PRECISE AND RELIABLE TIME-TRANSFER TECHNIQUES USING HIGH-SPEED NETWORK

Tsukasa Iwama, Akihiko Machizawa, Hiroshi Toriyama

National Institute of Information and Communications Technology,

4-2-1 Nukui-kita machi, Koganei, Tokyo, 184-8795 Japan

E-mail: iwama@nict.go.jp

Abstract - In a normal Internet environment, even over the same route, it is difficult for a NTP to receive an accurate time which is less than milli-second order. There are two major problems. The first problem is caused by cross-traffic and the second problem is network conditions. Toward the first problem, we have considered a precise method of estimating network time-transfer to reduce the effects of cross-traffic that uses data-filtering techniques. For the second one, the adjusting data-offset technique overcomes the effects of the link changes. Using a combination of these techniques, we can operate an atomic clock for a long time in an IDC. From the measuring results of the comparison with GPS common-view, a network time-transfer using data-filtering method with adjusting data-offset is practical and offers accuracy under the specific condition.

I. INTRODUCTION

In the time related business, the demand for an accurate network time-transfer techniques increase very rapidly. Network Time Protocol (NTP) is widely used for time-transfers in network environments. Unfortunately, in a normal Internet environment, even over the same route, it is difficult for a NTP to receive an accurate time[1]. There are two major problems. In this paper, we present effective solutions for these problems.

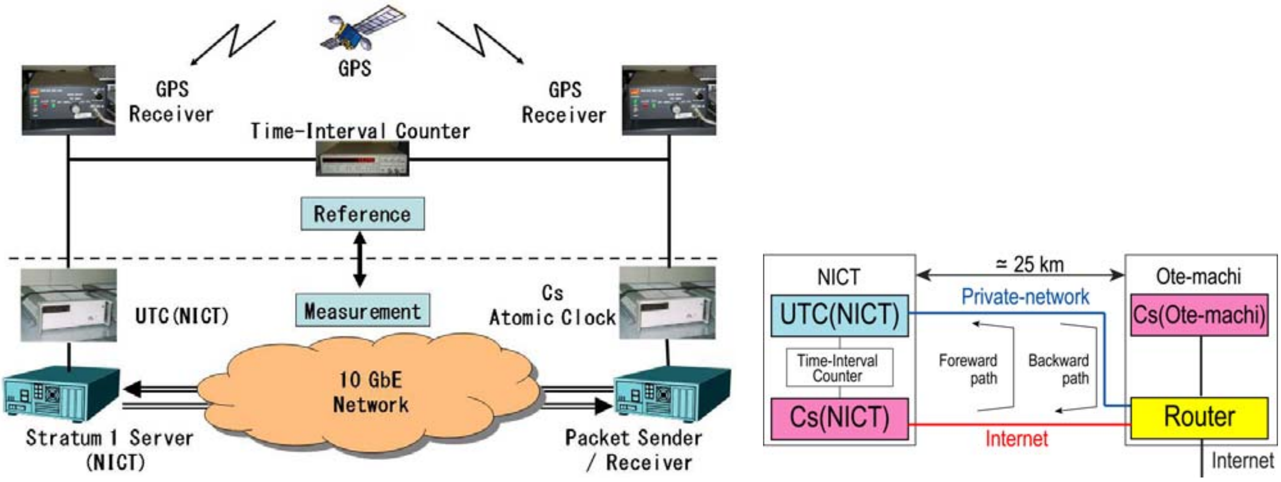
The first problem is caused by cross-traffic. Our hardware SNTP board can measure a one-way delay time with +/- 4 nanoseconds accuracy. In this situation, cross-traffic affects the precision of the measured data. We have considered a precise method of estimating network time-transfer to reduce the effects of cross-traffic that uses data-filtering techniques which was reported at ATF2006[2]. Using measured data, we estimated the performance of our method and found that it can offer almost the same accuracy as the Global Positioning System (GPS) common-view method.

The second problem is network conditions. NTP can measure the packet response time but it is greatly affected by routings. Routings are sometimes changed or suspended during long-term operations and the packet response time is often varies. Therefore, we set the offset time for both the up-link and the down-link and calculated the values for every measured piece of data using a linear-prediction method. This adjusting data-offset technique overcomes the effects of the network-link changes.

Using a combination of these techniques, we can operate an atomic clock for a long time in an IDC. From the measuring results of the comparison with GPS common-view, a network time-transfer using data-filtering method with adjusting data-offset is practical and offers accuracy to within the standard deviation, which is later than 2 μs. The operation is simple and it is an easy way to determine the time that is accurate enough for time related business use.

II. NETWORK TIME-TRANSFER SYSTEM

The measurement systems included, a packet sender/receiver, a packet responder (Stratum 1 Server), atomic clocks, and high speed (≥ 1 GbE) Network environment. Packet senders/receivers and the stratum 1 server set up at NICT consist of a



(a) Block diagram (b) Location and placement

Fig.1 Block diagram of Internet time-transfer system.

Free-BSD based PCs with a hardware NTP board installed between the PCs and the network.

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

The hardware NTP board automatically stamped a ntp-time on packet as they passed through[3]. Here, the time stamped was generated from signals carried from a atomic clock. In these measurements, the atomic clock on the packet responder was the UTC(NICT) and on the other each packet sender/receiver it was a Cesium (Cs) atomic clock. Both time scales were compared using the GPS common-view method and the time difference was recorded.

In these measurements, we used two packet senders/receivers, one at Ote-machi the center of Tokyo about 25 km far from NICT, and the other at NICT. At a NICT packet sender/receiver, packets are carried via Ote-machi Network Node. Therefore, a NICT packet sender/receiver and the stratum 1 server set up at NICT are placed at the different network-segments and connected through Ote-machi Network Node. The stratum 1 server set up at NICT is worked with using UTC(NICT) and packet senders/receivers are worked with Cesium atomic clocks.

III. NETWORK-LINK CONDITIONS

Network-link conditions sometimes change during long-term operations and packet response time is often varies. Figure 2 shows that the network-link change phenomenon on Cs(NICT) - UTC(NICT) link.

In Figure 2, we measured the NTP packet response from July 1 2006 to June 30 2007. After measurements, packet response data processed by data-filtering method were compared with the measured data using Time-Interval counter, and the difference time (time-transfer error) was plotted in Figure 2.

The bars of the figure 2 show points that time-transfer errors are discontinuous. From figure 2, many changes of network-link occur during one year. Therefore we have to take some kind of measures for these changes for long time operation.

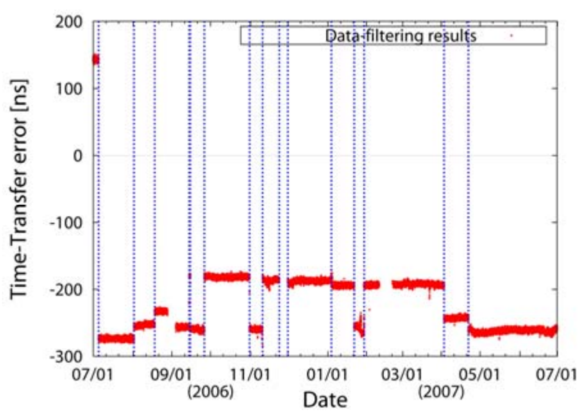
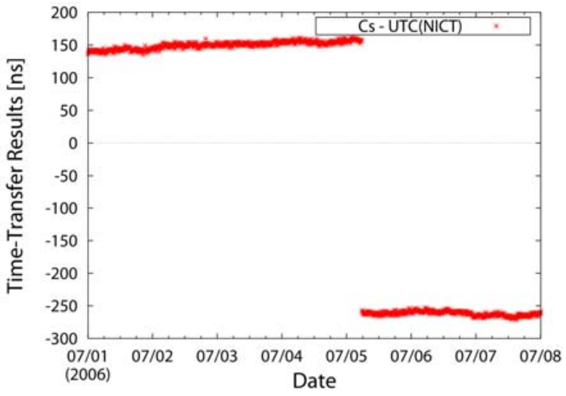
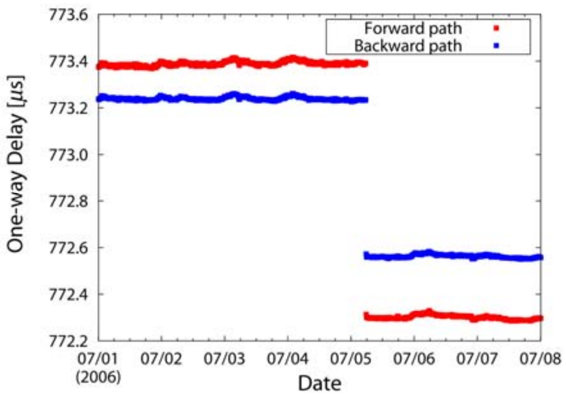


Fig.2 Comparison results between Time-Interval Counter data and data-filtering data.



(a) Time transfer results



(b) One-way delay results

Fig. 3 Data of network-link changed.

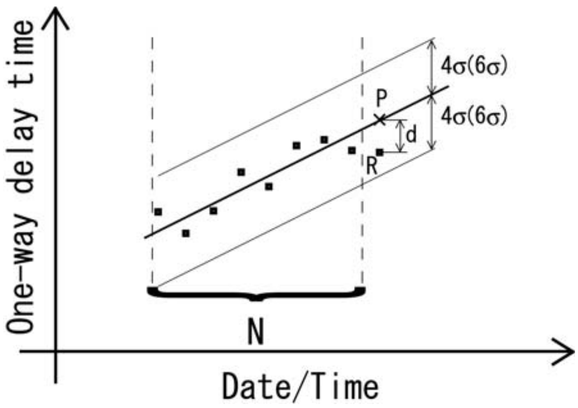


Fig. 4 Estimate of prediction error and threshold level.

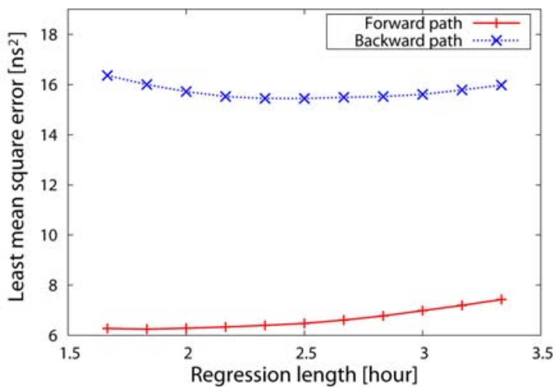


Fig. 5 Relationship between regression length and least mean square errors.

Figure 3 (a) shows the close-up view at the beginning of July 2006 and Figure 3 (b) indicates the difference of one-way delay time at Forward path and Backward path.

At 5th July, only 700 *ns* one-way delay time decreased in Backward path whereas 1.1 μs decreased in Forward path. Then, in time transfer results of Figure 3 (a), the data offset of the 400 *ns* difference occurs.

When the network-link change occurred, the quantity of the data offset depends on path length of network routing replaced by.

Our data-filtering method uses 10 minutes data to calculate one point result. Then this network-link change is usually observed as a jump of the data at one or two point intervals. So, we can easily determine the network-link change phenomenon.

Using this advantage, we propose a useful technique to estimate such a network-link change.

IV. DETECTING NETWORK-LINK CHANGE

In order to support network-link change suitably, we need to estimate these change precisely.

Because a Cs atomic clock has very high short-term stability, we can use linear-prediction for one-way delay data for a short time. Therefore we set the offset time for both the up-link and the down-link and estimate the change values for every measured piece of data using a the model of the linear regression analysis to show in Figure 4.

First, we choose N one-way delay data just before the prediction point. Using these N data, we evaluate the linear regression line with LMS (least mean square) method.

Second step, using this linear regression line, we calculate the prediction data P, shown in Figure

4. Here, we assume measuring data *R*, we can determine the prediction error *d*. When the value of this prediction error *d* exceeds the threshold level, we estimate that network-link change occurred.

To work this technique effectively, we have to determine the most suitable regression length *N* minimizing a LMS error in each prediction error *d*.

Figure 5 shows the relationship between regression length and LMS error on Cs(NICT) - UTC(NICT) link. In figure 5, we calculate LMS error while moving by one data using one month data without network-link change. From Figure 5, most suitable regression length on Cs(NICT) - UTC(NICT) link is 2.5 hours, or $N = 15$.

Finally, we need to determine the threshold level. In Figure 6, we plot both distributions of prediction error *d* of Forward path and Backward path using same data of Figure 5 at $N = 15$. From Figure 6, prediction error *d* in static state indicates the normal distribution. Then, standard deviation of prediction error *d* is σ when the correlation coefficient *r* of the linear regression analysis assumes high, there is most prediction error *d* statistically within $\pm 4\,\sigma$.

Therefore, we determine the threshold level is $\pm 4\,\sigma$ at correlation coefficient *r* is high and if correlation coefficient *r* is not so high, we use the threshold level of $\pm 6\,\sigma$. This difference of correlation coefficient *r* is based on a 1 % significance level.

In the case of Cs(NICT) - UTC(NICT) link, because regression length *N* is 15, the degree of freedom of the regression analysis is 13. Then the 1 % significance level of correlation coefficient is 0.64.

From these definitions, the value of the threshold level determines as follows.

・Threshold : $\pm 4\,\sigma$ when $r > 0.64$
・Threshold : $\pm 6\,\sigma$ when $r < 0.64$

In the case of Figure 6, standard deviation σ of prediction error *d* of Forward path and Backward path is 2.5 ns and 4 ns each. As a matter of course, a 1 % significance level of correlation coefficient *r* is different so that the value of regression length *N* is different if network-link is different.

With the threshold defined above, we detect the network-link change. However, prediction error *d* is only once to have exceeded the threshold, it may be an irregular data. Then, when two times of prediction error *d* exceeded the threshold level in the same side successively, we define that network-link change occurred.

V. ADJUSTING DATA-OFFSET

As the next stage, we consider quantity of offset to correct the network-link change[4].

Considering ideally, when data before and after the change became by N/2, we should estimate the value of the offset that the residual standard error of the regression line becomes smallest. By adopting that method, however, much time is necessary from a network-link change to evaluation of the offset value. In the case of $N = 15$, this delay is more than 1 hour. Then it is not a

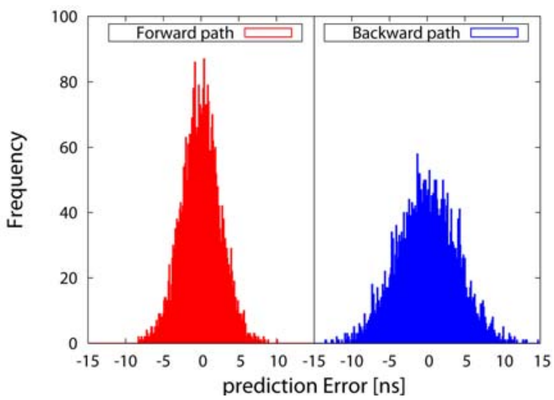


Fig. 6 Distributions of prediction error.

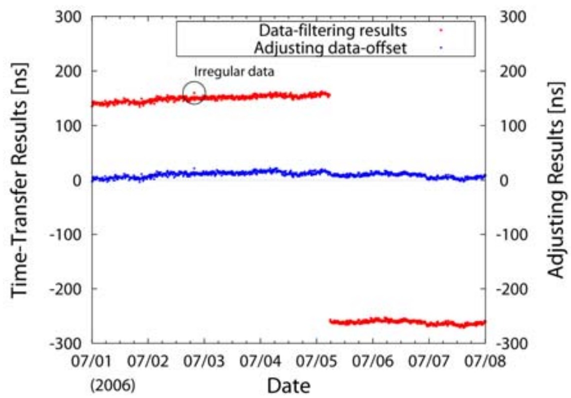


Fig. 7 Data samples of adjusting data-offset.

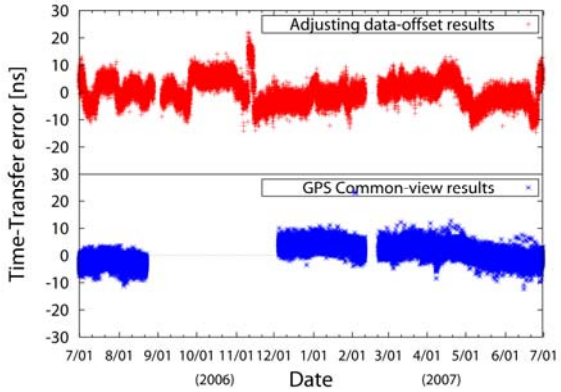


Fig. 8 Results of data-filtering method with adjusting data-offset and GPS common-view method (Cs(NICT) : Time-transfer error)

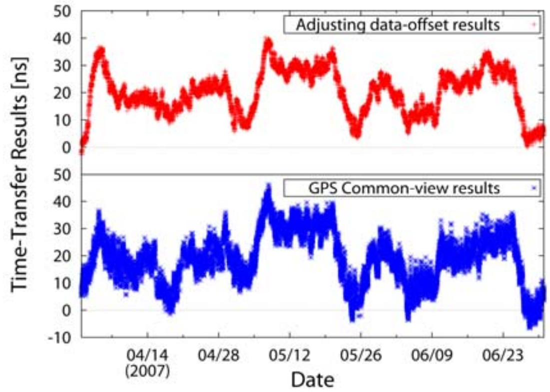


Fig. 9 Results of data-filtering method with adjusting data-offset and GPS common-view method (Cs(Ote-machi) : Time-transfer results)

practical method.

Therefore our adjusting data-offset technique adopts the method that started a calculation from the 2 time after the change and coordinated the offset value until N/2 times. By using this technique, we can start adjusting data-offset at least 30 minutes after of the change.

Figure 7 shows the example which applied our adjusting data-offset technique to Figure 3.

To calculate the time-transfer results, we apply our adjusting data-offset technique for both Forward path and Backward path. From Figure 7, we can eliminate influence of network-link change.

VI. APPLING AN ADJUSTING DATA-OFFSET

The Figure 8 upper part shows results that applied an adjusting data-offset technique to results of time-transfer error of figure 2. The Figure 8 lower part shows results that measured by using GPS common-view method. In a result of GPS common-view, the blanks from September to December depend on non-measurement due to trouble of the GPS receiver.

By comparing the figure 8 upper part with figure 2, an adjusting data-offset technique is very effective to the network-link changes and is applicable to the long-term operation.

As mentioned before, Figure 8 shows time-transfer error based on measured results using Time-Interval counter. Then, Figure 8 indicates the accuracy of each method. Therefore, we found that the data-filtering method with adjusting data-offset is almost same results as the GPS common-view method through 1 year operation.

But, it does not work for an offset less than the threshold level defined by its network-link. In addition, it also doesn't work to be seen in November and April when measured data drifted for long time. This is specifications to detect the trouble of the atomic clock.

By improvement of data-filtering method, it offers same accuracy to GPS common-view method within the standard deviation of one-way delay time (SD), which is later than 2 μs.

Finally, Figure 9 shows the results that applied an adjusting data-offset to the data-filtering data of Cs(Ote-machi), which is placed about 25 km far from NICT. In Figure 9, we also show the results that measured by using GPS common-view method. In this network-link, $N = 9$ and standard deviation σ of prediction error d of Forward path and Backward path is 1.2 ns and 1.25 ns each. But, by the limit of time resolution of NTP board, we set 4 σ = 8 ns for both Forward path and Backward path. To define the threshold level, we used a 1 % significance level of correlation coefficient r = 0.8 for the degree of freedom = 7.

In Figure 9, we cannot use a Time-Interval Counter, then we compare using the time-transfer results. The standard deviation of one-way delay time is later than 40 ns on Cs(ote-machi) - UTC(NICT) link. In this condition, data-filtering method with adjusting data-offset offers better performance to GPS common-view method.

Summarised above, on high speed (≥ 1 GbE) and low cross-traffic (SD < 40 ns) network environment, data-filtering method with adjusting data-offset offers better performance to GPS common-view method with almost real time.

VII. CONCLUTION

To realise simple and low cost network time-transfer using NTP packet, we have considered a precise method of estimating network time-transfer to reduce the effects of cross-traffic called data-filtering method. This method is very effective and its accuracy is almost same as GPS common-view method within high speed and medium cross-traffic network environment.

But, network-link conditions sometimes change during long-term operations and packet response time is often varies. Therefore, we set the offset time for both the up-link and the down-link and calculated the values for every measured piece of data using a linear-prediction method. This adjusting data-offset technique overcomes the effects of the network-link changes.

Using a combination of these techniques, we can operate an atomic clock for a long time in an IDC. From the measuring results of the comparison with GPS common-view, a network time-transfer using data-filtering method with adjusting data-offset is practical and offers accuracy to within high speed (≥ 1 GbE) and medium cross-traffic (SD < 2 μs) network environment.

Our method is simple to operate and offers accurate enough for time related business use.

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