Network Time Protocol (NTP) Accuracy As Seen By The Users

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BIOGRAPHY

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ABSTRACT

NTP accuracy at the server is masked to the user by internet and other asymmetries, and can also be degraded by the properties of and load on the client computer. This paper provides some examples and attempts to quantify the performance.

INTRODUCTION

NTP over the internet is an extremely popular form of time transfer, as judged by the number of users and the number of laboratories which provide the service. At many servers worldwide, packet requests are received at the billion per day level, which corresponds to 10's of millions of independent users. Applications range from setting the time on home computers to database management and official time-stamping of documents.

As a means of public time transfer, NTP applies an exchange of time-labeled packets between servers, ultimately to distribute time from the stratum 0 servers to the clients, which can themselves provide time to other clients as stratum 1 time-servers, etc. Specified by the Internet Engineering Task Force (IETF), computer code and information can be found at www.ntp.org, the writings of Dr. David Mills [1] and in past PTTI papers [2, 3]. NTP is initiated when a client computer sends a small UDP packet to a time server, which contains the client's time when it was generated. Upon receipt of the packet, the server shortly thereafter sends a return packet which contains the original time stamp along with the server's time when it received the packet and the time it sent off the return packet. The client records the return packet's time of reception and that is sufficient to estimate the difference between the server and client clocks along with the round trip travel time, assuming that the travel-time over the internet was the same in both directions.

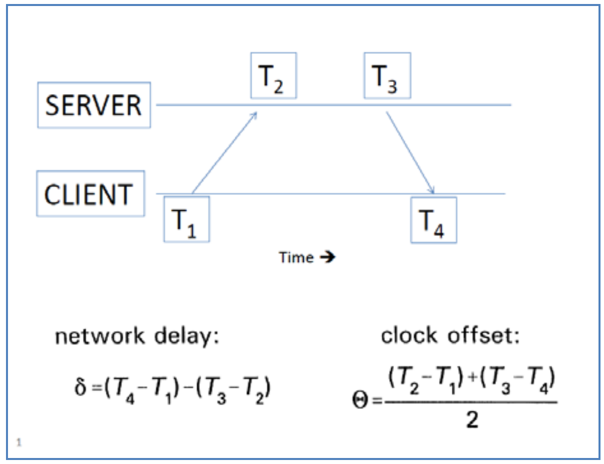

Figure 1. . Schematic of NTP time transfer. The T_i's represent the times of transmission/reception as measured by the local clock, and the formulas show how the time difference and network delay are computed. In a completely asymmetric situation (e.g. internet delay between T_1 and T_2 is zero), the error on the clock offset would be half the round trip time.

In practice, the assumption of symmetric travel-time is never 100% valid, and the asymmetry is typically the largest source of error. It is possible to estimate the time transfer errors by comparing the time transfer results in situations wherein the time of server and client is known to the nanosecond level, by double-differencing time transfers between a client and more than one server, or to a lesser extent between a client synchronized to a set of servers and the time at any one survey.

This study is based upon three years of data using 5 clients, two of which were HP-UX located at the USNO and AMC, within the NIPRnet. Three others were located at different times in either of two Washington, D.C. residences, which are 3.7 km apart and have the same commercial internet provider. On MJD 56137 one client was moved between residences, and after MJD 56519, all were located at the same residence. Two of those were Linux-based and the other was a Mac. Data were taken using ntpdate. Each client sequentially cycled through a set of servers, pausing for 1 to 4 seconds between calls to ntpdate. A typical server would be queried once every 2-5 minutes.

The set of Internet servers queried was by degrees expanded to include all servers advertised by the USNO and NIST services, the NTP pool, timing labs whose IP address had been provided to the BIPM, and a few commercial suppliers such as Apple. The total number of servers is about 150, so that a typical internet server might be queried every 5 minutes.

Packets from all DoD clients are blocked at the NIPRNet boundary, except for the USNO public servers. Those are identified with names tick, tock, and ntp2, although in practice all queries from the internet are fed into a load balancer that distributes them to various back-end servers in a quasi-random fashion. Some internet data are taken with one of those backend servers, and in addition USNO clients were used to query other servers not available to the public.

Due to the large quantity of data collected, the analysis presented here is not complete, and this paper is to be considered preliminary.

The important subject of calibration is not addressed in this paper. We refer the reader to [4], which presents observations of European internet delay variations that are similar to ours.

DATA ANALYSIS

For each successful packet request that was generated by ntpdate, the timetag (MJD), measured time difference (offset), and measured round trip time (delay) were extracted from the output and stored by client-server pair. Before being used to generate statistics, data were edited by removal of all data with offset > +/- 500 msec, or whose offset or delay differed by more than 5 "directional-sigmas" from the median of 1-day windows about each point. For the window about each point, the directional-sigmas were determined using the values at which 16% of the data were less than the median, or 84% of the data were larger than the median. Points whose windows contained < 15 other data points, or which were isolated from all other points by more than 2.4 hours were rejected. All possible double-differences between servers and clients were computed, and edited data were also averaged into 1-day and 10-day bins.

Although at times it is useful for comparisons with clock stabilities to present statistics using the Allan Deviation, the Time Deviation, and/or similar measures, these are insensitive to overall linear variations in the data. Therefore in this work we use only measures such as the RMS, Standard Deviation, and first-difference RMS (the square root of the average square of the first differences). Although the central limit theorem would in the long run ensure the reliability of the standard interpretations of these statistical measures, the non-Gaussian nature of the data we report would imply that all statistical summaries should be treated with care.

ILLUSTRATIVE DATA

Although evidence from multiple clients and round trip times clearly indicates that internet asymmetries are the dominant cause of NTP errors, there are times when the server itself can give the wrong time. Figure 2 shows an example of a lab in Southeast Asia, which is both topologically and geographically very distant from the clients. In this case, there are periods when the absolute value of the timing differences exceeded half the round trip times; these variations cannot be ascribed to internet asymmetries. The smooth behavior of the deviations also indicates that the observed runoffs are due to reference clock drift.

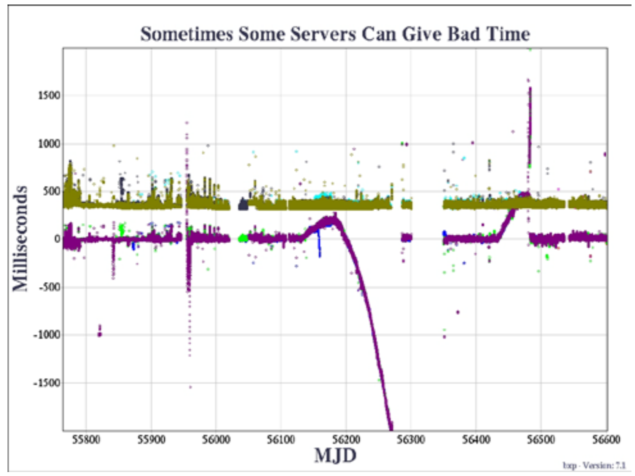

Figure 2. Unedited data from three clients observing a distant laboratory. The three curves representing round trip times usually fall on top of each other at about 400 milliseconds. A blow up would reveal daily variations, approximately 50 milliseconds peak to peak, that differ slightly but noticeably between residences. The remaining curves are the observed timing offsets; the purple one usually covers up the other two.

Along with the obvious runoff, the Washington D.C. internet clients in different residences at times recorded significantly different timing offsets (Figure 3), and this was correlated with differences in the round trip times.

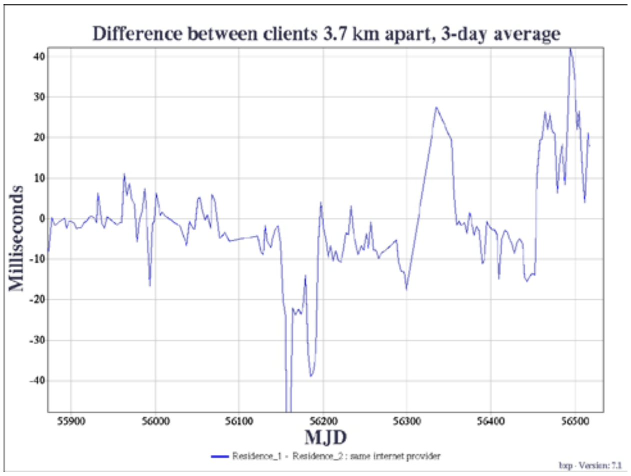

Figure 3. Difference between timing data of the previous figure for clients at separate Washington residences.

Bimodal behavior is often apparent in the timing differences, and at times this is correlated with bimodal round trip times. Figure 4, for example, shows the timing difference and round trip behavior observed between Japan and Washington, D.C. Paradoxically, the larger round trip behavior (thinner of two upper curves) was associated with a smaller bias in absolute value (thinner of two lower curves).

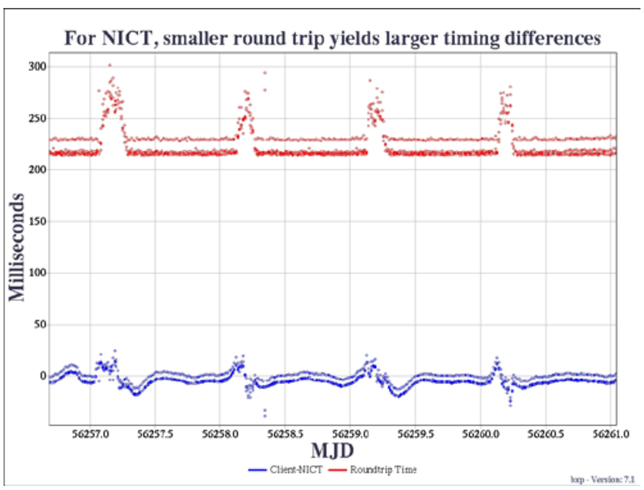

Figure 4. Bimodal behavior between Japan (NICT) and the USA in round trip time (red), and timing offset (blue).

A difference between the two residences was also noted in trans-Atlantic observations. Figure 5 shows the double-difference of two European laboratories (PTB and SP), as seen by the three clients. One of the two clients at one residence was shifted between residences on 56137, and the other one was moved on 56519. In all cases the clients at the same residence agreed with each other.

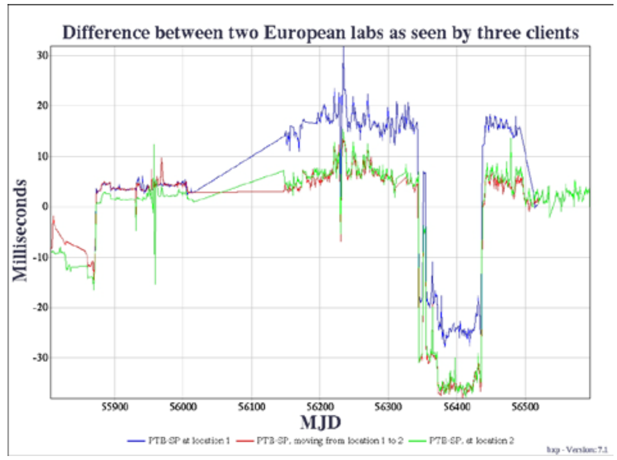

Figure 5. Double-difference between two European laboratories and each client. As described in the text, data from clients that were moved between residences switched to the double-difference of those already at the residence.

Within the United States, correlations are also observed between the round trip delays and the timing differences. Figure 6 shows how the USNO's internet server at Washington University in St. Louis appeared when measured by a client at the USNO.

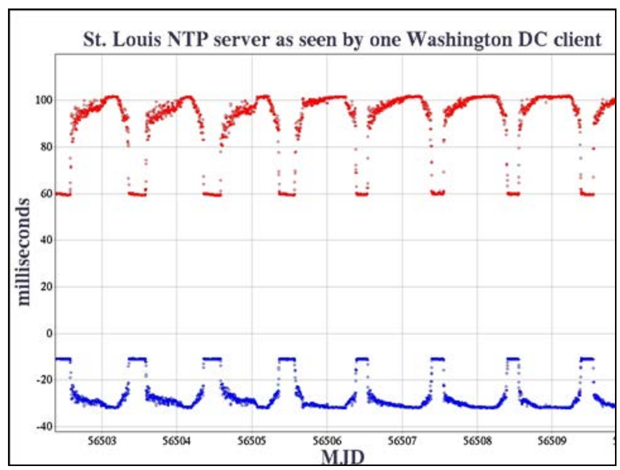

Figure 6. Timing offsets and round trip times for data between USNO-DC and USNO's St. Louis server.

Figures 7 and 8 show true bimodal behavior in two USNO internet servers; in both cases the bimodality in round trip times correlates perfectly with that in the observed delay. However, in the latter plot an overall change in round trip time was not associated with any change in timing differences. It could have been due to the addition of a delay-symmetric bidirectional component.

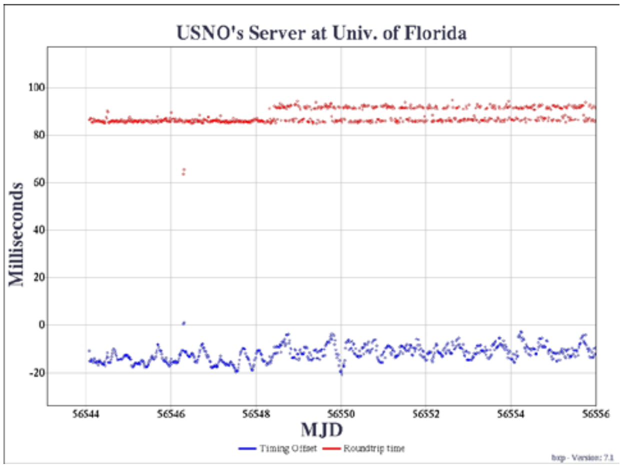

Figure 7. Onset of bimodal behavior. Round trip times (red) correlate with timing differences (blue).

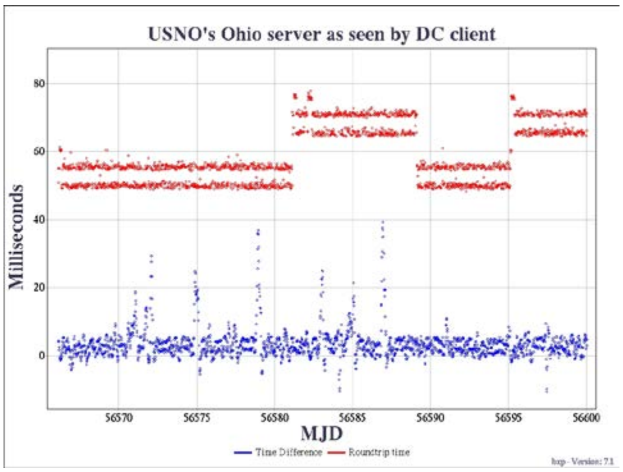

Figure 8. Bimodal behavior between Washington D.C. and Ohio. At least three of the isolated spikes in the timing differences cannot be ascribed to asymmetries as they exceed half the roundtrip time.

Asymmetries can even be found in intercity data. Figure 9 shows the offsets and delays in the USNO's public server farm (tick, tock, and ntp2), as observed by one of the Washington, D.C. clients. Observations of other servers were similarly perturbed, although there was considerable variation in magnitude and sign. The other two clients showed qualitatively similar variations.

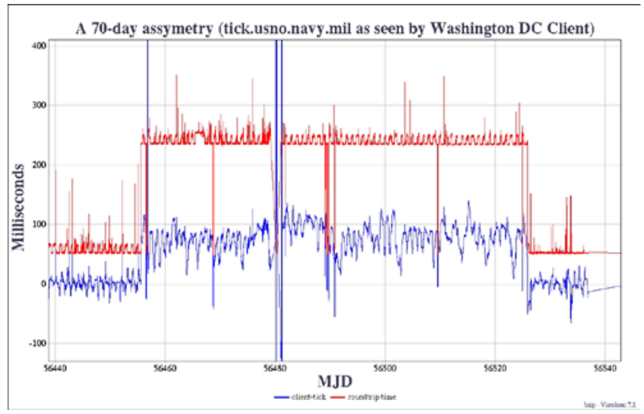

Figure 9. Time transfer (blue) and delay (red) variations as seen by a client in Washington, DC in the summer of 2013. Note the cyclical variations of the round trip delay, with one-day periodicity.

Even though the performance of today's NTP servers is mostly limited by internet issues, the ability of a client to retain its time depends on many things, and Figure 10 shows the noise difference when two different clients within the USNO query the same USNO server. One is our main analysis computer whose time is set via NTP, while the other is a server whose time is set directly to the Master Clock.

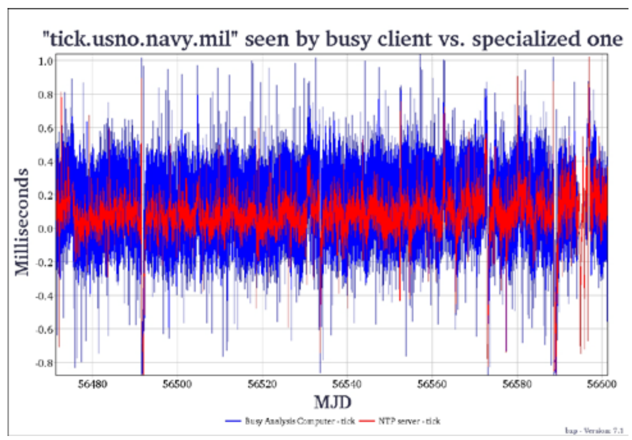

Figure 10. USNO server as seen by a busy USNO client (blue) and by a single-purpose NTP server acting as a client (red).

STATISTICAL SUMMARY

Figure 11 presents the overall time transfer accuracy of each server as an RMS, and the precisions as standard deviations of unfiltered data. Precisions can also be described by the RMS of first-differences of averaged filtered data (Figure 12). Data were edited as described above; different algorithms would yield somewhat different results for some servers. There was a factor of two discrepancy in the overall statistics of the three clients. This could be due to a variety of reasons; below we present only the statistics of the best client. One would expect that larger geographical distances to display larger variations, and this is in a general way evident in the figures shown, and also in the data not presented here.

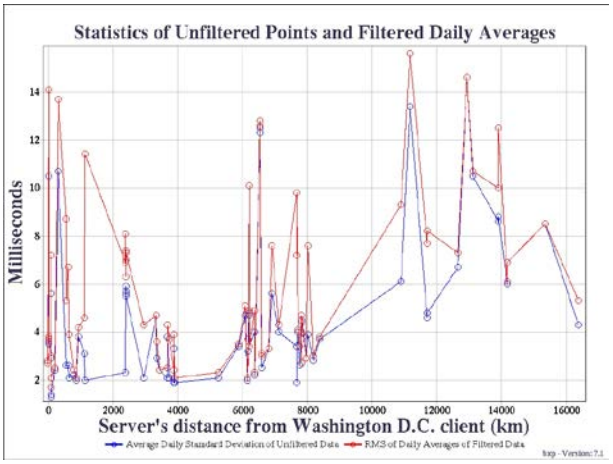

Figure 11. Observed server precisions as average standard deviation of one-day batches of unedited data (blue), and server accuracies as RMS of filtered one-day averages.

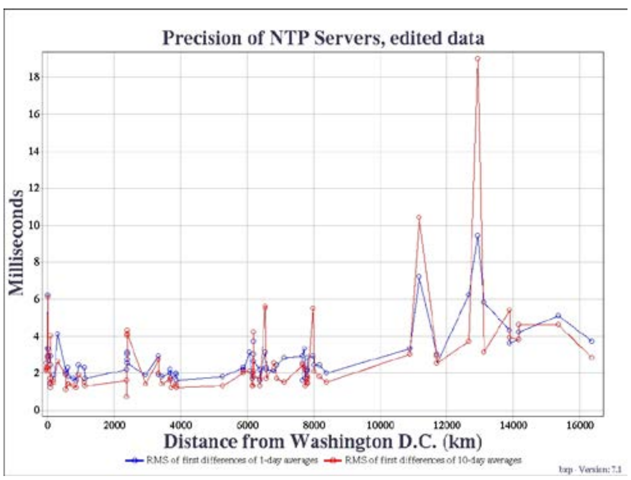

Figure 12. Precision of NTP servers as RMS of first differences of one-day and ten-day averages of edited NTP data.

DISCLAIMER

USNO does not endorse commercial products. Any identifications provided are for technical clarity only. As made clear in the text, timing data from individual NTP servers almost never reflect the qualities of the servers' NTP performance; rather they are a function of the internet topology between the server and clients.

ACKNOWLEDGEMENTS

The author thanks Ed Powers, Jeff Prillaman, and Richard Schmidt for many helpful discussions.

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