Precise Estimations of High-Speed Network Time-Transfer

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Abstract

The Global Positioning System (GPS) common-view method is one of the main methods used for time-transfer to remote atomic clocks. This method gives accurate time, but it is difficult to set up and operate. Network Time Protocol (NTP) is widely used for time-transfer in network environments. However, it is difficult for simple NTP to receive accurate time because of the effects of cross-traffic and the interrupt requests of software processing.

We have recently developed the hardware for a Simple-NTP (SNTP) board that can measure a one-way delay time with ns-order accuracy. This SNTP board can be operated by an external atomic clock. Thus, we can compare precision time at remote sites through a network.

We have also developed a precise method for estimating network time-transfer that reduces the effects of cross-traffic by using data-filtering techniques. Using measured data, we estimated the performance of our method and found that it is almost as accurate as the GPS common-view method when the standard deviation (SD) is ≤ 2 μs.

1. Introduction

The demand for a high-speed and high-precision network time-transfer technique is increased in line with the development of the information and communications technology. The Global Positioning System (GPS) common-view method is usually used for time-transfer to remote atomic clocks. This method offers accurate time, but it is difficult to set up and operate, especially in Internet Data Centers (IDCs). Network Time Protocol (NTP) is widely used for time-transfer in network environments. Unfortunately, in the typical Internet environment, even on the same route, it is difficult for simple NTP to receive accurate time because of the effects of cross-traffic and the interrupt requests of software processing. Therefore, an estimate of actual transfer delays is needed to improve the accuracy of time distribution.

We have recently developed hardware in the form of a Simple-NTP (SNTP) board that can measure one-way delay time. It is applicable to Giga-bit Ethernet (GbE) connections and has a theoretical time resolution of 4 ns. By installing SNTP boards on both sides of a transfer path, we can immediately obtain the delay time of the path with a precision within 10 ns. However, this requires highly stable atomic clocks on both sides. Thus, we compare the precision time at remote sites through a network.

In this study, we also developed a precise method for estimating network time-transfer that reduces the effects of cross-traffic using data-filtering techniques. Using measured data, we estimated the performance of our method and found that it is almost as accurate as the GPS common-view method. From the comparison results, the network time-transfer method using data-filtering is practical and accurate when the standard deviation (SD) is ≤ 2 μs.

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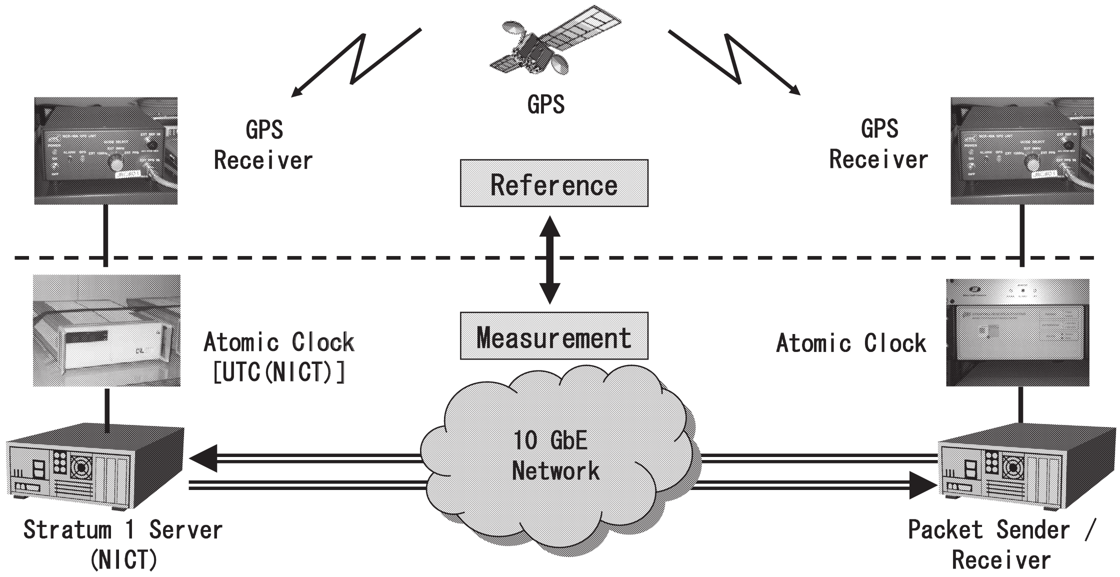


Figure 1. Block diagram of Network Time-Transfer System.

2. Network Time-Transfer System

In Fig. 1, a block diagram of the network time-transfer system used to measure real-time, one-way time delay in an Internet environment is shown.

The measurement systems included a packet sender/receiver (P-S/R), a packet responder (P-Res: stratum 1 server), atomic clocks, and a high speed ($\geq$ 1 GbE) network environment. The P-S/Rs and P-Res consist of Free-BSD-based PCs with a hardware SNTP board installed between the PCs and the network.

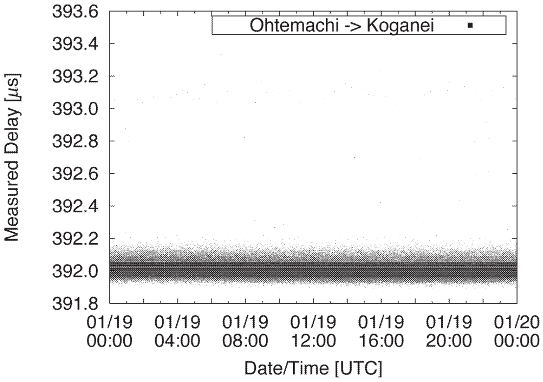
The hardware SNTP board automatically stamps an NTP-time on each packet as they pass through. Here, the time stamp is generated from signals sent from an atomic clock. In these measurements, the atomic clock on the P-Res was a UTC(NICT), based on Coordinated Universal Time, and on the P-S/Rs, it was a cesium atomic clock. Both time scales were compared using the GPS common-view method, and the time difference was recorded.

In these measurements, we used three P-S/Rs, the first was at Ohtemachi, which is in the center of Tokyo and about 30 km from NICT, the second was at Dohjima in the center of Osaka, about 400 km from NICT, and the other was at NICT, located in Koganei, in west Tokyo. At the NICT P-S/R, packets were carried via the Ohtemachi Network Node. Therefore, an NICT P-S/R and a P-Res were placed at different network-segments and connected through the Ohtemachi Network Node.

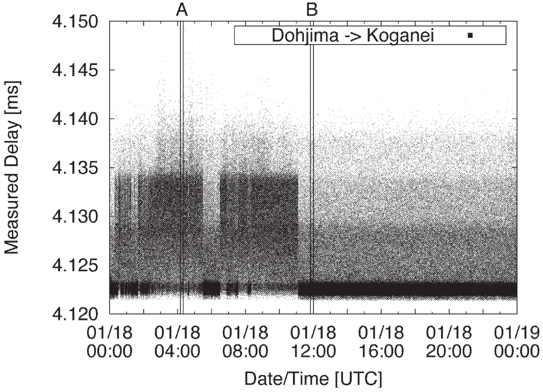
3. Time-Transfer Results

3.1. One-way delay data

NTP packets were sent from the P-S/R at the rate about 7 or 8 per second. In Fig. 2, samples of received one-way delay data are presented. Figure 2(a) indicates the one-way data from Ohtemachi to NICT received in one day. In this network environment,

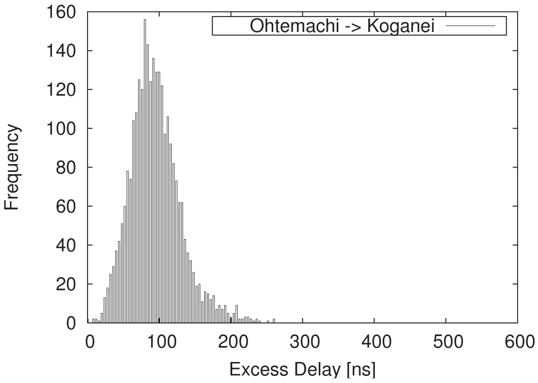


(a) Ohtemachi->Koganei

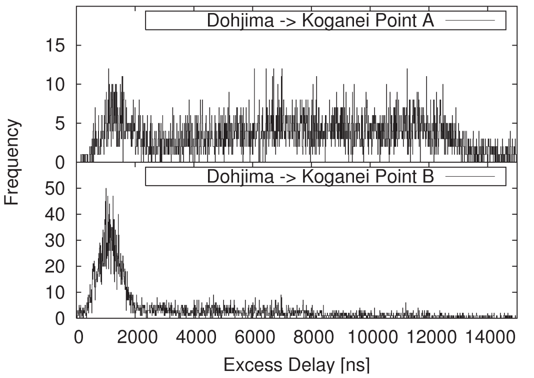


(b) Dohjima->Koganei

Figure 2. Samples of Received One-way Delay Data



(a) Ohtemachi->Koganei



(b) Dohjima->Koganei

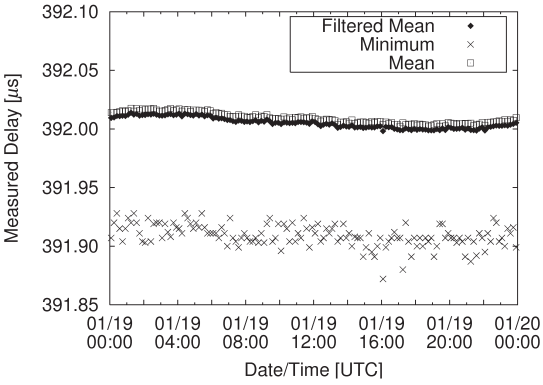
Figure 3. Histograms of Measured Excess Delay Data

cross-traffic is light, and the excess delay of one-way delay data was about 200 ns. Figure 2(b) is the one-way delay from Dohjima to NICT received in one day. In this network environment, there was heavy cross-traffic due to the large number of packets that flow between Tokyo and Osaka. Therefore, the excess delay was more than 18 μs in this route. From Fig. 2(b), it is clear that cross-traffic was most intense in the morning.

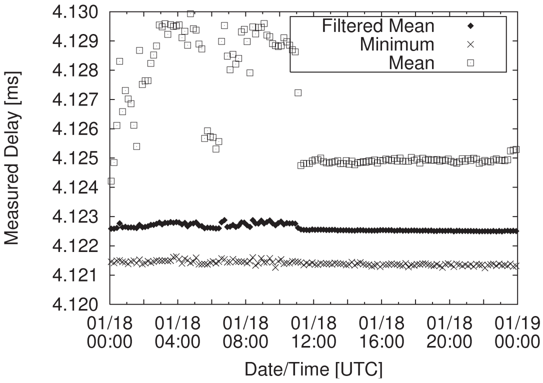
Figure 3 shows the histograms of received excess one-way delay data. In Fig. 3(a), the SD σ is about 40 ns, and 95% of the data are within the 160 ns from the minimum delay time. In Fig. 3(b), SD is about 3-4 μs in the morning and about 2 μs in the afternoon.

From Fig. 3, we can see that a forward domain of the delay profile forms a bell shape regardless of the traffic conditions. When there is heavy cross-traffic, data from a queueing delay domain increase, and data from a bell-shaped domain relatively decrease. In Fig. 3(b), the delay profile is different at point A and B, but the widths of the bell shapes are the same, at about 2 μs. This result indicates that the bell-shaped domain is independent of the cross-traffic.

By paying attention to this point, it is possible to estimate the actual transfer delays that are not easily affected by cross-traffic. That is, by filtering only the bell-shaped domain and extracting and averaging the data, we can provide more accurate measurement data.

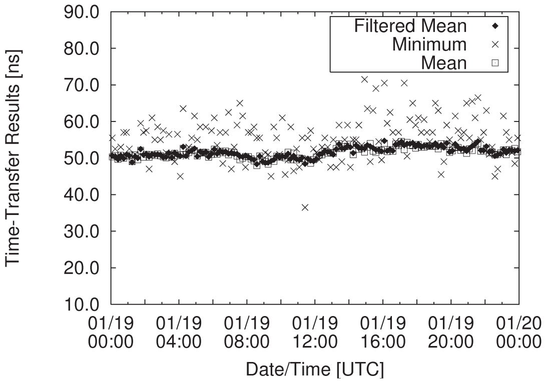


(a) Ohtemachi->Koganei

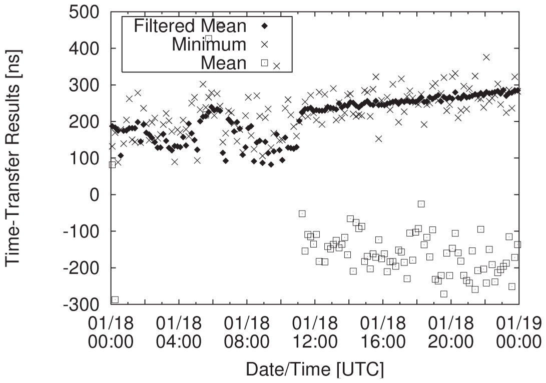


(b) Dohjima->Koganei

Figure 4. Samples of Calculated One-way Delay Data



(a) Ohtemachi->Koganei



(b) Dohjima->Koganei

Figure 5. Samples of Network Time-Transfer Results

3.2. Data-filtering

To estimate the data accuracy, we need to compare the measurement data with GPS common-view data. Therefore, received data were filtered and averaged every 10 minutes in order to obtain the measurement data.

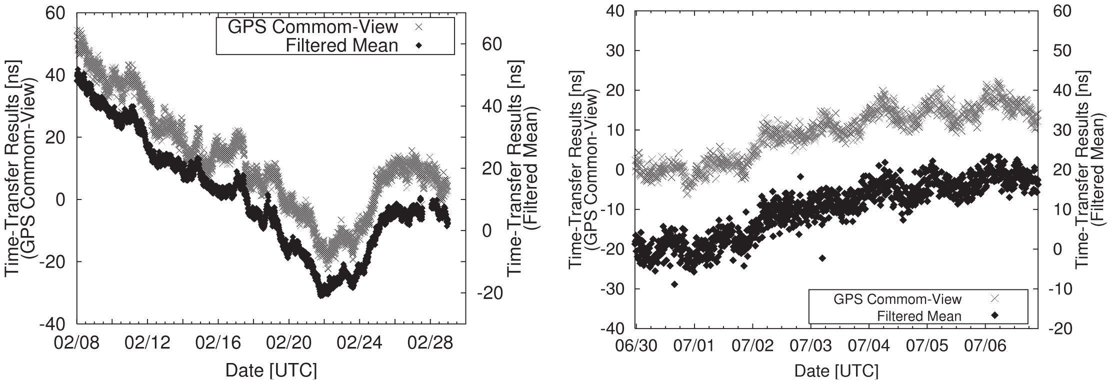
Figure 4 shows samples of the calculated results of one-way delay data. Source data are the same as in Fig.2. In Fig. 4, the mean of all-data and the minimum data in 10 minutes are plotted for comparison. Fig. 4(a) depicts the data in light cross-traffic, the data-filtered mean is almost the same as the all-data mean and has better stability than the minimum data. On the contrary, in condisions with heavy cross-traffic (b), the data-filtered mean has almost the same stability as the minimum data and much better stability than the all-data mean. These results demonstrate that the data-filtering method operates effectively.

To estimate the effect of the data-filtering method, we calculated the network time-transfer. Figure 5 shows samples of the results. Source data were also the same as in Fig.2. In Fig. 5, time-transfer results are not calibrated, but are half of the difference between the up-link and down-link.

In Fig. 5(a), SD is about 40 *ns*, and data stability is several *ns* in the data-filtered mean and all-data mean, and about 10-15 *ns* in the minimum data. At the left side of Fig. 5(b), SD is 3-4 *mus*, and data stability is 100-200 *ns* in the data-filtered mean and the minimum data, and about 200 *ns* with a 2-*mus* data offset in the all-data mean. At the right side of Fig. 5(b), SD is about 2 *mus*, and data stability is 10-20 *ns* in the

Table 1.   Comparison of SD with data stability

SD	Data-filtered mean	Mean	Minimum
40 ns	several ns	several ns	10-15 ns
200 ns	10 ns	20 ns	40-50 ns
2 μs	10-20 ns	200 ns (offset -400 ns)	100 ns
3-4 μs	100-200 ns	200 ns (offset -2 μs)	100-200 ns
10 μs	100-200 ns	1 μs (offset -3 μs)	200 ns



(a)$\sigma \approx 40$ ns (b)$\sigma \approx 2.2$ μs

Figure 6.   Compare Data-filtered Mean with GPS Common-View

data-filtered mean, about 100 ns in the minimum data, and about 200 ns with a 400-ns data offset in the all-data mean.

Using a NICT-Ohtemachi-NICT network link with additional controlled cross-traffic, we estimated the relationship between SD and data stability. Table 1 presents this relationship. The superior results of the data-filtering method are evident in all the SDs listed in the table.

3.3.   Compare with GPS common-view

Finally, to estimate the accuracy of the data-filtering method, we compared the data-filtered mean with GPS common-view data. Figure 6 shows the comparison results. In the figure, we adopted only highly precise data where the GPS altitude was more than 60 degrees. The data-filtered means were plotted with a 20-ns offset. Figure 6(a) shows that the accuracy of the data-filtered mean is less than 10 ns and is almost the same as the highly precise GPS common-view data when SD $\approx$ 40 ns. In heavy cross-traffic conditions, as in Fig. 6(b), accuracy of the data-filtered mean is 10-20 ns and corresponds to Table 1.

From these comparison results, it is evident that network time-transfer using data-filtering is a practical method with the accuracy listed in Table 1.

4. Conclusion

We have developed a hardware SNTP board that can measure a one-way delay time with ns-order accuracy. This SNTP board can be operated by an external atomic clock. We have also developed a precise method for estimating network time-transfer that reduces the effects of cross-traffic using data-filtering techniques. Using measured data, we estimated the performance of our method and found that it is almost as accurate as the GPS common-view method.

The comparison results indicate that network time-transfer using a data-filtering method is practical and accurate when the standard deviation $\leq 2\ \mu s$.

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References

Iwama, T., et al. 2004, Proc. ATF2004, 317.
Iwama, T., et al. 2006, IEICE Trans. vol. J89-D.