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CNRS-INFN

| Technical Note | LIGO T020118-00-D<br>VIR-NOT-LAP-1390-219 | August 17, 2002 |
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# Measurement of the Time Offset Between the LIGO and VIRGO Data Acquisition Systems Using Internet Time Transfer

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# 1 Introduction

This note is a follow up of a previous note[1] on the measurement of the time offset between the LIGO and VIRGO Data Acquisition Systems. Additional data have been taken to understand the limitation of this time-offset measurement with the “NDAS Clock” method.

# 2 Principle of the End-to-end time offset measurement

The time offset between the two data acquisition system was measured by comparing the arrival time of so-called “NDAS Clock Events”.

The NDAS clock events are synchronously produced by clocks, independent of the GPS system used by the DAQ systems. The synchronization of the event generators is done using the Network Time Protocol (NTP) over the Internet. This protocol measures the travel time of data on Internet and uses this information to determine a correction that removes the propagation time offset. It is worth noting that this event synchronization is completely independent of the GPS that is used to drive the data acquisition systems.

These events are recorded with each DAQ system, written to frames and transferred by the Network Data Analysis Server (NDAS)[2]. An offline analysis compares their times of arrival. This difference gives the systematic error when conducting the common analysis.

# 3 Description of the event generators

The NDAS clock events are produced by two identical PCs (HP VL 400MTS), called “NDAS clocks”, located at each site. The PCs are running the Linux operating system (Red Hat v6r2). The internal clocks of both PC’s are slaved to an external clock using the Network Time Protocol (NTP) over Internet. Different NTP servers have been used in this study. On each PC, a program is polling the PC clock. When the time is exactly a multiple of 13 seconds, a pulse is generated on the parallel port, which is connected to an ADC channel of the data acquisition system. In order to check for large errors and simplify the analysis, the pulse length encodes the time and NTP server used to set the PC clock.

The event arrival time is defined by the time when the signal on the parallel port exceeds a threshold which is about half of the pulse amplitude. Any known delays in data acquisition systems are removed. In the previous note[1], it has been shown that the event resolution is less than 50μs, a value much smaller than the effect we are looking at. The delay introduced by the driver of the PC parallel port is expected to be smaller than values observed in this study (in the millisecond range) and is neglected.

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[1] LIGO-T020036-00-D and VIR-NOT-LAP-1390-198
[2] “Network Data Analysis Server (NDAS) prototype development” Sz. Marka, B. Mours, R. Williams, Class. Quantum Grav. 19 (2002) 1-4

# 4 Time difference using the NDAS Clock PC as NTP server

## 4.1 PC Clock setting

To study the effect of the NTP protocol, especially the asymmetry in the internet path, we turned the NDAS Clock PCs into NTP servers. We use the time setting sequence shown by figure 1. First, both PC clocks are set using an external atomic clock and a first set of event is recorded. The NTP server used is "time-A.timefreq.bldrdoc.gov", an atomic clock based stratum 1 referred as ‘NIST’ in this note. Then one PC is used as NTP server and a second set of event is recorded. Finally the other PC is used as NTP server and a last set of event is recorded.

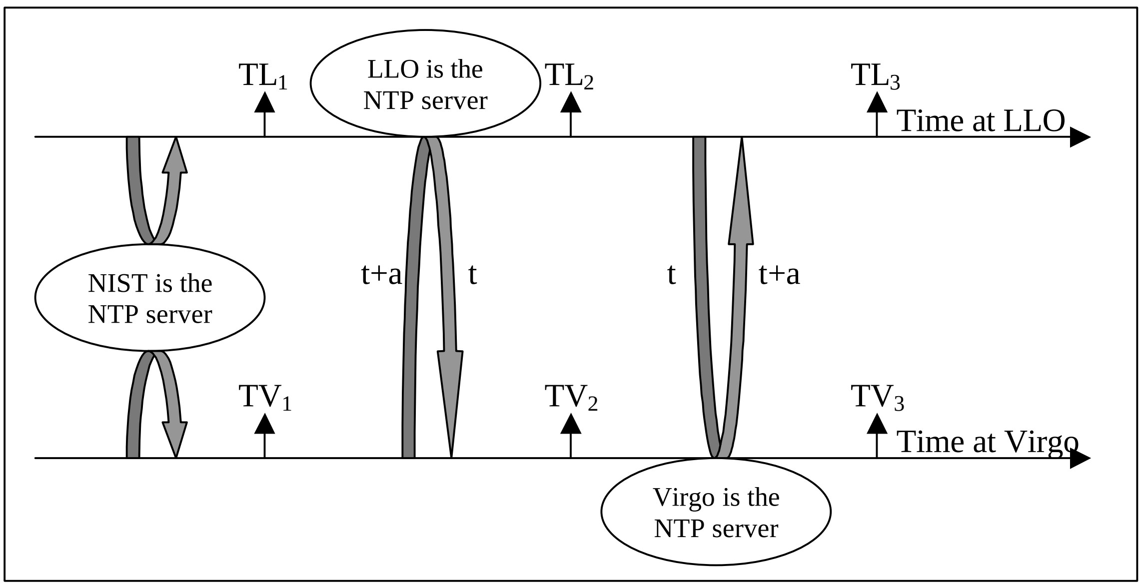


**Figure 1 Clock setting scheme when using the PC as NTP server. TLn and TVm indicate the time of the events**

It is interesting to notice that if there is an asymmetry ‘a’ in the Virgo to LIGO path as shown in figure 1, then $(TV_2\text{-}TL_2) = (TV_3\text{-}TL_3) = a/2 +$ Virgo_DAQ_time_offset - LIGO_DAQ_time_offset. The second and third sets of values should give the same result, but there is no way to separate the effect of the Internet path asymmetry and DAQ time offsets.

## 4.2 Results

Data were recorded during 11 hours on July 18, 2002 (GPS staring time = 711052490). Figure 2, shows the difference in the arrival time $(TV_n\text{-}TL_n)$ as function of time. Two sets of points are shown: the red squares for when the Virgo PC was used as NTP server and the blue dots for when the LLO PC was used as NTP server. Figure 3 presents the histogram of these two sets of points.

Like in the previous note, the time-offset varies along the time and shows different discrete levels.
This could come from the variation of:

- The NTP server clock
- The asymmetry in the internet path (east bound versus west bound)
- The DAQ time offsets

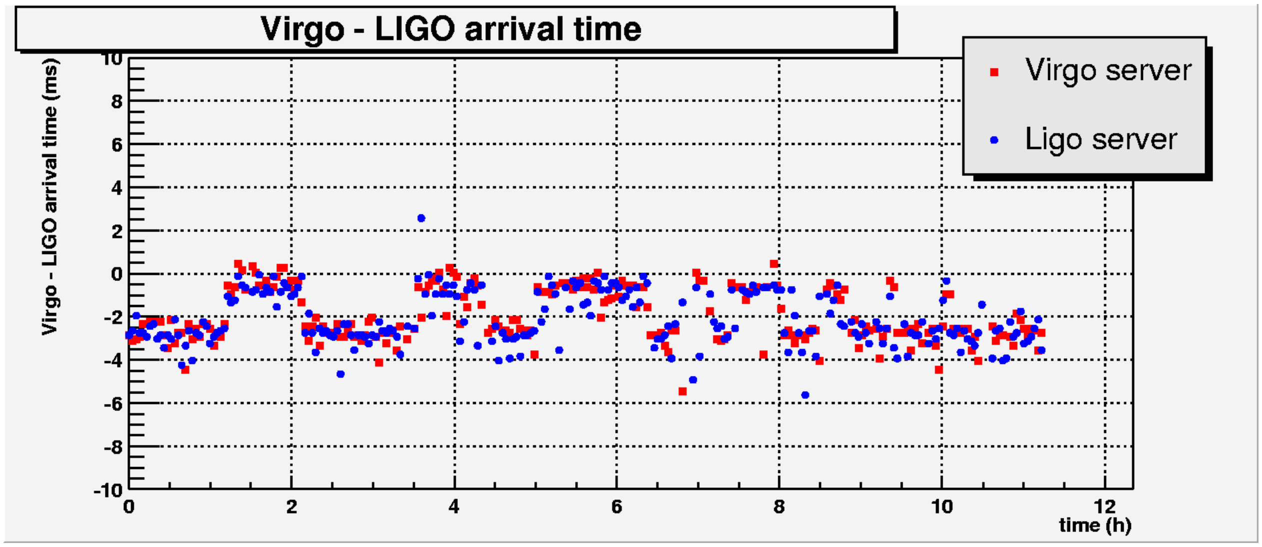


**Figure 2 Arrival time difference as function of time. The two sets of points correspond to the use of two different NTP servers.**

The strong correlation between the two set of points confirms the second hypothesis since in this measurement, the NTP server are two identical PCs with their clocks set in a coherent way. This shows that the asymmetry in the Internet path is the dominant systematic error in this measurement. The fluctuation in this measurement over time gives an idea of this systematic error; no other effect is involved in this measurement at this order of magnitude.

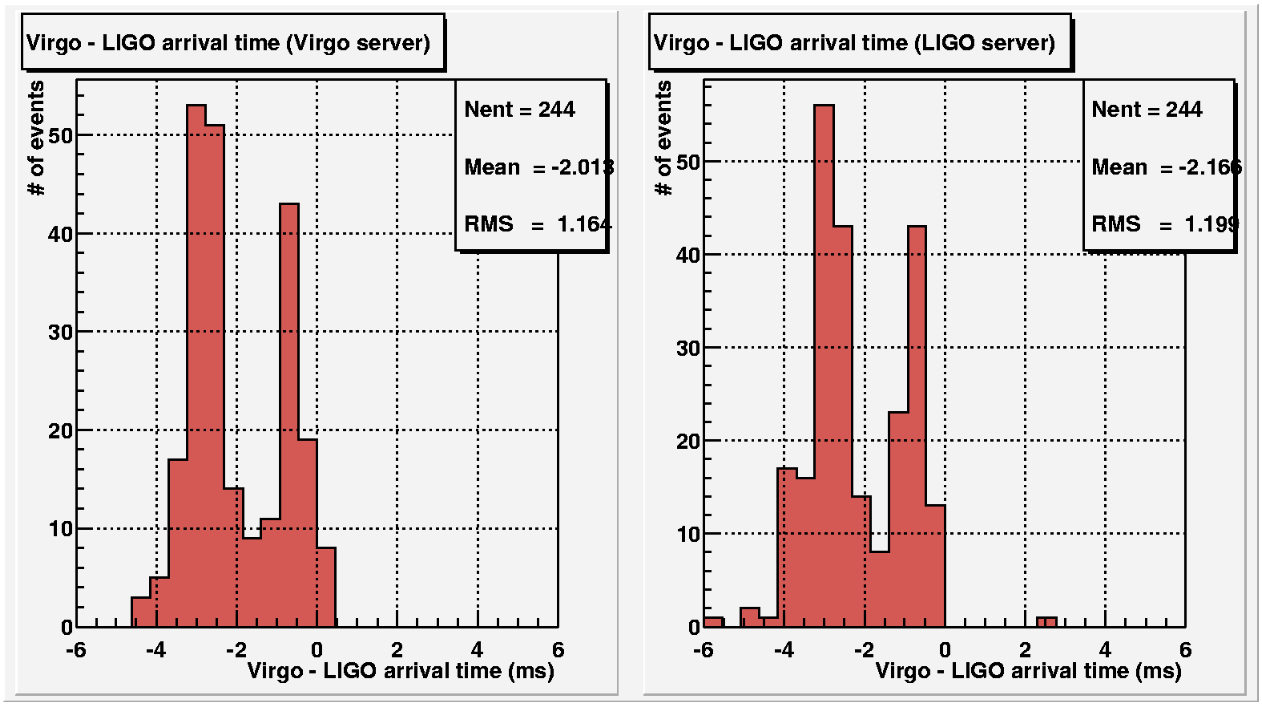


**Figure 3 Arrival time difference when using the Virgo (left) or LIGO (right) PC as NTP server.**

Conclusively, this measurement confirms the existence of asymmetries in the Internet path. The observed asymmetries are of the order of a few milliseconds and they dominate the 2ms arrival time difference observed (mean values of the figures 2). They could not be canceled by using a symmetric set of NTP servers.

# 5 Time difference using nearby NTP server

## 5.1 PC Clock setting

Since it is not possible to avoid the effect of the asymmetry in the Internet path, we tried to reduce it by using nearby timeservers. The LIGO PC was still using the 'NIST' NTP server and the Virgo PC was using the 'Lyon' NTP server ("ntp.univ-lyon1.fr", a GPS based[3] stratum 1). In this case, the PCs are not tuned to the same clock. The master clocks are assumed to be properly set and maintained.

[3] We will have to find a GPS independent stratum 1 NTP server in Tuscany for best results.

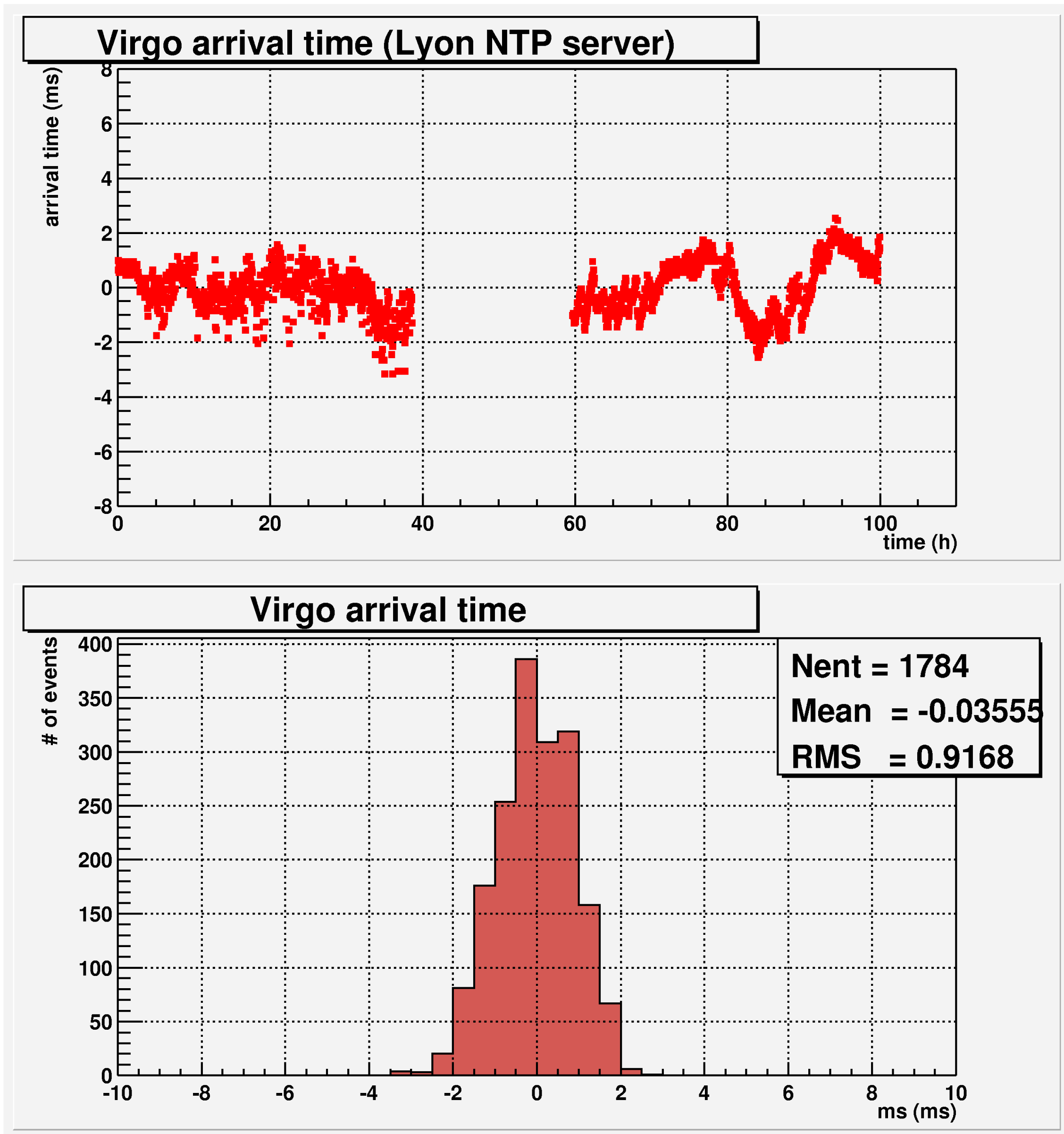


**Figure 4 Arrival times of the NDAS clock events at the Virgo site relative to the 1 Pulse Per Second from GPS. Two sets of data have been taken separate by about 14 days that has been reduced to 21 hours for convenience in the upper plot.**

### 5.2 Results

Data have been taken for several days at both sites. The figures 4 and 5 show the results.

We still observed fluctuations in the event arrival time of a few milliseconds. The LIGO and Virgo mean values are both close to expected zero value (-0.04ms for Virgo and 0.3 ms for LIGO). This is closer than the previous measurements. This 'better' result could be due to:

- A longer averaging time (several days) which better averages the Internet asymmetry path.
- A lucky cancellation of the Internet asymmetry path and the DAQ time offset.

At this point, no more precise conclusion could be drawn.

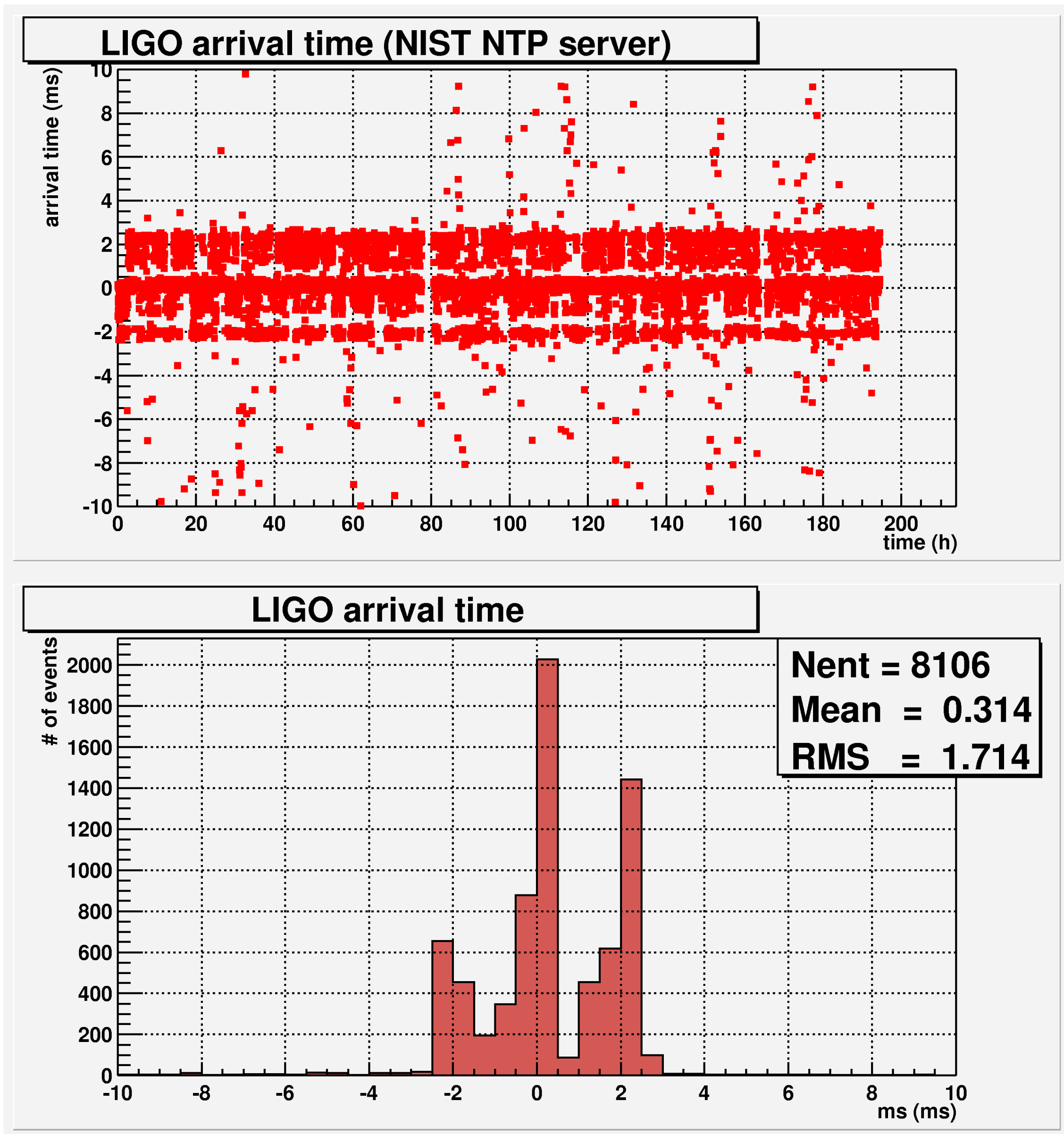


**Figure 5 Arrival times of the NDAS Clock events at the LIGO site relative to the 1 Pulse Per Second from GPS**

## 6 Conclusion

The NDAS clock system could provide a relative timing calibration with an accuracy of a few milliseconds when using the same NTP server. If we use close NTP servers and long averaging, the observed time offset in each data acquisition system seems close to zero, but the systematic uncertainty due to the Internet path asymmetry remains.

However this method offers a direct, stand alone and permanent test of the absolute timing at each site with a systematic error of a few milliseconds. This is especially useful in the case of DAQ hardware or software change.

To reduce the error on the relative timing calibration, a portable atomic clock coupled with local atomic clocks has to be set up.

## 7 Acknowledgements

We are grateful to the Virgo DAQ group and the LIGO Livingston Observatory for their support, which made this study possible. We would like to thank Nadine Neyroud for her help with the NTP servers setting. We are grateful to Hareem Tariq for her comments. LIGO is funded by the National Science Foundation under the Cooperative Agreement PHY-9210038. This work is a collaborative effort of Laser Interferometer Gravitational-wave Observatory and the Virgo Collaboration.