5-6-2 Time Distribution Using the Network

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The network time protocol (NTP) is used by a network to synchronize time between computers. CRL generates a UTC (CRL) and standard time signal for Japan, and disseminates them to users by time-signal emissions. CRL has advanced a plan to distribute UTC (CRL) on the computer network. This paper described the composition and the content of service of the NTP time distribution system.

Keywords
NTP, Time distribution using the network, Time synchronization using the network, Japan Standard Time, UTC (CRL)

1 Introduction

As networks develop, more and more computers are being connected and the methods of network use are becoming increasingly diversified. At the same time, the importance of time data in computer functioning is also growing. NTP (network time protocol) has become popular as a network-based method for time synchronization among computers. It is not easy to conduct precise time synchronization or time distribution in a communication environment such as the Internet, where the signal route is not specified and compensation is not made for delay. Nevertheless, NTP has become increasingly widespread, as it has proven sufficiently accurate in everyday applications.

CRL has moved forward with joint research on NTP-based time distribution, developing an NTP-dedicated server and conducting an experiment to open the NTP server to the Internet. Through such activities, we have completed a system for network dissemination of the CRL's UTC, which serves as the basis of Japan Standard Time, and have decided to provide this as a routine service. This paper introduces our accomplishments thus far and describes the details of the network-based time distribution system and the contents of the service.

2 Principle of NTP and our accomplishments

2.1 NTP operating principle

The operating principle of NTP has often been discussed[1], so this paper will provide only a brief overview. NTP consists of servers that provide time data and clients that synchronize their times based on the provided time data. The servers and clients have a layered structure, and an NTP layer is called a "stratum."

Stratum 1 is normally a server synchronized with coordinated universal time (UTC), located at the top layer. Stratum 2 is a computer synchronized by NTP with the stratum 1 server. In short, a stratum 2 server works as a client of a stratum 1 server. Likewise, a stratum 3 server works as a client of a stratum 2 server. NTP conducts time synchronization using this type of layered structure.

Time is synchronized by exchanging packets containing a time stamp. First, a client computer sends a packet to a server. This packet carries time data T_{i-3} indicating when the packet was sent from the client (local time of the client). The server that has received the packet adds time data T_{i-2} to the packet, indicating when the server received the packet, and then sends the packet back to the client. Time data T_{i-1}, indicating when the server sent the packet, is also recorded in the packet. In this way the client receives a packet having three items of time data; it then adds time data T_i indicating when it received the packet. The discrepancy between the server clock and the client clock is calculated from these four times. With NTP, the time discrepancy is calculated by the following equation, assuming that the delay in network is the same in both directions.

$$\Delta T = T_{peer} - T_{host} = \frac{1}{2}\left[\left(T_{i-2} - T_{i-3}\right) + \left(T_{i-1} - T_i\right)\right] \quad \cdots(1)$$

where *Tpeer* is the time of the server clock, and *Thost* is that of the client clock.

The client collects a number of such time records and smoothes them to reduce fluctuations in network delay, and chooses a stable server to follow among a number of servers. The client calculates the absolute time discrepancy of its own clock and performs correction (by controlling the frequency) to synchronize with the server. This synchronization is carried out gradually and not at once, to prevent discontinuity in time data.

2.2 Progress in collaboration

CRL began collaboration with a domestic Internet provider—Internet Initiative Japan Inc. (IIJ)—in 1994 to study NTP-based standard time distribution over the Internet. The former Frequency and Time Standards Section of the Standards and Measurement Division and the Space and Time Measurements Section of the same division were in charge of this joint research on behalf of CRL, and worked under the stated goal of providing the Internet with Japan Standard Time, as generated and maintained by the CRL.

At that time, the UNIX-based computer serving as the NTP server had a number of problems: time resolution was not high, data processing speed was low, and the multi-tasking UNIX OS produced fluctuations in time processing. We therefore developed an NTP-dedicated server[2] capable of directly acquiring UTC (CRL), and this server is currently operational. In our collaboration with IIJ, we conducted experiments using the NTP-dedicated server in various networks (LAN-WAN, dedicated line-packet exchange network, etc.) in CRL. We succeeded in collecting the data we needed, but the developed system was found incapable of meeting the requirements for public use.

As the next step, we began joint research with Nippon Telegraph and Telephone Corporation (NTT) in October 1998. In this collaboration, we applied wide-range time transport technology using ISDN, which was developed by the NTT Software Laboratories (now the NTT Information Sharing Platform Laboratories), and made efforts to build an Internet-based time distribution network. In addition, we allowed public access to the NTP server, and initiated three-party joint research in November 1999 with IIJ and the Internet Multifeed Co. (MFEED), in order to disseminate Japan Standard Time efficiently over the Internet. In this joint research project, we studied and tested the system configuration of the time distribution network using the Internet, obtaining in the process valuable insights concerning the future of this technology.

2.3 Open experiment of Internet-based time distribution

We initiated a four-party joint research project with NTT, IIJ, and MFEED in December 2000 to develop an NTP server that would be open to general Internet users and began an open test in April 2001[3][4]. The outlines of this open test were as follows:

- We allowed the general Internet users to have access to the server so that they could use Japan Standard Time through NTP.
- We provided error information about discrepancies in user time relative to Japan Standard Time in real time; this was the first such service available anywhere in the world. Moreover, to enhance reliability, we prepared more than one time server adopting both the time distribution method jointly developed by

CRL and IIJ and NTT's ISDN-based time distribution method[5] (hereinafter, the server employing the NTT ISDN technology is called the "ISDN clock server"). We also worked to ensure the accuracy of distributed time information, using the time distribution network operating technology developed by MFEED. Fig.1 illustrates the system configuration.

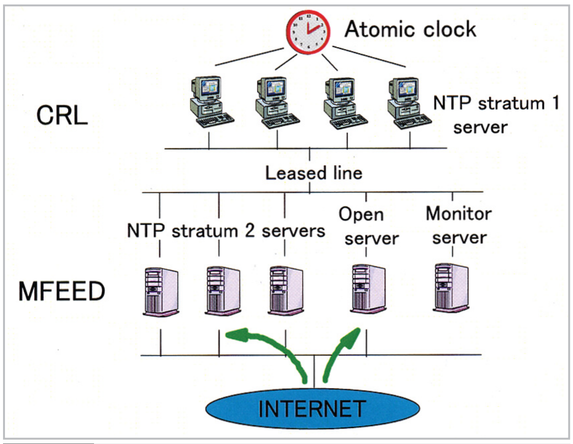

Fig.1 *NTP server configuration for the open experiment*

This experiment is designed to examine the time data distribution mechanism and system distribution network, evaluate techniques of system operation and management, and establish a method of monitoring time data.

We evaluated[6] the server stability and accuracy by comparing two times conveyed by two completely different methods of conveying time data, with reference to the ISDN clock server.

Fig.2 shows the time offset of the open NTP servers with reference to the ISDN clock server. The offsets are within ±1 ms during the measurement. Two steps observed halfway through the experiment are probably due to time synchronization with the ISDN clock server on the master side, caused by rebooting of the ISDN clock server.

Time synchronization error of the NTP server with reference to the ISDN clock server

The open test was announced to the public and introduced in the media and technical magazines, drawing significant attention and frequent hits from the outset. Fig.3 shows the number of hits per day for each of the three open NTP servers. The number of hits increased as the days went on. Although not shown in this figure, up to 3 million hits per day were recorded for a server in October 2002. Fig.2 and 3 indicate that the accuracy of timekeeping by the open NTP server was maintained unaffected by this increase in access.

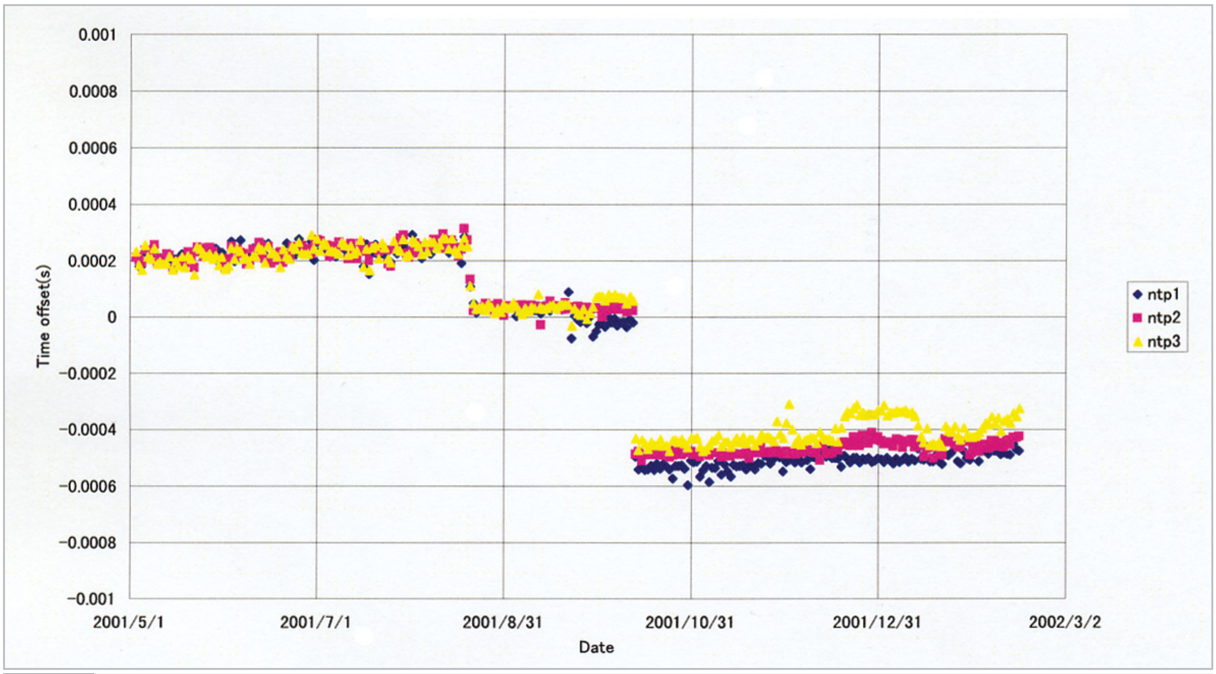

Fig.2 *Time synchronization accuracy of the open NTP server*

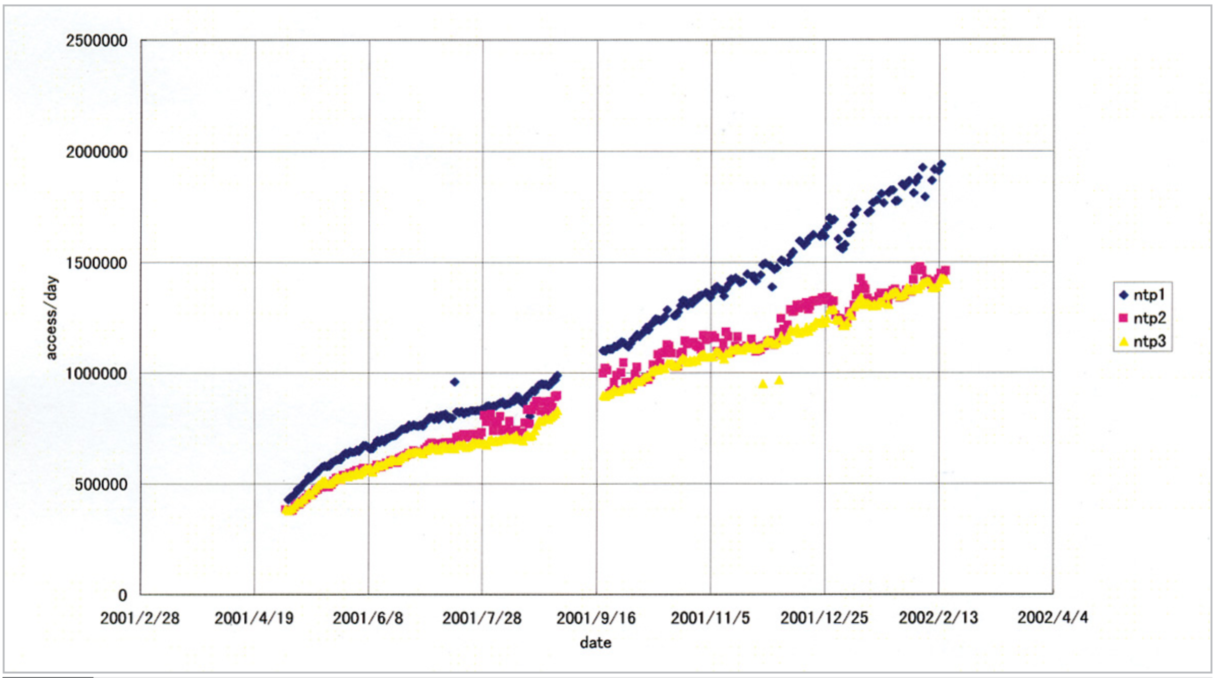

Fig.3 Hits on the open NTP server

3 Network-based time distribution system and services

Based on the results of the open experiment, we have established a system that is capable of providing routine services. Following is an outline of the system.

3.1 Configuration of the time distribution system

The developed network-based time distribution system is based on the system configuration adopted in the open experiment and is capable of disseminating time data among multiple client computers. Specifically, we did not change the server configuration and employed a router instead of a bridge for connection to the dedicated line, sharing servers by routing control. In order to increase the processing speed and reduce delay, we adopted an L3 (Layer 3) switch router (CISCO Catalyst 2948 G). Fig.4 shows the system configuration. Layer 3 is the third layer in the OSI (Open System Interconnection) model, also called the network layer. Compared with the common software router, the Layer 3 switch router can handle packets at higher speed due to the advantages inherent in its hardware design.

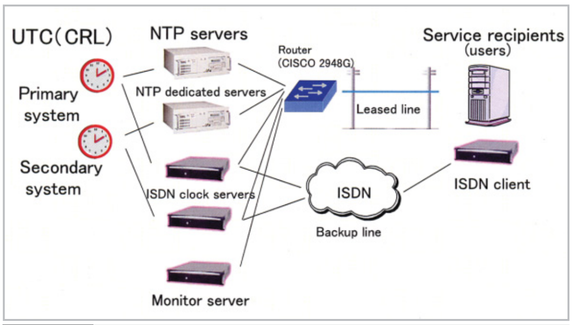

Fig.4 Network-based time distribution system configuration

The system is installed in three racks to save space. Currently, the maximum number of channels open to clients is limited to 12 due to rack capacity. Because the switch router has 48 ports, the number of available channels will increase if this space limitation is lifted.

3.2 System redundancy

Redundancy is built into the system to lower the risk of system failure and to stabilize the distribution of time data. CRL's standard time generator mechanism features two system lines, and UTC (CRL) is connected to both. The two systems are synchronized with UTC within an error margin of several tens of nanoseconds, offering accuracy as high as that of the NTP reference clock. We have decided to use these two systems (A and B) as reference clocks to reduce the risk of system failure.

As described in **2.3**, we have prepared two types of servers per reference clock, such that there are a total of four NTP stratum 1 servers.

Connection to clients is via direct connection using a dedicated line. Additionally, the ISDN server and ISDN public telephone network serves as a backup in case of line failure.

In terms of power equipment, we have an in-house power generator (commercial power plus a 20-kVA UPS and a 55-kVA generator) for the reference clock and an additional UPS backup for each reference clock system.

3.3 Monitoring system configuration

Monitoring is absolutely necessary for routine server operation. We will therefore construct a monitoring system based on that used in the open experiment.

For monitoring, a dedicated monitor server (UNIX) is synchronized with the stratum 1 server to be monitored with the NTP daemon software, ntpd. The monitor server activates the NTP peer monitoring program, ntpq, at regular intervals and obtains information about the accuracy of time synchronization. In the event of significant data fluctuation, the monitor server issues an alert, as the peer server displaying such fluctuations may be deactivated. The monitor server also issues an alert when the time offset exceeds a predetermined limit, under the assumption that time distribution accuracy has declined. This alert is delivered by e-mail, to be checked by the operator. No auto-stop or supplementary functions have been prepared; however, the developed system worked successfully without fatal errors in the open experiment.

3.4 Features of the server

As we have already reported[7] on the design of the stratum 1 server, we will not repeat a description here. Resolution of the time stamp of this server is assumed to be 1μs. Here we will describe the delay between the

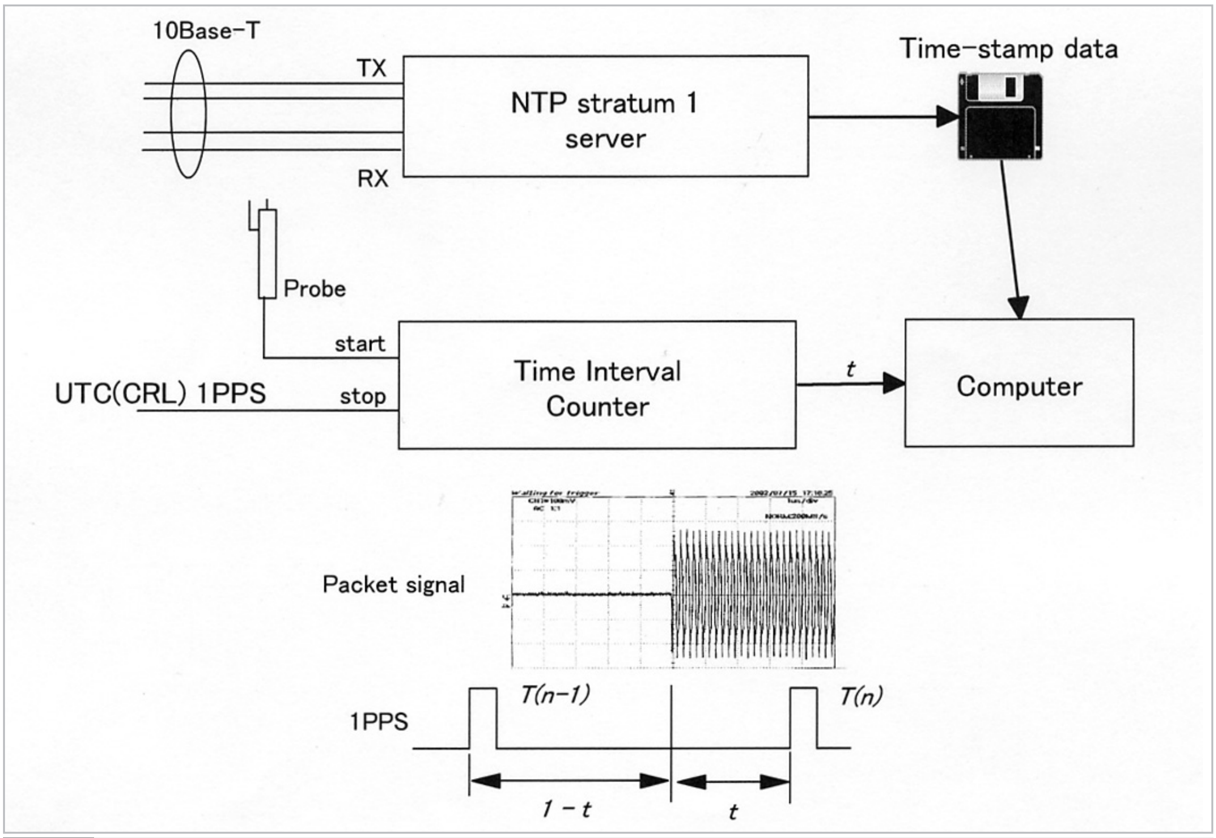

Fig.5 *Measurement of internal delay of the NTP packet*

moment an NTP packet passes the network interface and the moment the program issues a time stamp.

In order to detect the actual NTP packet, we used a 10 Base-T network interface and entered the extracted transmission signal and received signal as triggers for the time interval counter. Fig.5 shows the measurement configuration. The use of a 10 Base-T connection makes it easier to extract the preamble signal in the packet. The initiating point of the preamble signal was used as the start signal for the counter. Table 1 shows the specifications of the server used.

Table 1 *NTP server specifications*

NTP stratum 1 server specification	
CPU	Intel pentium III 800MHz
chip set	Intel 440BX AGPset
Network Interface	intel PRO/100+
Time coder	NTP time code generator card (Cosmo research)
OS	IBM PC DOS 2000
Packet Driver	e100bpkt (Crynwr version 11.9)
NTP software	PCNTP (CRL original)

The time interval counter measures time difference *t*, which is shorter than one second, between the NTP packet initial time and the UTC (CRL) 1PPS time. Since time is $T(n)$ when time difference *t* is acquired, the actual time, *T*, for packet issuance is expressed by the following equation.

$$T = T(n) - t \quad \cdots(2)$$

Comparing time *T* measured by the above method and the time of the time stamp added by the server program, we measured the delay corresponding to internal packet processing. Fig.6 and 7 are histograms showing measurement results for packet processing delay in transmission and reception, respectively.

For packet transmission, the packet to which a time stamp is assigned is placed in the transmission queue and then immediately sent, unless there is congestion in the network. Thus the measured delay was short, at around 42.6 μs, and the deviation was also small-about 5 μs. Conversely, the delay during packet reception was large, at about 145 μs.

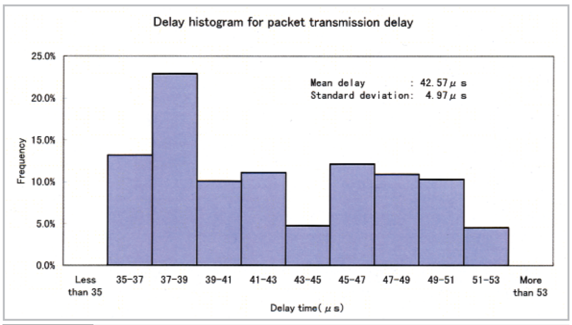

Fig.6 *Delay histogram for packet transmission delay*

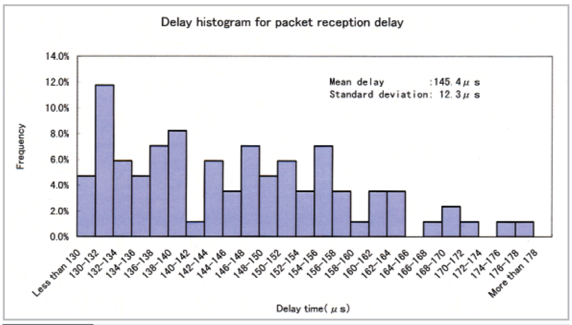

Fig.7 *Delay histogram for packet reception delay*

This is because it takes about 90 μs to add a preamble, Ethernet header, IP header, NTP packet data, and a frame check sequence to the NTP packet; thus the delay due to the addition of a time stamp was about 55 μs. Relative to packet transmission, the deviation in delay is doubled during packet reception. This is probably because packet reception is affected by the network interface (card) and driver.

In NTP, the reception delay is regarded as equal to transmission delay. As a result, any actual difference between these delay periods appears in the form of an offset in time synchronization among computers.

3.5 Service policy

When providing time services, we must establish a clear security policy, as ensuring security is a key requirement. The primary element to be protected is the server system that conducts the network-based time distribution. When handling time information, the integrity of the data is critical. Maintaining this integrity entails ensuring correct hardware operation, accurate time data, and smooth data transmission over the network.

System security is incorporated into our contracts with clients (enterprises or others). The concepts underlying the provision of service are as follows:

- Provision of time data, whether the client intends to use it for fee-based or for free services
- Clarification of the responsibilities of the

Table 2 Requirements for the Network-based Time Distribution Service

A client wishing to connect to the network-based time distribution service provided by the Communications Research Laboratory (hereinafter "CRL") must meet the following technical requirements.

1. Hardware requirements

- Equipment installed at the CRL must be held in the rack unit prepared by the CRL.
- Allotted rack space is 410 mm in width, 380 mm in depth, with height of up to 4 rack units.
- One grounded two-pin outlet is available.
- Power supply is AC 100 V / 50 Hz.
- Power limit is 200 VA.
- Connection to the NTP server must be made through one 10/100Base (RJ45) port.

2. Rules for routing control

- The client prepares an address for connection. When a private address is to be used, the CRL determines the address.
- The address for connection must be provided separately from the external network, and external packets must not be drawn into the address for connection.
- Connection is controlled by static routing.
- The client performs access control with the client router and sends only specified packets to the CRL router.

3. Requirements for connection to the server

- Limit the number of devices having access to a CRL stratum 1 server per connection to the separately determined number.
- Allow at least 64 seconds for polling time for one stratum 2 server.

4. Other

- Other technical requirements not referred to herein will be determined by mutual consultation between the CRL and the client.

CRL and of the client
- Provision of time data on a continuous basis, except during service maintenance (as necessary)
- CRL released from any liability for damages due to NTP server connection difficulties or due to problems with the accuracy of time data
- No guarantee provided as to the accuracy of time data in the client NTP stratum 2 server
- Restricted access to the ISDN clock server
- Prohibition of a global connection to the router in the connection IP
- Limitation on number of clients with access to the NTP server
- Client required to pay for connection equipment, for electrical work, and for communications charges
- Access to the CRL's NTP server restricted to identified clients

We have specified the necessary requirements for connection equipment. These specifications will be established as the "Requirements for the Network-based Time Distribution Service."

We will ensure system security by urging clients to meet all necessary requirements, providing services only to identified clients, sending only NTP packets to the Internet, and avoiding direct connection to the Internet.

4 Conclusions

Almost ten years have passed since the start of the first round of collaboration on network-based standard time distribution. Time synchronization remains a challenge, with a great deal to be resolved, while at the same time the Internet has evolved drastically. This discrepancy in progress is due to a lack of clarity in user needs relating to time standards, and to the need for a breakthrough in the improvement of accuracy. Nevertheless, we expect that the future of this technology will become clearer after this network-based time distribution service is in place and becomes subject to routine use.

To date, we have completed a system that can distribute Japan Standard Time over a network. The accuracy and stability of this system are sufficient to meet current needs. Meanwhile, the usefulness and importance of time data has become a major topic in the business of time verification. Accordingly, we believe it is necessary to upgrade the system to form part of the network infrastructure.

Acknowledgments

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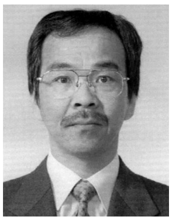

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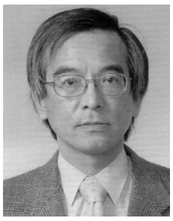

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