•			•					1024†		•	
	Tymnet	1971	150 cities in 1978		•							•	•	64*			•

not be identical. This latter factor plus the possibility that the specification of planned PDNs may be modified before the networks are implemented means that the data shown should be regarded as a general guide only.

Table 7 Packet-switched PDN tariff structures

Country	*Network or service name*	*Access charge*		*Usage charge*											
		Service area dependent	Bit rate dependent	Distance dependent	Source/destination pair dependent	Volume dependent	Bit rate dependent	Connect time dependent	Call quantity dependent	Volume discount	Minimum usage or account charge	Character or octet based charge rate	Packet based charge rate	Off-peak discount
Canada	Datapac		•		•	•			•				•	
	Infocall		•	•		•	•	•	•	•	•	•		
France	Transpac		•			•	•	•				•		•
Japan	DDX*		•	•		•						•		
United States	Graphnet		•			•	•						•	
	Telenet		•			•	•	•		•	•		•	
	Tymnet	•	•			•	•	•		•		•		
	AT&T's ACS*	•	•			•	•	•						

*Not approved at time of writing by regulatory body.

leased-circuit networks

In Table 4, which shows the leased-circuit PDNs, the geographic access column provides a rough guide to network availability and pervasiveness but can be misleading. For example, the Japanese Digital Data Circuit (DDC) was planned to service only seven cities in 1978, but those cities account for a large majority of the data traffic. Multipoint is not currently included in the X.21 recommendation, but DDC plans to offer this service.

WE303C represents the physical interface control interchange circuits provided by the Western Electric 303C modem which are similar to RS232C. Its timing and data interchange circuit specifications are unique.

The Data Service Unit (DSU) of the U.S. Dataphone ® Digital Service (DDS) converts RS232C or V.35 interface signals to baseband bipolar line signals and vice versa; the Channel Service Unit (CSU) provides a six-wire interface to a DDS channel, but the customer's terminal must perform functions normally carried out by a DSU.

circuit-switched networks

Geographic access comments for Table 4 apply equally in Table 5 which shows circuit-switched PDNs. Call setup and cleardown times are provided as an indication only. In most cases they are design objectives and are specified by carriers to apply to a specific percentile of calls. They may also vary with calling distance and number of network switches traversed.

packet-switched networks

In the packet-switched networks of Table 6, the geographic access comments of Table 4 also apply.

All of the networks offer X.21 bis interfaces to allow the attachment of many existing synchronous terminals. Two networks have announced plans to offer X.21 and X.20 interfaces.

The physical interfaces and access protocols shown relate horizontally; for example, the first row for the Japanese DDX service indicates that X.21 and X.21 bis physical interfaces will be used with X.25 access protocols. The column heading Start/Stop is used in the generic sense to cover asynchronous protocols, though most of the networks support only a small subset of them. The table highlights the wide range of access protocols used or planned. In fact, the range is greater than shown here, as implementations of general protocols vary between networks. For example, Datapac in its 3303 service plans to support the IBM 3270 BSC (binary synchronous communications) protocol. By completely specifying the protocol to be used by an attached terminal, the 3303 service is able to offer polling from the network. Infocall, however, supports a wider variety of terminals by specifying only the BSC framing characters to be used, but requires that the attached terminal provide polling.

DDX access protocols support HDLC as well as start-stop protocols including ISO Basic Mode. The DDX PAD does not comply with X.3, X.28, and X.29.

PDN tariffs

Table 7 provides a comparison of the general tariff characteristics of some packet-switched networks. Tariffs have been divided into two categories: (1) the generally fixed access charge and (2) charges that are based on usage. The access charge columns indicate if the charge varies between service areas, i.e., varies from city to city (service areas are typically city size), and if it varies with the access speed used by the subscriber.

Usage charge subheadings are self-explanatory except for "Source/Destination Pair Dependent," which indicates that the charge is not related to transmission distance but is based on the service areas in which the communicating terminals are located. The effect of this structure is that the usage charge on a heavy traffic route between widely separated cities can be less than for a lightly loaded route between closer cities.

Summary

This paper has traced the development of PDNs from services based on the analog telephone network to services using digital techniques.

Digital technology offers major benefits for data carriage including significantly reduced error rates and increased bandwidth efficiency plus a potential for lower data transmission cost.

The typical features of three digital PDN categories have been described: (1) Leased-circuit networks provide point-to-point, full-duplex, and, in some networks, multipoint services; (2) Circuit-switched networks offer point-to-point, full-duplex service with fast call setup and small billing increments; (3) Packet-switched services aim to provide better utilization of carrier resources by sharing network paths among multiple users.

Network attachment interfaces have been discussed, including the general-purpose interface X.21 with its reduced number of interchange circuits, improved electrical characteristics, and enhanced functional capability compared to some earlier CCITT and EIA interfaces.

The general characteristics of packet networks have been reviewed and the CCITT "X" series recommendations outlined.

Tables have been presented that provide a summary of available information on the major characteristics of many of the world's existing and planned PDN services. The tables show the increasing implementation rate of PDNs that highlights the need for adherence to national and international standards to avoid a proliferation of interface varieties with their attendant support implications for machine suppliers and users.

Usage of the various PDN services will depend upon existing and emerging user applications and configurations. In some cases, an optimum user system design may utilize all service types, and it is IBM's objective, where feasible, to support product attachment to them.[11]

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3. The term "carrier" is used generically throughout this article to describe all variations of governmental postal telephone and telegraph authorities, telecommunications authorities, and recognized private operating agencies.
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10. *Public Data Networks*, CCITT Sixth Plenary Assembly, Geneva, September 27–October 8, 1976. International Telecommunications Union, Geneva, Switzerland, Orange Book, **VIII.2** (1977) and supplements.
11. Announcement of this capability for these IBM products will be determined on a case-by-case basis.
12. "Interchange circuit" is the CCITT designation for the individual electrical connections across the specified interface.
13. In a communications sense, "transparency" refers to a property of a communications service whereby the form and content as well as the timing relationship of information delivered is identical to that entered.
14. The term bis denotes a second version of the interface to the new networks and is not an acronym or abbreviation.
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