Packet switched network in Japan

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ABSTRACT

Research and development of public data networks have been conducted by various countries to cope with recent diverse data communication demands. Nippon Telegraph and Telephone Public Corporation (NTT) has also been advancing developmental projects on a packet switched network and a circuit switched network. Commercial tests on each will be begun in 1979.

Public data networks require the use of standard device-independent interfaces between networks and user devices. Especially, standard interfaces used in packet switched networks need to be specified even concerning an information transfer phase. As the fruits of energetic discussions made by CCITT, ISO etc., CCITT Recommendation X.25 for packet-mode terminals has been completed recently. On the other hand, the interface for non-packet-mode terminals will be discussed in CCITT SG VII during this study period 1977-1980.

This paper describes NTT’s packet switched network, laying emphasis on details of communication protocols for packet-mode and non-packet-mode terminals.

INTRODUCTION

NTT has been carrying out developmental research on a new switched data network since 1971. As the first stage of development, an experimental data switching system, DDX-1, was designed and installed at the Musashino Electrical Communication Laboratory in June 1973. The DDX-1 was a hybrid switching system, which could serve a subscriber with either circuit switching or packet switching, according to the call type. Based on experience gained by the DDX-1, an improved experimental data switching system, DDX-2, was developed as a prototype for commercial use. In the DDX-2, circuit switching and packet switching functions are separately embodied, considering feasibility of system configuration advancement. Field trial of the DDX-2 circuit switching system was begun on a twenty-four-hour full operation basis in March 1976. With regard to a packet switching function, basic technology required for computer communications has been preliminarily tested in the laboratory. The DDX-2 packet switching system will be put into full operation by late 1977. Commercial switching systems for a circuit switched network and a packet switched network are now being designed, in parallel with the developmental research. Each system will be put into commercial service in 1979.

The circuit switched network and the packet switched network have their own optimum application fields, respectively. Judging from the communication cost viewpoint, the circuit switched network is appropriate to rather long-message transmission, while the packet switched network is appropriate to rather short-message transmission. The result of NTT’s market research concerning future demand growth shows that each network will be used by more than several thousand customers even at the initial service stage. Therefore, it was decided to develop the circuit switched network and the packet switched network independently for the present, in view of network extension flexibility.

There are two types of basic packet switched service: virtual calls and datagrams. In datagram service, datagrams may not be delivered to a destination address in the same order in which they were input to the network. Also, datagrams sent from different subscriber terminals or computers may be simultaneously delivered to the same destination address, resulting in data from originating subscribers being tangled with each other. Consequently, users are required to individually take steps to manage these phenomena. Moreover, datagrams have another problem to be taken into account by the network, wherein no flow control and delivery confirmation technique relating to datagram service has been established as yet. On the other hand, virtual call service enables the network to provide common flow control procedures to avoid the above-mentioned phenomena. Therefore, NTT has adopted virtual calls as basic packet switched service. Although one of datagram service benefits is that subscribers can omit call establishment and clearing procedures, NTT expects that the same benefit would be given to subscribers by offering permanent virtual circuit service as well as virtual call service. However, there may be possibility of providing datagram service in the future, although further study is required.

For the purpose of international standardization concerning virtual calls and permanent virtual circuits, the specifi-
cation of the packet-mode interface was submitted as a draft recommendation to CCITT SG VII during the last study period. This was finally declared as CCITT Recommendation X.25. NTT's packet switched network incorporates the Recommendation at almost all points. In addition, NTT has specified communication protocols for the non-packet-mode interface, by which effective data communications between packet-mode terminals and non-packet-mode terminals would be actualized.

**GENERAL DESCRIPTION**

NTT's packet switched network outline is presented hereafter.

**Service specifications**

All data communications within the network are provided by means of full duplex virtual circuits. A virtual circuit may be permanent or switched. A permanent virtual circuit allows data transmission between two pieces of equipment, which are assigned at the time of subscription to the service, at any time without using call establishment and clearing procedures. On the other hand, a switched virtual circuit, called a virtual call, allows data transmission after a temporary logical connection between calling and called parties has been established using an access protocol.

Two types of terminals are accommodated to the network: packet-mode terminals and non-packet-mode terminals. A packet-mode terminal can send or receive data in the form of packets. Consequently, it can simultaneously communicate with a number of terminals through a single subscriber line by establishing many virtual circuits. This system is called packet interleaved communication. A non-packet-mode terminal cannot manage packets by itself. Messages transmitted from a non-packet-mode terminal are assembled into packets by the network, while packets addressed to a non-packet-mode terminal are disassembled into messages by it. A non-packet-mode terminal cannot perform packet interleaved communication. Figure 1 illustrates a communication example within the network using virtual circuits.

Data signaling rates of the terminals accommodated to the network are 2.4 kb/s, 4.8 kb/s, 9.6 kb/s and 48 kb/s for synchronous packet-mode terminals, 2.4 kb/s, 4.8 kb/s and 9.6 kb/s for synchronous non-packet-mode terminals and 200 b/s, 300 b/s and 1.2 kb/s for start-stop non-packet-mode terminals.

Optional user facilities on a virtual call are direct call, closed user group with or without outgoing access, calling line and called line identification, abbreviated address calling and lump-sum center payment.

Physical characteristics of the interface between data terminal equipment (DTE) and data circuit-terminating equipment (DCE) are based on those of CCITT Recommendations X.20 and X.20bis for start-stop terminals and X.21 and X.21bis for synchronous terminals. Other characteristics of the DTE/DCE interface are described in the following sections, including procedures for physical link establishment, call control and data transfer.

Transmission control procedures, which can be used for access to the network, are the High Level Data Link Control (HDLC) procedure, the conversational basic mode control procedure, the full-duplex basic mode control procedure and the delimiter procedure. Although a start-stop non-packet-mode terminal can select one out of the above-mentioned procedures except the HDLC procedure, a synchronous packet-mode or non-packet-mode terminal should use the HDLC procedure. In the case of the delimiter procedure, the end of a message should be indicated by special characters called delimiters, which are specified by the network, and there are no other restrictions. In principle, mutual communications between all terminals within the network may be possible by means of speed, code and procedure conversion. However, code or procedure conversion will cause communication cost increase, because a considerable quantity of software is needed at each Packet Assembler Disassembler (PAD) in order to offer this facility to all combination of data terminals. Therefore, it is provisionally desirable to set some limit to the possible combination of transmission control procedures. Table I shows the allowed combination of the transmission control procedures in the network.

**Charging scheme**

The tariff in the network is composed of monthly charge and packet charge. The monthly charge changes, depending on DTE data signaling rates. The following description is concerned only with the packet charge.

In general, there are two basic charging techniques which might be used within public packet switched networks to charge for packet traffic. One is uni-directional charging, in which only one party is charged for the entire call or transaction. The other is bi-directional charging, in which the charge for the call is split between both parties, according to which party sent or received the packet.
TABLE I—Possible DTE transmission control procedures combination

<table>
<thead>
<tr>
<th>Called Party</th>
<th>Procedure</th>
<th>PT HDLC</th>
<th>(1)</th>
<th>(2)</th>
<th>(3)</th>
<th>(4)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PT</td>
<td>HDLC</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
</tr>
<tr>
<td>(1)</td>
<td>Basic Mode, Conversational</td>
<td>O</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>(2)</td>
<td>Basic Mode, Full Duplex</td>
<td>O</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>(3)</td>
<td>Delimiter</td>
<td>O</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>Δ</td>
</tr>
</tbody>
</table>

Note

- O : Possible
- Δ : Possible with conditions

Technically, either of these packet charging techniques could be utilized successfully in the case of virtual calls. However, NTT's packet switched network has adopted uni-directional charging, in view of future possibility of interworking between the packet switched network and existing telephone or telex networks.

On a normal virtual call, all packets are charged to the calling party. In addition, if the called party has contracted lump-sum center payment, which is one of the optional user facilities in virtual call service, all packets during the course of a virtual call are charged to the called party. Namely, lump-sum center payment means reverse charging on an agreed contractual basis.

Each message is charged for according to the number of packets required for its transmission. The packet charge will slightly depend on the distance between calling and called parties, although it is independent of the call duration and other factors, such as DTE data signaling rates.

In the case of permanent virtual circuit service, all packets are charged to one of the two parties, according to a determination made at the time of subscription to the service. In other words, the packet charge for the permanent virtual circuit is linked to the volume of packets transmitted and is the same as that of the virtual call.

System configuration

A packet-mode terminal is directly accommodated to a Packet Switching Exchange (PSE) and a non-packet-mode terminal is accommodated to a Packet Multiplexer (PMX) which operates as a PAD.

Access to the network is possible through analog or digital leased circuits as well as four-wire subscriber lines. Access to the network via the telephone network or the telex network is not available for the present. Subscriber accommodation patterns are illustrated in Figure 2.

The PSE stores packets sent from/to packet-mode terminals, PMXs or other PSEs in its processor memories via the High-speed Signal Control Equipment (HSE) and then forwards them, as shown in Figure 2. The PSE processor is the same as that of D10, which was developed for stored program control electronic telephone switching systems and has achieved satisfactory operation results at more than one hundred telephone exchanges in Japan. The PMX assembles characters or bit streams sent from non-packet-mode terminals into packets on an octet basis and disassembles packets sent from the PSE into original form. All transmission lines between PSEs or between PSE and PMX are duplicated 48 kb/s channels. Each PSE and PMX function unit is also duplicated to realize high system reliability.

Traffic control

In the packet switched network, a feedback signal regulating input packet flow is needed to keep step with output packet flow, because the number of network buffers is finite. Traffic control adopted in the network is classified into window control and packet buffer allocation. The window control is used for setting some limit to the number of packets travelling on a logical link. In addition, receiving packet buffers in the PSE are allocated individually to each PMX or packet-mode terminal. The number of receiving packet buffers for a packet-mode terminal is determined at the time of subscription to the service. In case of buffer shortage, input of packets from remote terminals is suppressed for a period, independently of window control.
All packets during the course of a call are numbered at the source PSE. The packet sequence number is checked at the destination PSE and the packets are sent to the destination PMX or packet-mode terminal, being rearranged into the correct sequence order. If there is a missing packet in the sequence, the destination PSE waits for the packet to be transmitted for one second. After the packet concerned arrives at the destination PSE, it is sent to the PMX or the packet-mode terminal with the remaining packets. If it is not transmitted within the pre-ordained time limits, the destination PSE discards the subsequent packets to the packet concerned. In this case, all undelivered packets should be retransmitted by means of retransmission procedures of the destination PMX or packet-mode terminal.

Service quality

Sixteen bit length Frame Check Sequence (FCS), based on the HDLC procedure, is annexed to each packet in the network. Bit errors are detected with high accuracy at the receiving side. Therefore, bit errors are caused only by packets where FCS cannot detect error occurrences. If the lines with an order of $10^{-9}, 10^{-10}$ bit error rate are used, the bit error rate through the network is expected to be on the order of $10^{-11}, 10^{-12}$.

Each packet is transferred by store and forward technique. Therefore, the packet transfer time becomes longer in comparison with circuit switching. Packet transfer time consists of electrical transmission delay, handling time in the switching equipment, waiting time for transmission and serial-parallel conversion time. The target value of this transfer time through the network is 150 msec on an average, which is much shorter than the allowed time in conversational communications.

NETWORK ACCESS PROTOCOL SCHEME

Subscriber interfaces, which is required to access NTT’s packet switched network, include three types of protocol shown in Figure 3, the Network-Host protocol that specifies the packet-mode interface, the PAD-Host protocol that defines the interface between the Packet assembly/disassembly function (PAD) and the packet-mode terminal, and the Network-Terminal protocol which is required to enable non-packet-mode data terminals to be accommodated to the network.

Network-host protocol

In order to make it easy to implement the end-to-end protocol from the viewpoint of hardware and/or software, the end-to-end protocol should be divided into three independent layered protocol levels, besides the physical interface level, as shown in Figure 4. Network-Host protocol defined by the network specifies two of them, that is, the Frame level protocol and the Packet level protocol. Frame level protocol has error detection and correction functions for transmission errors on the subscriber line between the DTE and the network. That is, the Frame level protocol ensures an error free link for the Packet level delivery of packets. The Frame level protocol is compatible with the HDLC procedure standardized by ISO. The Packet level is the highest protocol, by which virtual call control, data transmission, flow control, etc., are handled. The virtual call is set up with the Call Request packet, shown in Figure 5. In the Call Request packet, the logical channel number, chosen by the DTE, is indicated as well as the network address of the called DTE. The permanent virtual circuit is discriminated from the virtual call with a certain logical channel number specified by the network and the DTE. The facility field is needed only when the user wishes to request optional user facilities, such as the closed user group and the indication of window size for the flow control. When the DTEs wish to use the closed user group facility, each DTE should register the opposite DTE address mutually to the network by the Registration packet, shown in Figure 6, with an abbreviated number indicated in the facility field.
When the DTE finishes registering the opposite DTE address and abbreviated number properly, the DTE receives a Confirmation packet from the network. Through this mutual registration method, the DTE may request a call with the Call Request packet having the abbreviated registration number of the called DTE in the facility field, as shown in Figure 7. If the DTE, which has already accomplished the registration, wants to cancel it, the DTE can do with a Cancellation packet, and also may get the Confirmation packet from the network. User data may be added, following the facility field, up to a maximum of 128 octets.

Data packet, shown in Figure 8, should be used for data transmission after the virtual circuit has been set up. In the data packet, the packet send/receive sequence number has to be indicated similarly to the control byte of HDLC information frames. The modulo 128 is adopted as the sequence number, because the Data packet delivery is confirmed from end to end by the Receive Ready packet with the receive sequence number. Sequence numbers are indicated on the third octet of the packet header for the packet send sequence number $P(s)$ and on the fourth octet for the packet receive sequence number $P(r)$. User data length in the data field may be variable up to a maximum of 256 octets. For the present, only one maximum data field length, 256 octets, is adopted and More Data Indication may be used on a user basis.
In order to prevent the receiving DTE buffer overflow, flow control is executed with the window size $W_s$, based on the packet sequence number, which is specified in the Call Request packet facility field. The calling DTE, which has received the Receive Ready packet with a sequence number $P_r$, may send Data packets with a sequence number up to $P_r + W_s - 1$. The Receive Ready packet should be transmitted from one end to another, not link by link. End-to-end Receive Ready packet transmission means that the sending DTE can detect a lost packet, if any, certainly, when the Receive Ready/Receive Not Ready packet has been received from another end. When the call cannot be established or the call is cleared, the network delivers the Clear Indication packet which contains call progress signals, specified in X.25, indicating the reason for the clearing.

**PAD-host protocol**

As the communication between a packet-mode terminal and a non-packet-mode terminal is executed through the PAD function provided by the network, the PAD-Host protocol should be specified with functions such as flow controls, lost packets recovery, conversion of data terminal control procedures, etc. A window size, which is indicated in Call Request packet being sent from the packet-mode terminal to the PAD, should be specified according to the data signalling rate of the called non-packet-mode data terminal. Non-packet-mode terminals accommodated to the network can be classified into either standard class or delimiter class. The terminal recognized as the standard class must be equipped with network standard transmission control procedure functions. This standardization gives an advantage for Hosts which provides the possibility to handle various standard transmission control procedures as one network virtual terminal. The PAD assembles data into packets with a virtual terminal control character which indicates transmission control command for communication between PAD and Host. Examples of the virtual terminal control characters are shown in Table II, and the virtual terminal control character is indicated in Call Request packet or Data packet for the virtual terminal control character transmission. Data transmission through PAD is shown in Figure 9.

**Network-terminal protocol**

Non-packet-mode data terminals accommodated to the network can be classified into either standard class or

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**TABLE II—Virtual Transmission Control Character**

<table>
<thead>
<tr>
<th>V.T.C.</th>
<th>Abbreviations</th>
<th>Bit patterns</th>
</tr>
</thead>
<tbody>
<tr>
<td>Enquiry</td>
<td>ENQ</td>
<td>0 0 0 0 1 0 0</td>
</tr>
<tr>
<td>Acknowledgement</td>
<td>ACK</td>
<td>0 0 0 0 1 0 0</td>
</tr>
<tr>
<td>Negative acknowledgement</td>
<td>NAK</td>
<td>0 0 0 1 0 0 0</td>
</tr>
<tr>
<td>End of transmission</td>
<td>EDT</td>
<td>0 0 1 0 0 0 0</td>
</tr>
<tr>
<td>End of connection</td>
<td>EOC</td>
<td>0 1 0 0 0 1 0</td>
</tr>
<tr>
<td>Quit</td>
<td>QIT</td>
<td>0 0 1 0 0 0 0</td>
</tr>
<tr>
<td>Suspend</td>
<td>SPD</td>
<td>0 0 0 0 1 0 0</td>
</tr>
<tr>
<td>Wait before transmission</td>
<td>WBT</td>
<td>0 0 0 1 0 0 0</td>
</tr>
<tr>
<td>Request response</td>
<td>RQR</td>
<td>0 0 0 1 1 0 0</td>
</tr>
<tr>
<td>Acknowledgement and quit</td>
<td>AQT</td>
<td>0 0 0 1 1 0 0</td>
</tr>
</tbody>
</table>

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Figure 9—Illustration of data transmission through PAD
delimiter class, as described before. The standard class includes synchronous terminals with the HDLC procedure and start-stop terminals with Basic mode control procedures (conversation/full duplex). The data terminal HDLC procedure is also compatible with ISO standard. In order to set up and clear a virtual circuit, the terminal with the HDLC procedure has to have switching connection control, including dialing procedure. Signaling information, including selecting signals, is delivered to the network on UI command/response in the HDLC procedure, without adopting X21 signaling sequence. On the Basic mode control procedures of data terminals in standard class, selecting control is executed by X.20 or X.20bis with the Network Control Unit.

For the delimiter class which includes only start-stop terminals, the network defines a few sets of delimiters syntactically, which trigger packet assembling, and is not concerned with the algorithms of the transmission control procedures itself. In order to ensure network transparency for end-to-end functions such as error control, information for end-to-end functions can be put into packet format by assembling the packet within a certain time after a delimiter is received, as shown in Figure 10. Delimiter sets are shown in Table III.

CONCLUSIONS

This paper has described service specifications, charging scheme, system configuration and communication protocols in NTT’s packet switched network. Public packet switched networks require the adoption of internationally agreed upon standard device-independent interfaces between networks and user terminals. Therefore, it is urgently needed to standardize the non-packet-mode interface, which has not been specified by CCITT Recommendation as yet. NTT considers that the non-packet-mode interface presented in this paper is an approach to accommodating various data terminals, including existing ones, to the packet switched network effectively.

NTT’s commercial packet switched network is now at the system design stage. Its hardware and software manufacture will be begun soon and its service will be cut over in 1979.

ACKNOWLEDGMENTS

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