Real-Time Measurement of One-Way Delay in the Internet Environment

Tsukasa Iwama, Akihiro Kaneko,
Akihiko Machizawa, and Hiroshi Toriyama

National Institute of Information and Communications Technology (NICT)
4-2-1 Nukui-Kita, Koganei, Tokyo, 184-8795 JAPAN

1. Introduction

The Network Time Protocol (NTP) is widely used to synchronize timekeeping among a set of distributed time servers and clients. Unfortunately, in the usual Internet environment, delays in data transfer are not constant, even for the same route, so the delay from the NTP server to a client is not always the same as that from the NTP client to the server. This has a significant effect on the accuracy of time synchronization. Therefore, information on actual transfer delays is required to improve the accuracy of time distribution.

We developed a hardware time- stamper (HTS) that stamps the local time on identified packets without delay. It is applicable to Giga-bit Ethernet (GbE) connections and has a time resolution of 4 ns. By installing HTSs on both sides of a transfer path, we can immediately obtain the delay time of the path with a precision of within 10 ns. However, this requires highly stable clocks on both sides.

We can use the HTSs to measure various network characteristics. In this paper, we report the results of measuring packet-size dependence for about 25-30 km data transfer. For these measuremenst, we used cesium atomic clocks on both sides and measured time differences using the GPS common-view method. The results revealed the network properties of the transfer path and showed that the HTS could stamp the time accurately without interrupting the system.

These measurements showed that the HTS performed satisfactorily. We can therefore use this architecture to develop economical, simple, high-performance systems for time synchronization. In the next step, we will begin developing time- synchronizing systems corresponding to IEEE 1588 and construct various time-based networking systems.

2. One-way delay measurements

Figure 1 shows a block diagram of the system used to measure real-time one- way time delay in the Internet environment.

The measurement systems included, packet sender/receiver sets in an Internet Data Center (IDC) and packet responder sets at NICT about 30 km far from the center of Tokyo. In these measurements, we used two IDCs in the center of Tokyo, one at Shinjuku and the other at Ohte-machi.

The IDCs and NICT were connected via an Internet which is almost applicable to higher than Giga-bit Ethernet (GbE) connections. Only the Shinjuku IDC had a 10 mega-bit connection.

The packet sender/receiver and packet responder consist of a Free-BSD based PCs

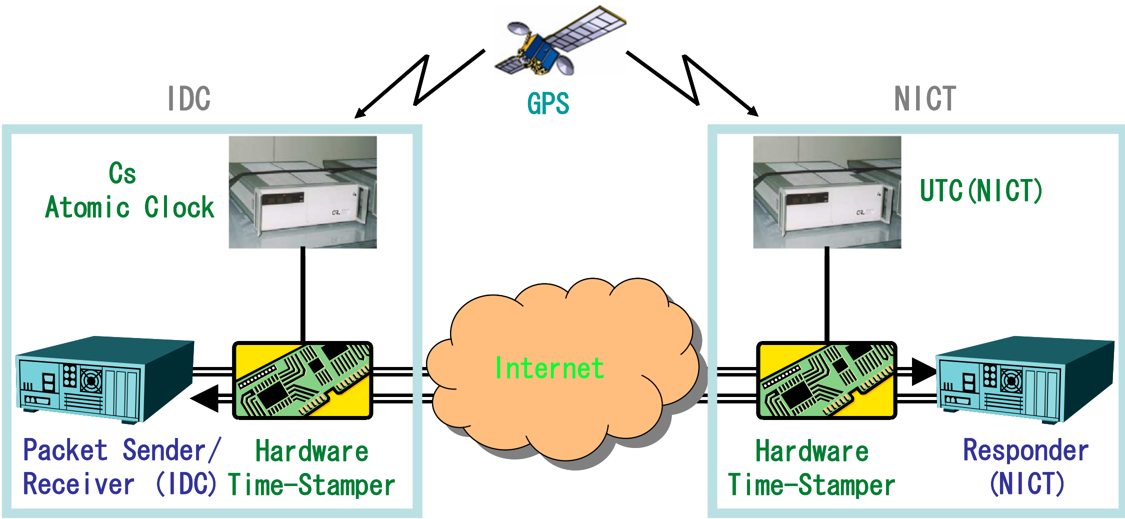

Figure 1 Block diagram of measurement system

with a hardware time-stamper (HTS) installed between the PCs and the network.

The HTS automatically stamped a unix-time on packet as they passed through. Here, the time stamped was generated from signals carried from a standard clock. In these measurements, the standard clock on the NICT side was the UTC(NICT) and on the other side it was a cesium atomic clock.

Both time scales were compared using the GPS common-view method and the time difference was recorded. Throughout the measurement, the time differences were less than 100 ns and the measurement results were corrected using the time differences at that time.

The time resolution of the HTS was ±4 ns and HTSs were inserted on both sides of the Internet. Therefore the total time resolution for measuring a one-way delay was ±8 ns.

Usually, one packet was sent from one side to the other with the HTS automatically stamping the time on both sides of the Internet. This meant that two time-stamps were recorded on one packet and the difference in the two time-stamps showed the time delay. By sending only one packet, we could determine the internet time delay in real time.

In our experimental measurements, one packet was sent from the IDC (packet sender) to NICT (packet responder) and the packet responder immediately returned it to the IDC (packet receiver). As a result, the HTSs stamped each packet four times, thus providing a record of several time delays. Using these results, we investigated the time dependent factors in the Internet environment.

3. Measurement results

3.1. Characteristics of one-way delay

In the Internet environment, data packets are sent through various network equipment like routing switches and so on. The behavior of this equipment is dominated by the one-way delay time. Usually, this behavior is based on the store and forward mode and the size of data packet therefore has a significant effect on the one-way delay characteristics.

First we measured the dependency of one-way delay on packet size. In this measurement, we sent packets ranging from 56 to 1,426 bytes in 1 byte steps. By repeating these cycles 1,000 times, we obtained a total 1,371,000 pieces of measurements.

Figure 2 shows all the data for the one-way delay measurements between the Shinjuku IDC and NICT. In the Internet environment, data traffic is usually very crowded, so the delay time results were widely distributed (Fig. 2).

To reduce this dispersion, we grouped five dara for the same packet size and chose the smallest, i.e., the fastest available delay. Figure 3 shows the results of this data grouping.

To investigate the packet size dependency of the results shown in Figures 2 and 3, we analyzed the correlation factors using the linear regression method. The results of this estimation were 188-192 ns/bit ≒5.22-5.32 Mbps dependency for both IDC -> NICT and NICT -> IDC, for both sets of results (Figs. 2 and 3). However, there was a large difference in the residual standard error between the figures. In Figure 2, the residual standard error was about 100 μs and in Figure 3, it was about 18 μs. Similar results were reproduced on other days.

Figure 4 shows all the data for one-way delay measurements between the Ohte-machi IDC and NICT. In these measurements, we repeated the packet step cycles 200 times.

There was a 10 GbE connection between the Ohte-machi IDC and NICT, and there was no crowding of data traffic. The results of this estimation were 5.3 ns/bit ≒ 189 Mbps dependency for both IDC -> NICT and NICT -> IDC, and the residual standard error was about 3 μs.

As these results show, the dependency of time delay on packet size was linear. Even in a crowded Internet environment, data grouping and selection were effective.

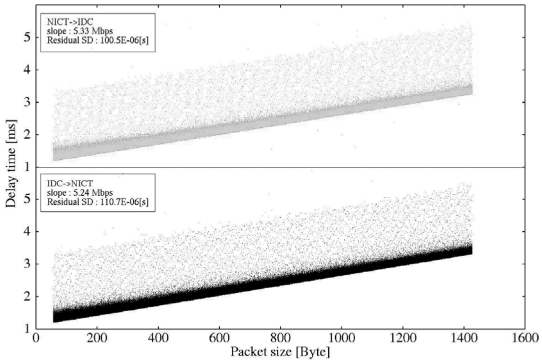

Figure 2 One-way delay [all data] (Shinjuku IDC – NICT)

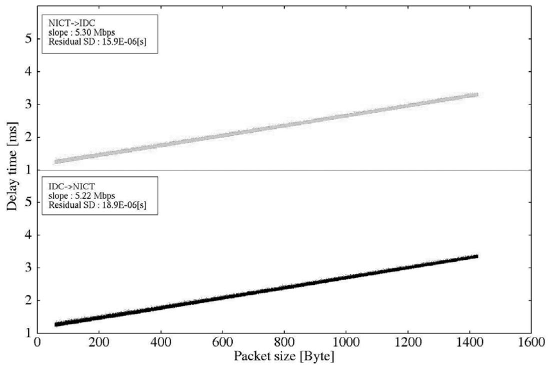

Figure 3 One-way delay [fastest of 5] (Shinjuku IDC – NICT)

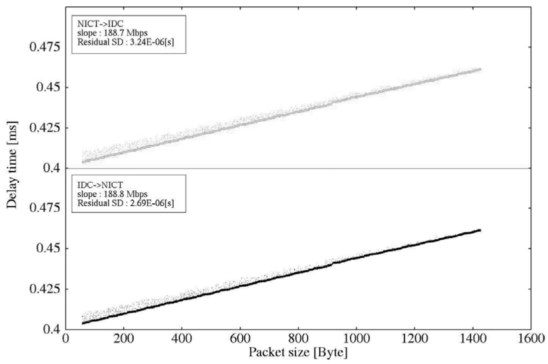

Figure 4 One-way delay [all data] (Ohte-machi IDC – NICT)

3.2. Other characteristics

Our HTS performed well in relation to time resolution. We then measured the one-way delay under different network conditions. Figure 5 shows the results of measuring the one-way delay from the Shinjuku IDC to NICT. The gray data are the same results as shown in Figure 2. When we measured the black data, we deleted one routing switch from the IDC – NICT connection., The black data therefore represent a better performance in comparison with the gray data.

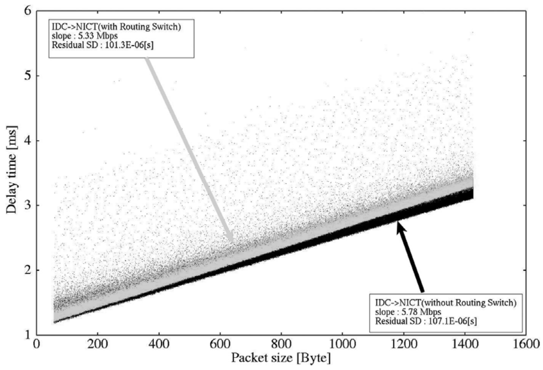

Figure 5 One-way delay [all data]
(Shinjuku IDC –> NICT)

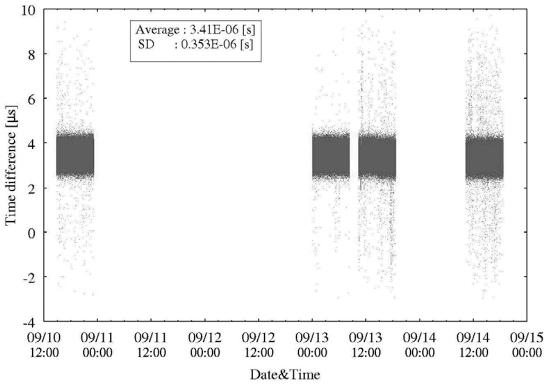

Figure 6 Time differences
(Ohte-machi IDC – NICT)

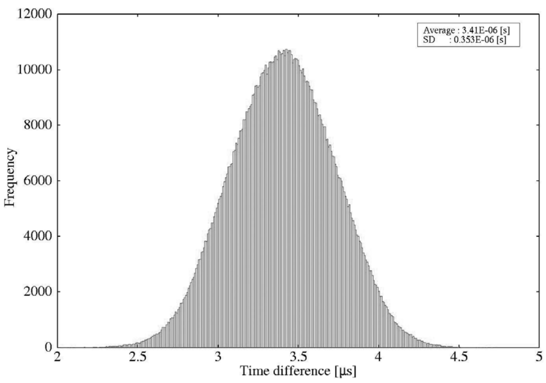

Figure 7 Histogram of Time differences

These results indicate that our HTS is capable of inspecting a network under high performance conditions and in real time.

For the Ohte-machi IDC, we did not set a GPS common-view system, so cesium atomic clock used in the Ohte-machi IDC was not synchronized with the UTC(NICT), the time difference was roughly 1.5 μs.

These differences in the clock time represent time differences in the time delays between up and down links twice.

Figure 6 shows the time differences between time delays in the up and down link between the Ohte-machi IDC – NICT. These measurements were the total for 5 days. The measurement results showed an ideal normal distribution (Fig. 7). From these measurements, the time difference was about 3.4 μs with SD = 0.35 μs. We then estimated the clock-time difference as 1.7 μs.

4. Conclusions

To enable actual transfer delays to be determined, we developed a HTS that stamps the local time on identified packets without delay. Using the HTS, we measured variousl Internet time delay characteristics.

The results showed linear dependency between the size of data packets and one-way time delay. Even in a crowded Internet environment, data grouping and selection were effective for estimation purposes.

The measurement results also showed the HTS performed well in inspecting network conditions under high performance conditions and in real time, and in estimating clock-time differences.

Our next step is to develop high performance time synchronizing systems corresponding to IEEE 1588 and to construct various time-based networking systems.