TWO-WAY TIME TRANSFER THROUGH 2.4 GBIT/S OPTICAL SDH SYSTEM

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Abstract

An experiment to transfer time and frequency over 2.488 Gbit/s SDH (Synchronous Digital Hierarchy) systems using 175-km commercial optical fibers has been set up by CRL and NTT. We confirm that the frequency stability of the time comparison data is 10^{-12}/square root of tau at averaging times above 10 s. This equals that of the Cs frequency standard (HP5071A) used in this experiment. The time comparison resolution is of the order of 10^{-11} s (square root of time variance). The long-term stability of this system is expected to be better than 1 ns. The time comparison results of this experiment agree well the GPS common-view results.

INTRODUCTION

Terrestrial cable systems can be applied for time and frequency comparison and transfer as is possible with satellites[1][2]. While cable systems are disadvantaged in requiring repeaters to transmit information over long distances, they offer very stable communicationlinks. Optical transmission systems based on SDH (Synchronous Digital Hierarchy) have been developed and deployed with bit rates of 600 Mb/s, 2.5 Gb/s, and 10 Gb/s. These bit rates enable highly stable frequency and time transfer.

We have been tackling transfer time and frequency over 2.488 Gbit/s SDH systems. The first goal was to ascertain the limitation of SDH systems in terms of frequency and time transfer capability. The second was to develop an accurate and stable standard signal distribution scheme over telecommunication networks. This paper describes the system configuration and initial results of the experiment.

EXPERIMENTAL SYSTEM

CRL in Koganei and NTT in Yokosuka were directly connected with a 2.488 Gbit/s SDH system as shown in Fig. 1; cross-connects were not used. The 175-km optical fiber cable contained 7 repeaters. The SDH termination equipment receives the reference signal generated by each standard, and transmits the reference signal using a data format based on SDH. Figure 2 shows the experimental system configuration. Reference second signals and measurement data are transmitted and received by time information transmitters and receivers that manipulate 2.488 Gbit/s SDH signals synchronized to a reference signal of 5 MHz. Measurement systems have functions of time interval counting and measurement data processing.

DATA PROCESSING

Measurement results at one site are immediately transmitted to the other site over the same SDH system as the time transfer experiment. This experiment system can thus achieve both conventional two-way time transfer and real-time data processing for frequency and time correction. The national standard of frequency and time generated in CRL can be continuously transferred to NTT.

The time difference (Δ) between two sites is determined from four data: the differences, measured in CRL, between the reference and transmitted second signals (t1) and between the received and transmitted second signals (t2), and the differences, measured in NTT, between the reference and transmitted second signals (t3) and between the received and transmitted second signals (t4). Time difference (Δ) is given by

$$\Delta = t1 - t3 + (t2 - t4) + (\tau 1 - \tau 2)/2$$

where t1 and t2 are the transmission delays from CRL to NTT and from NTT and CRL, respectively. Total transmission delay is

$$\tau 1 + \tau 2 = t2 + t4.$$

The asymmetry of transmission delay causes time error in Δ. While SDH signals are transmitted over different optical fibers, the two fibers are jacketed in the same cable. Transmission delay (t1 and t2) and delay variation are approximately the same. Time error factors are difference in wavelength between the two optical fibers, connector attaching processes in the ends of the optical fibers and circuit-delay difference in the repeaters (if used).

TIME TRANSFER FORMAT

Current digital transmission systems are based on Time Division Multiplex (TDM) and designate time slots for data transmission. We have to identify which time slot holds the reference second because the delay imposed by the transmitter is unpredictable. In this experiment, one bit of an undefined Section OverHead (SOH) byte is used to indicate carriage of the reference second. Measurement data are also transferred in other bits of the same SOH byte. Figure 3 shows SDH data format including SOH and the SOH byte used to transfer time. Time information is embedded in SOH bytes once per one frame period of 125 μs. 8000 successively embedded SOH bytes construct one-second frame as shown in Fig.4.

FREQUENCY COMPARISON AND TIME TRANSFER

Figures 5 and 6 show the time comparison result and the total transmission delay between CRL and NTT, respectively. The constant time difference increase is caused by the frequency difference between CRL and NTT. Frequency deviation of the cesium standard in NTT is -1.27×10^{-13} compared to that in CRL. The total transmission delay is 1.7 ms, and the delay variation is approximately 200 ns over the period shown in Fig.6. The annual delay variation is expected to be around 300 ns based on the experimental results.

Figure 7 shows the short-term stability in Allan variance. This two-way time transfer system capability was measured in a room using a unique reference, and is plotted as 'system' in Fig.7. The experimental system can compare frequencies of 10^{-15} over a one day measurement period. The actual measurement result, plotted as 'CRL-NTT', basically follows the performance of the cesium standard used in NTT. If we use a hydrogen maser to generate the reference time, it is expected that the frequency comparison would show a flicker floor of 10^{-15} over the measurement period of more than 10^5 s.

Figure 8 shows time deviation as a function of averaging time. This two-way time transfer system can compare time at the order of 10^{-11} over measurement periods greater than 1 s. Time signals generated by an HP5071 cesium standard can be compared over measurement periods longer than

10 s. Figure 9 shows a comparison of this experimental system with GPS common view. Time difference increase due to frequency offset was removed before plotting these values. The time comparison of this experimental system agrees well the GPS common-view result. While these results do not show the time transfer capability in terms of long-term stability, since they include the time variation between the NTT standard and UTC(CRL), the long-term stability in this system is expected to be better than 1 ns.

CONCLUSION

We confirmed that the frequency stability of the time comparison is 10^{-12}/square root of tau for the averaging time region, tau, greater than 10 s. This is equal to that of the Cs frequency standard (HP5071A) used in NTT. This result implies that two time scales based on Cs frequency standards can be compared using 2.488 Gbit/s SDH time transfer as if the two standards were standing alongside each other.

REFERENCES

[1] M. Kihara, and A. Imaoka 1995, "SDH-based time and frequency transfer system", Proceedings of the 9th European Frequency and Time Forum.
[2] M. A. Weiss, S. R. Jefferts, J. Levine, S. Dilla, T. E. Parker, and E. W. Bell 1996, "Two-way time and frequency transfer in SONET", Proceedings of the 1996 International Frequency Control Symposium, pp. 1163-1168.

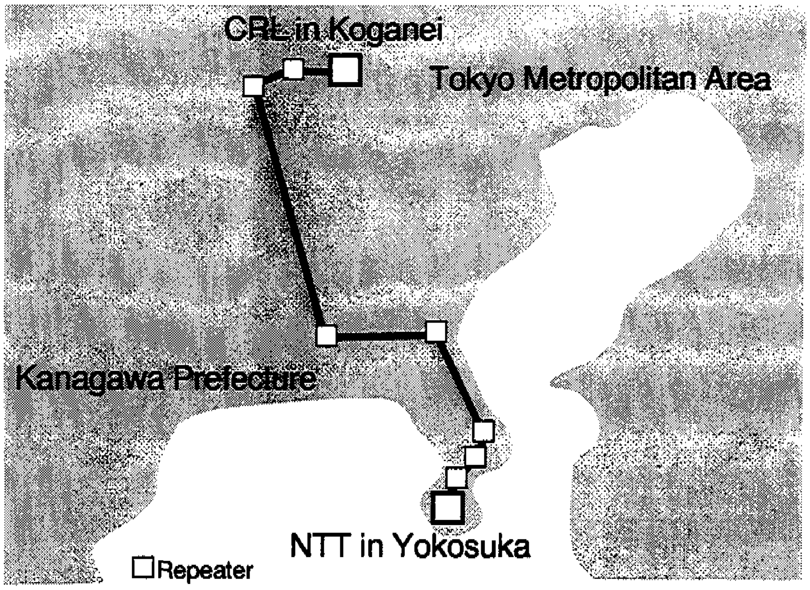

Figure 1 - Two-way time transfer experiment configuration

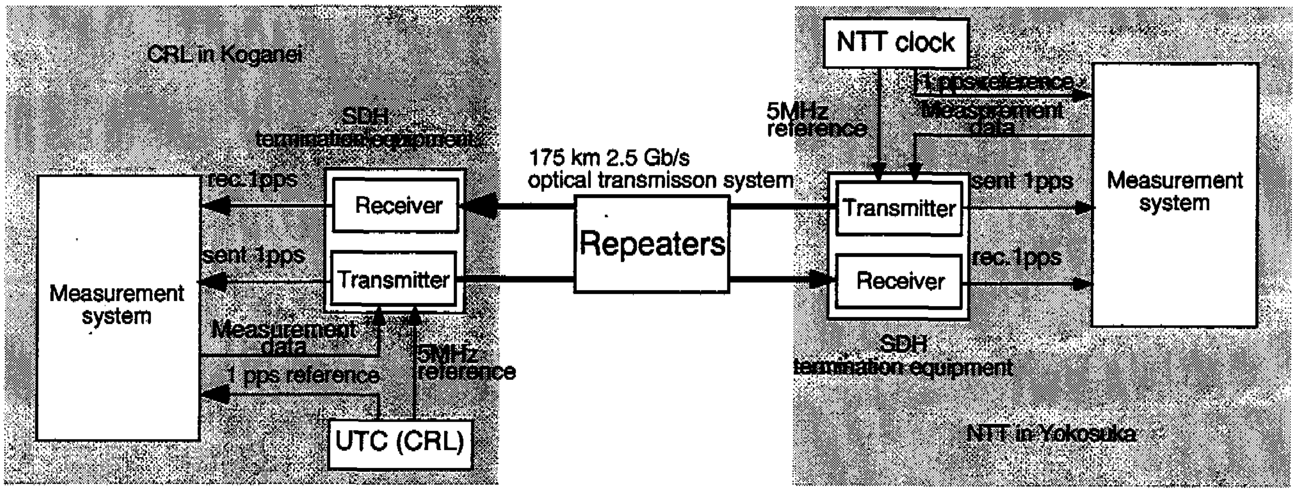

Figure 2 - Experimental system configuration

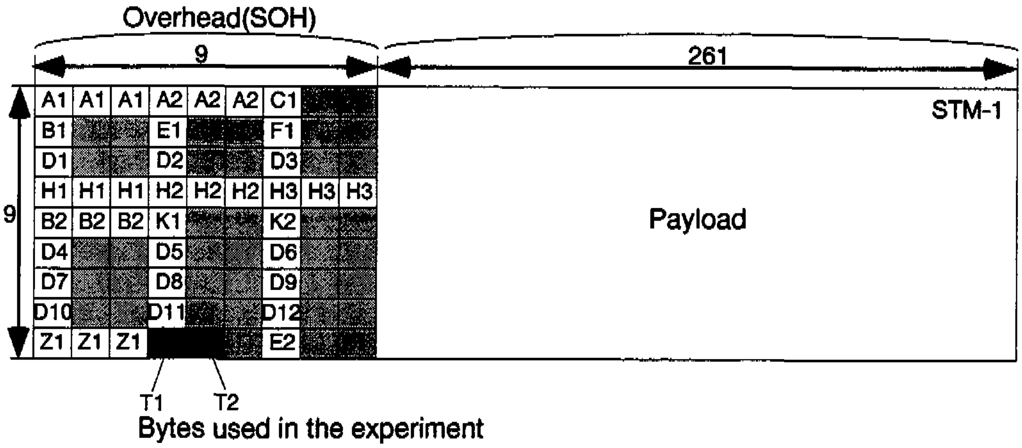

Figure 3 - SDH frame format (STM-1)

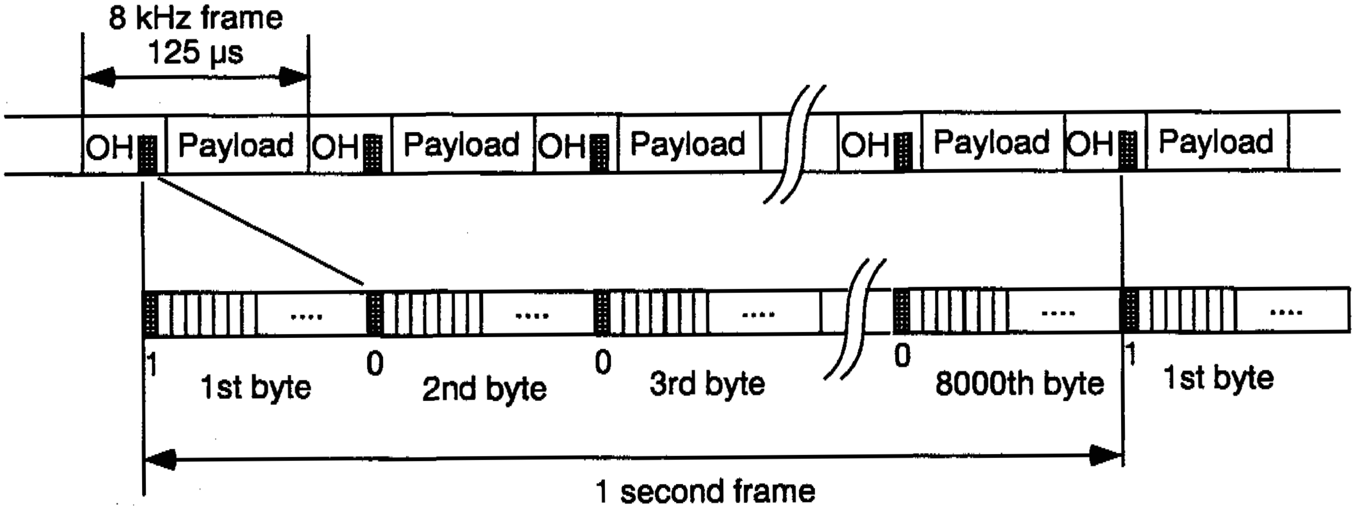

Figure 4 - SOH byte and one second frame

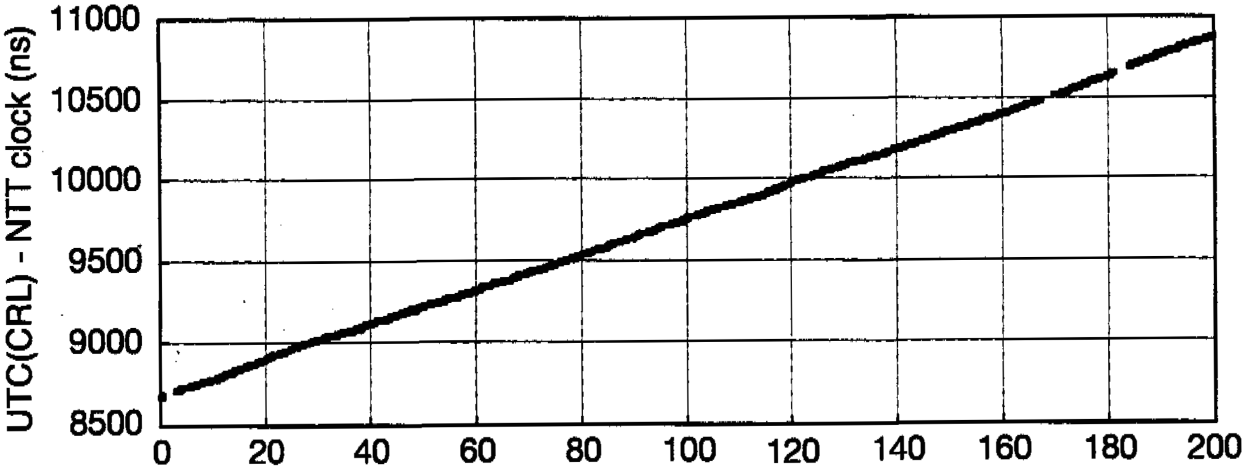

Figure 5 - Time comparion result

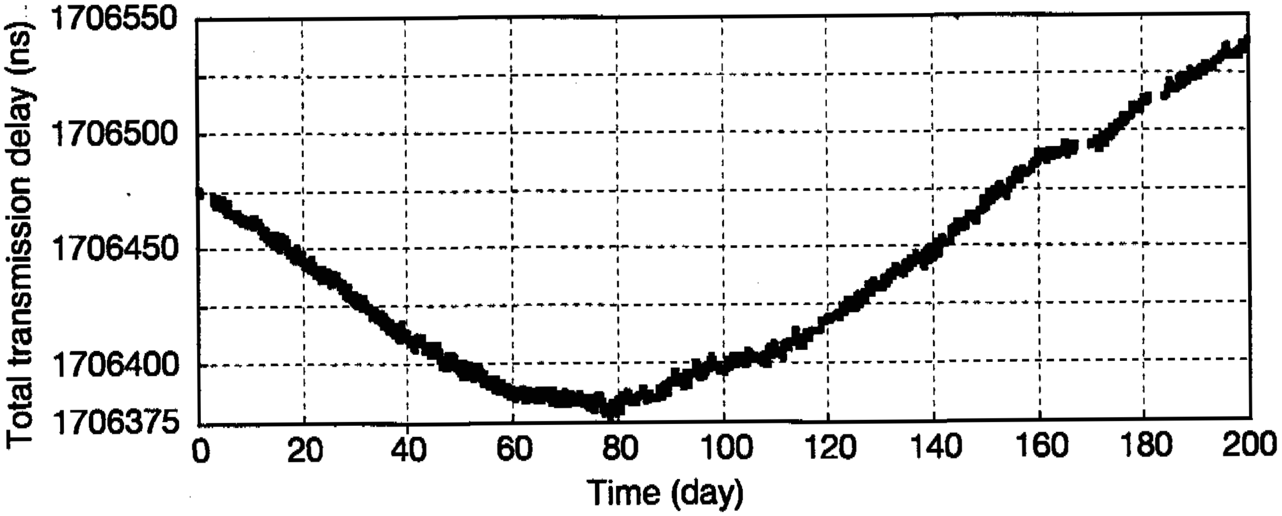

Figure 6 - Total transmission delay

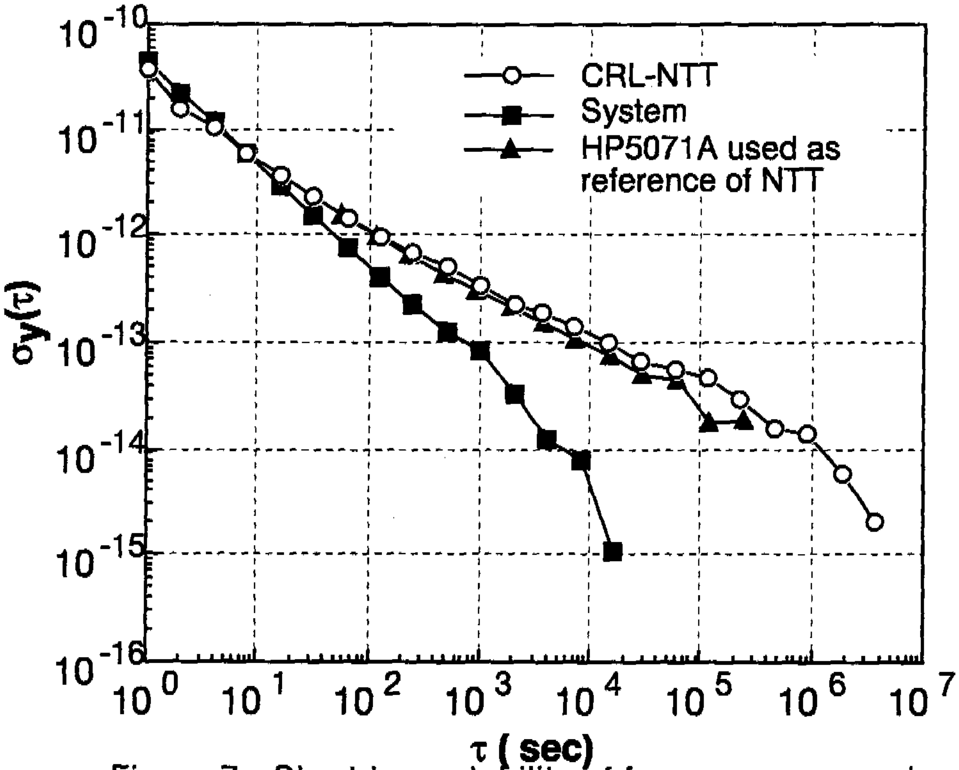

Figure 7 - Short-term stability of frequency comparison

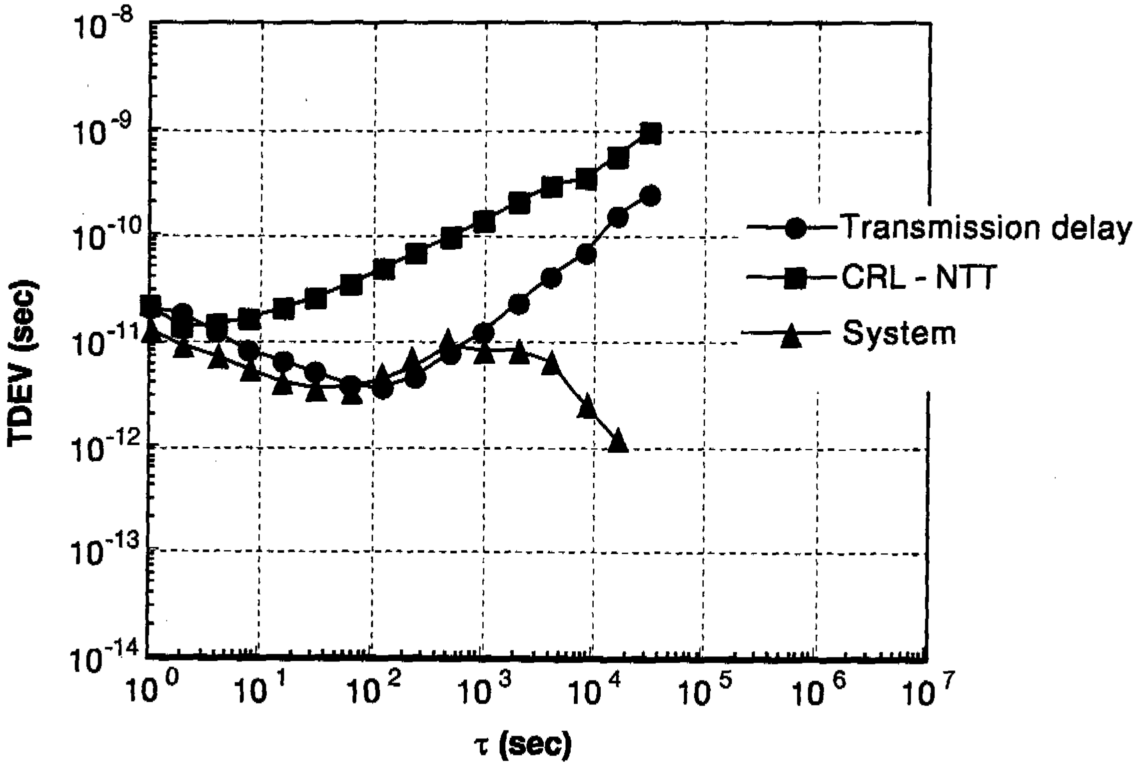

Figure 8 - Time deviation of time transfer

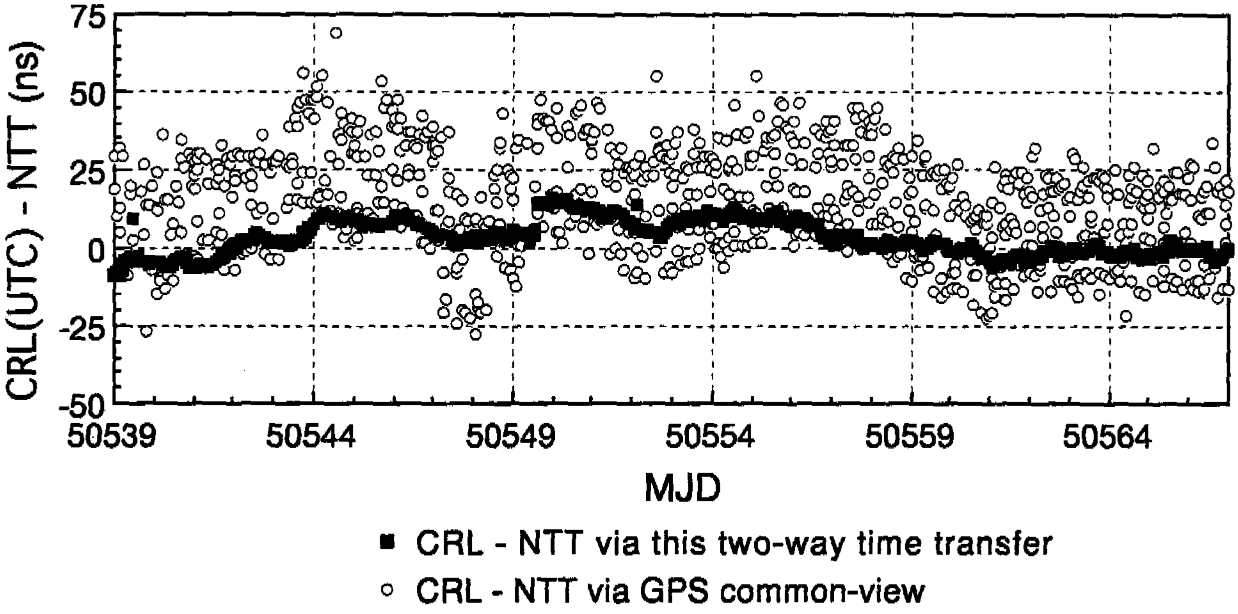

Figure 9 - Comparison of this two-way time transfer with GPS common-view