NTP Performance Analysis

David L. Mills
University of Delaware
http://www.eecis.udel.edu/~mills
mailto:mills@udel.edu

Sir John Tenniel; *Alice's Adventures in Wonderland,*Lewis Carroll

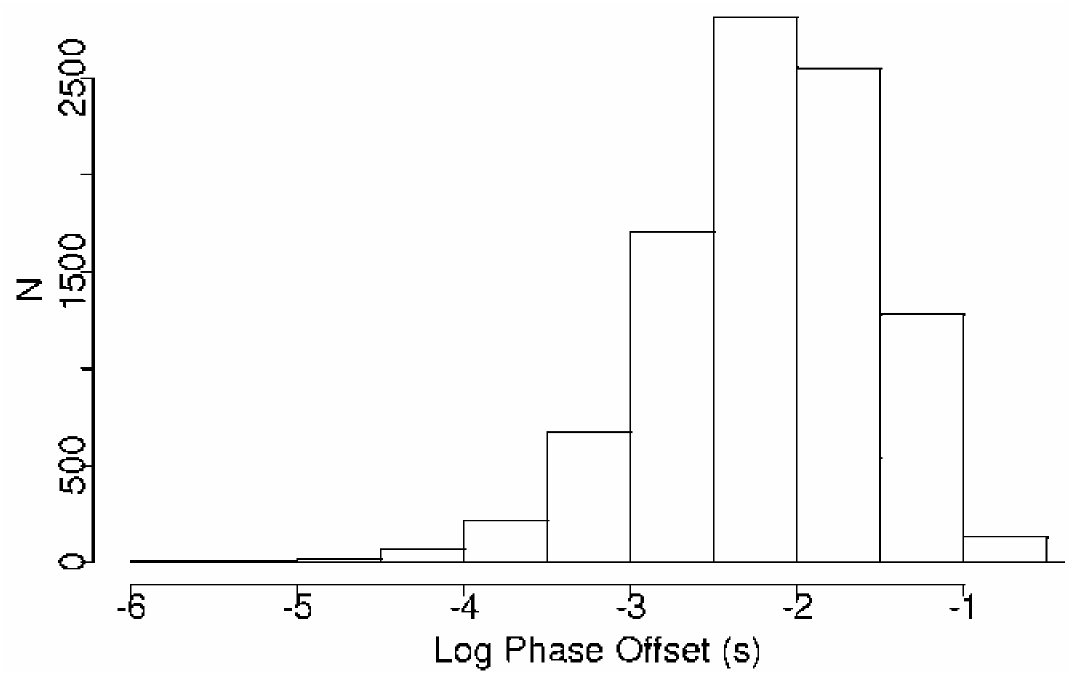
Introduction

- Network Time Protocol (NTP) synchronizes clocks of hosts and routers in the Internet
- Well over 100,000 NTP peers deployed in the Internet and its tributaries all over the world
- Provides nominal accuracies of low tens of milliseconds on WANs, submilliseconds on LANs, and submicroseconds using a precision time source such as a cesium oscillator or GPS receiver
- Unix NTP daemon ported to almost every workstation and server platform available today - from PCs to Crays - Unix, Windows, VMS and embedded systems
- NTP performance in the global Internet has been determined by simulation and nonintrusive measurement using extended surveys of many thousands of hosts and routers in regular operation

NTP capsule summary

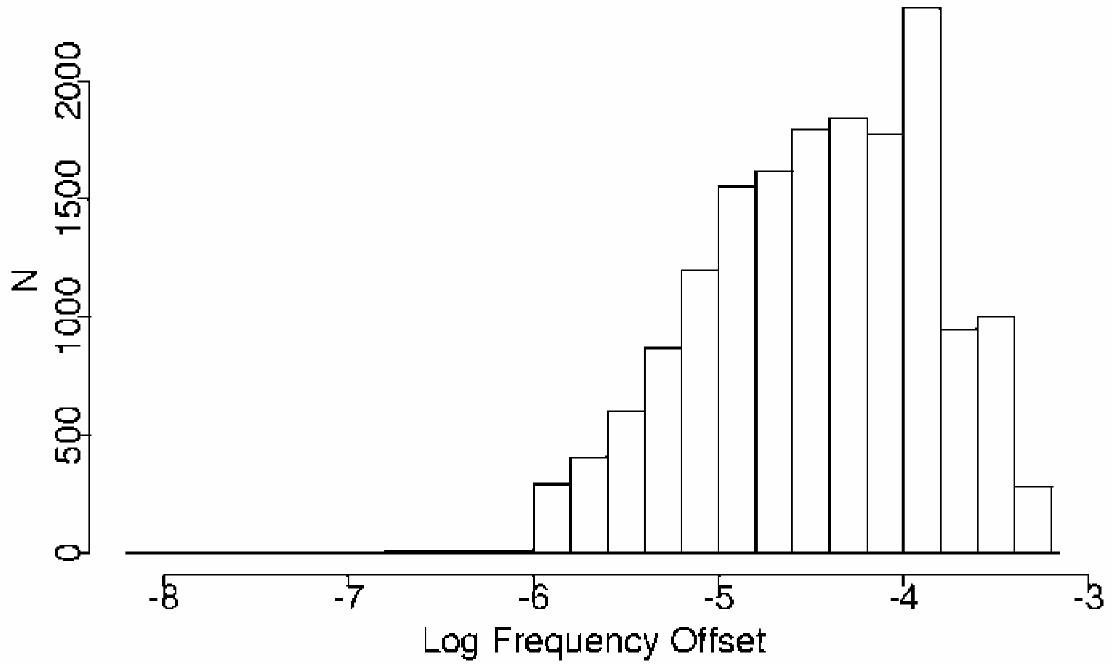
- Primary (stratum 1) servers synchronize to national time standards via radio, satellite and modem
- Secondary (stratum 2, ...) servers and clients synchronize to primary servers via hierarchical subnet
- Clients and servers operate in master/slave, symmetric or multicast modes with or without cryptographic authentication
- Reliability assured by redundant servers and diverse network paths
- Engineered algorithms reduce jitter, mitigate multiple sources and avoid improperly operating servers
- System clock is disciplined in time and frequency using an adaptive algorithm responsive to network time jitter and clock oscillator frequency wander

Typical local clock phase offsets (from survey)



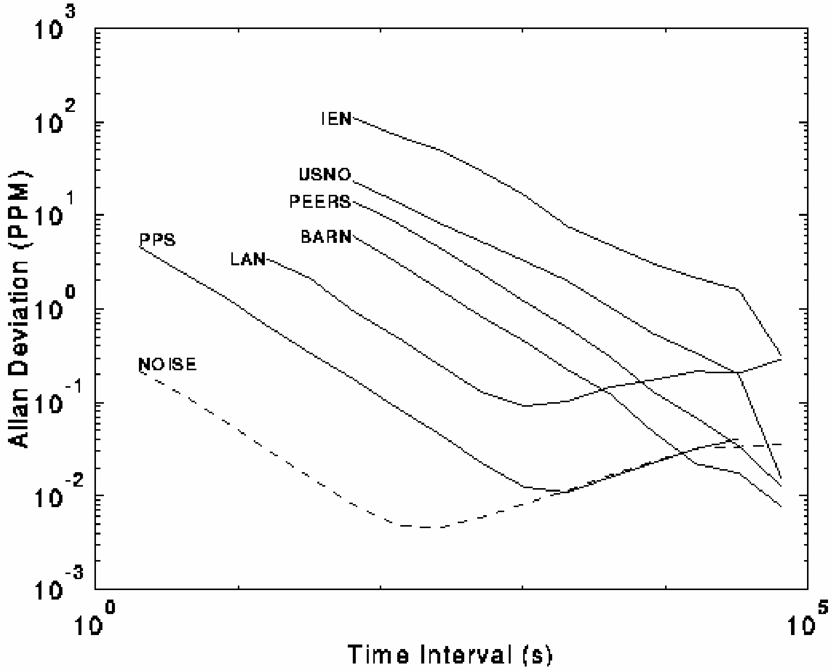
- Histogram of local clock absolute phase offsets
  - 19,873 Internet peers surveyed running NTP Version 2 and 3
  - 530 offsets equal to zero deleted as probably unsynchronized
  - 664 offsets greater than 128 ms deleted as probably unsynchronized
  - Remaining 18,679 offsets: median 7.45 ms, mean 15.87 ms

Typical local clock frequency offsets (from survey)



- Histogram of local clock absolute frequency offsets
  - 19,873 Internet peers surveyed running NTP Version 2 and 3
  - 396 offsets equal to zero deleted as probably spurious (self synchronized)
  - 593 offsets greater than 500 PPM deleted as probably unsynchronized
  - Remaining 18,884 offsets: median 38.6 PPM, mean 78.1 PPM

Allan deviation - combined data



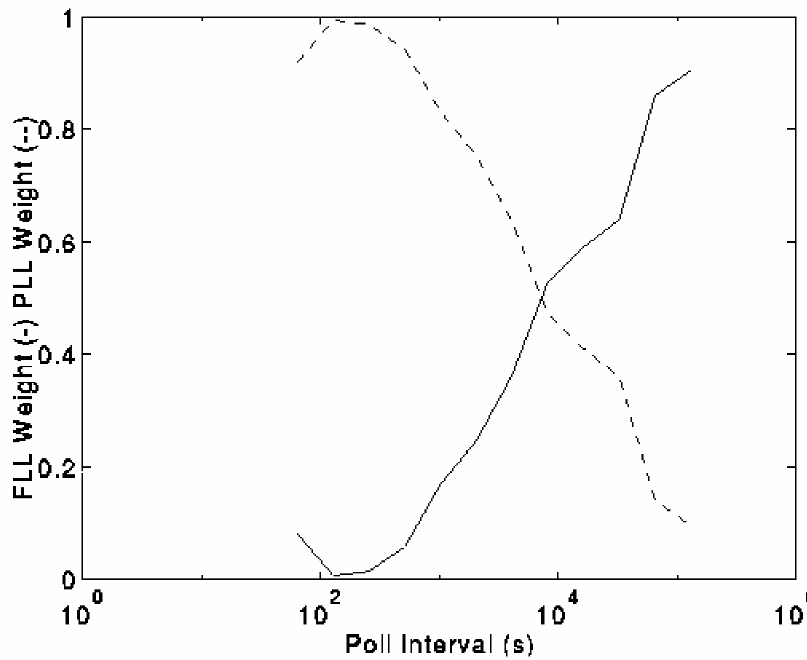
Legend

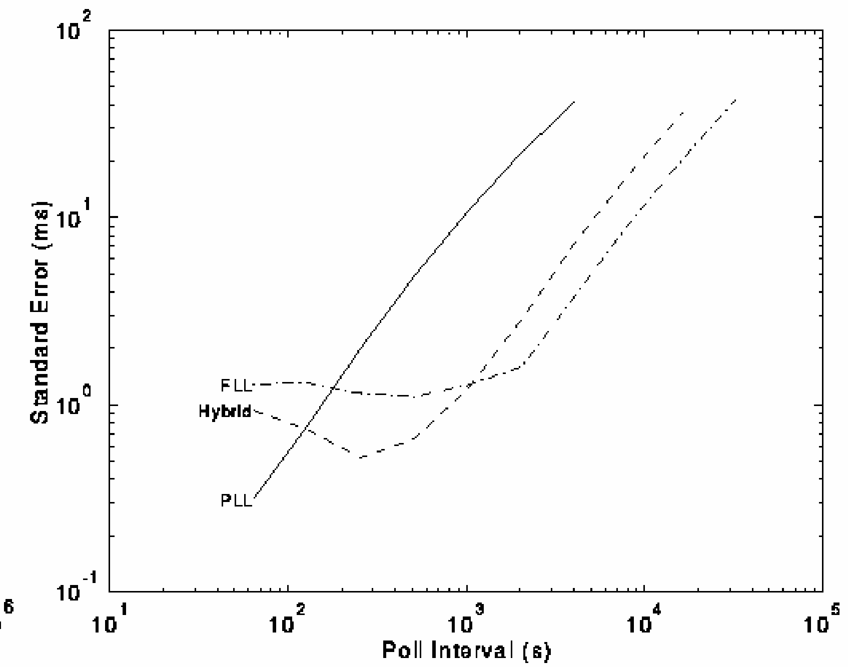
IEN	IEN Torino, Italy
USNO	US Naval Observatory, Wash DC
PEERS	19 nonlocal time servers in Europe, Japan, Australia, North and South America
BARN	local time server on DCnet
LAN	free-running clock via Ethernet
PPS	free-running clock via PPS signal
NOISE	free-running clock (synthesized)

All servers are synchronized to GPS
All NTP algorithms are operative

- Vee-shaped curves show local servers with free-running local clocks; other curves show remote servers synchronized to GPS
  - Lines with slope –1 represent white phase noise due to network jitter
  - Lines with slope +0.5 represent random-walk frequency noise due to clock oscillator wander
  - Intersection of phase and frequency noise lines is called the Allan intercept
  - In general, PLL is best when T_c is below Allan intercept; FLL is best above it

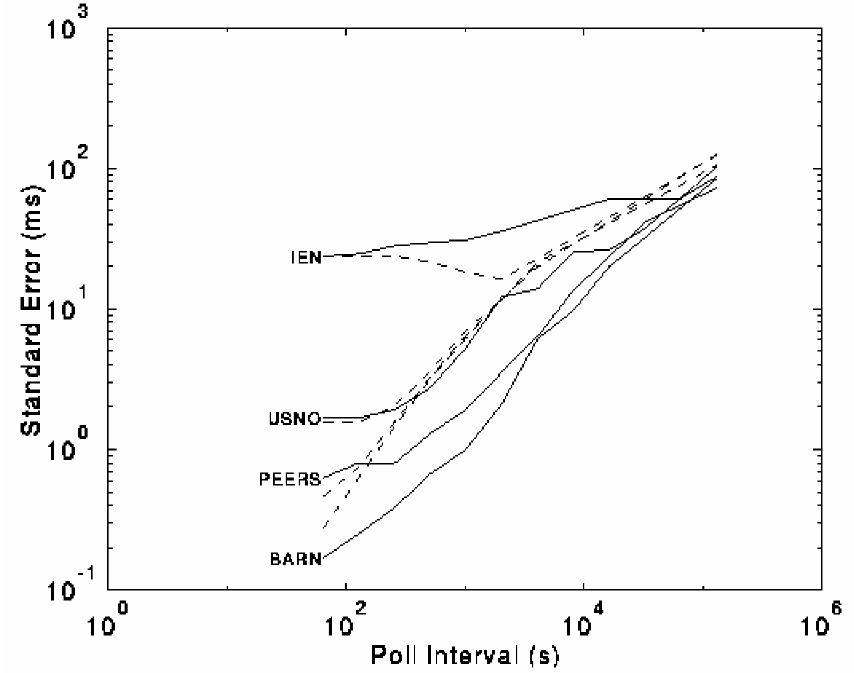
Compare FLL, PLL and hybrid modes for USNO peer





- Left graph shows FLL and PLL weights, right graph shows standard error as a function of poll interval for FLL, PLL and hybrid modes
  - Note FLL is best above 200 s, PLL is best below this
  - Hybrid mode is best between most important range, 100 s to 1,000 s, and not much worse than FLL or PLL outside this range.
  - PLL comes unstable above 4,000 s due to loss of lock.

Standard error for various network paths



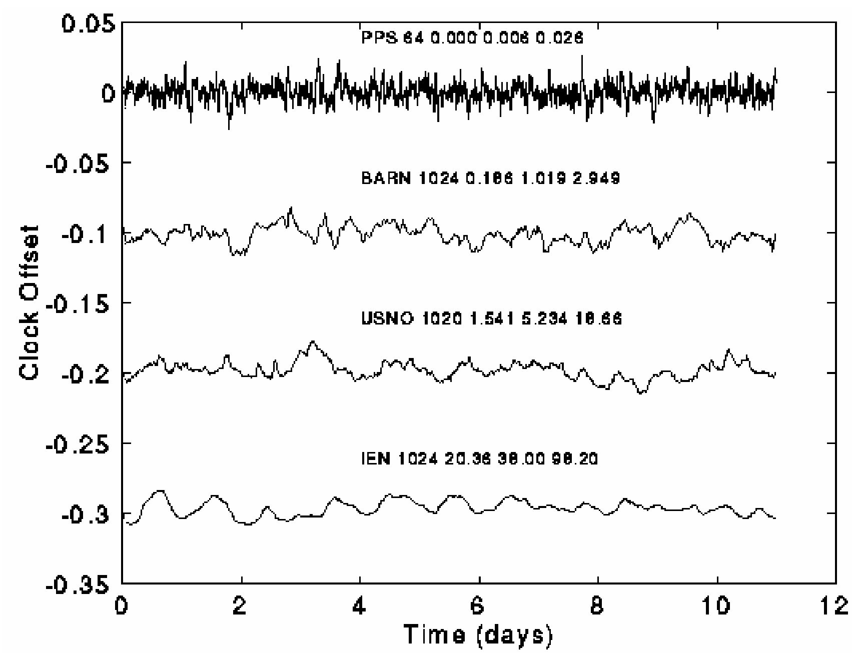
Legend

IEN	IEN Torino, Italy
USNO	US Naval Observatory, Wash DC
PEERS	19 nonlocal time servers in Europe, Japan, Australia, North and South America
BARN	local time server on DCnet

All servers are synchronized to GPS
All NTP algorithms are operative

- Solid lines show hybrid mode performance, dashed lines PLL mode, both over a ten-day period
  - Hybrid mode better than PLL mode by a factor of ten over important range
  - Local time server better than 200 μs standard error at poll = 64 s
  - All nonlocal time servers better than 2 ms at poll ≤ 1,024 s
  - Standard error of all nonlocal time servers (including best USNO) is better than any server separately

Performance



Legend	
IEN	IEN Torino, Italy
USNO	US Naval Observatory, Wash DC
BARN	local time server on Dcnet
PPS	PPS signal (64-s poll clamp)

Label Format	
1	server name
2	mean poll interval (s)
3	mean error (ms)
4	RMS error (ms)
5	max error (ms)

All servers are synchronized to GPS
All NTP algorithms are operative

- Typical performance of stratum-2 servers synchronized to remote primary servers
  - Except for PPS, which uses simulated phase noise, all use actual network noise measured in real time
  - Frequency noise is simulated with curve fit to PPS data

A day in the life of a busy NTP server

- NTP primary (stratum 1) server rackety is a Sun IPC running SunOS 4.1.3 and supporting 734 clients scattered all over the world
- This machine supports NFS, NTP, RIP, IGMP and a mess of printers, radio clocks and an 8-port serial multiplexor
- The mean input packat rate is 6.4 packets/second, which corresponds to a mean poll interval of 157 seconds for each client
- Each input packet generates an average of 0.64 output packets and requires a total of 2.4 ms of CPU time for the input/output transaction
- In total, the NTP service requires 1.54% of the available CPU time and generates 10.5, 608-bit packets per second, or 0.41% of a T1 line
- The conclusion drawn is that even a slow machine can support substantial numbers of clients with no significant degradation on other network services

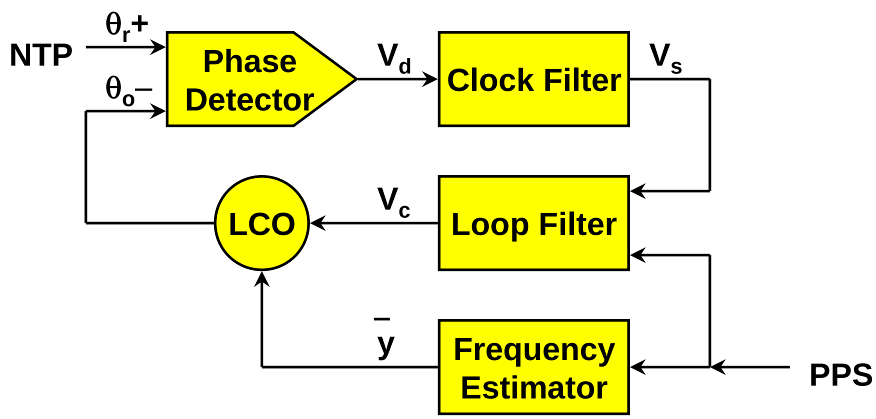
The Sun never sets on NTP

- NTP is argueably the longest running, continuously operating, ubiquitously available protocol in the Internet
- USNO and NIST, as well as equivalents in other countries, provide multiple NTP primary servers directly synchronized to national standard cesium clock ensembles and GPS
- Over 230 Internet primary servers in Australia, Canada, Chile, France, Germany, Isreal, Italy, Holland, Japan, Norway, Sweden, Switzerland, UK, and US
- Over 100,000 Internet secondary servers and clients all over the world
- National and regional service providers BBN, MCI, Sprint, Alternet, etc.
- Agencies and organizations: US Weather Service, US Treasury Service, IRS, PBS, Merrill Lynch, Citicorp, GTE, Sun, DEC, HP, etc.
- Several private networks are reported to have over 10,000 NTP servers and clients behind firewalls; one (GTE) reports in the order of 30,000 NTP-equipped workstations and PCs

NTP enhancements for precision time

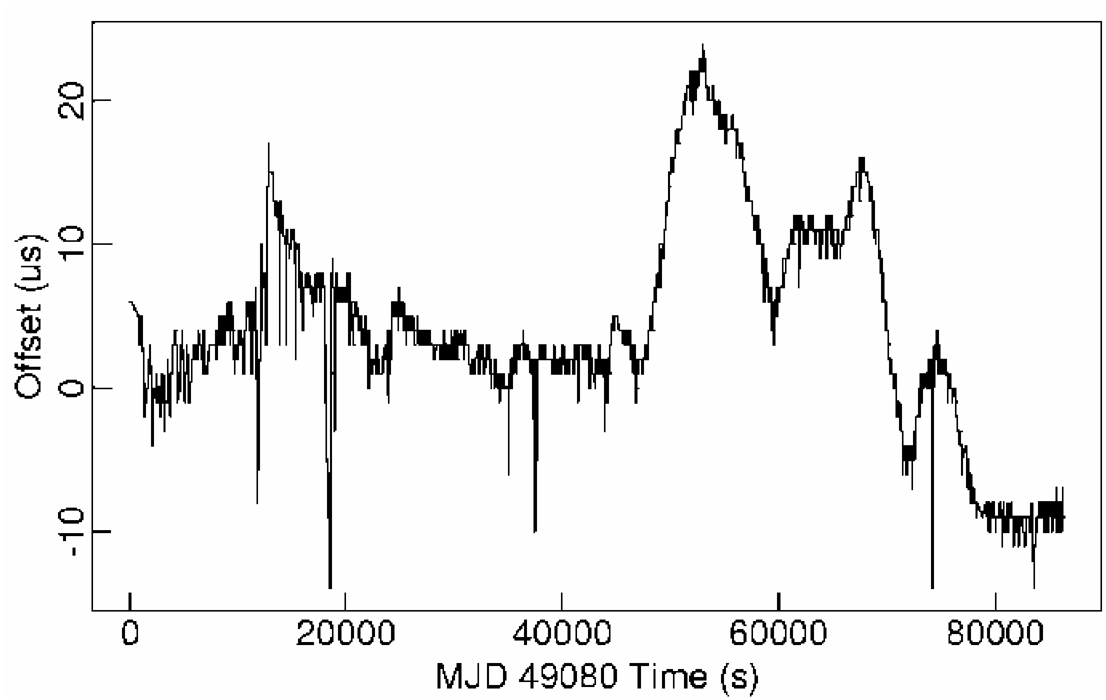
- Precision time kernel modifications
  - Time and frequency discipline from NTP or other source
  - Pulse-per-second (PPS) signal interface via modem control lead
  - CPU clock wrangling for symmetric multiprocessor (SMP) systems (Alpha)
- Improved local clock discipline algorithm
  - Hybrid phase/frequency discipline
  - Message intervals extended to several hours for modem services
  - Improved glitch detection and supression
- Precision time and frequency sources
  - PPS signal grooming with median filter and dynamic adaptive time constant
  - Additional drivers for new GPS receivers and PPS discipline
- Reduced hardware and software latencies
  - Serial driver modifications to remove character batching
  - Early timestamp/PPS capture using line disciplines
  - Protocol modifications for multiple primary source mitigation

Improved NTP local clock discipline



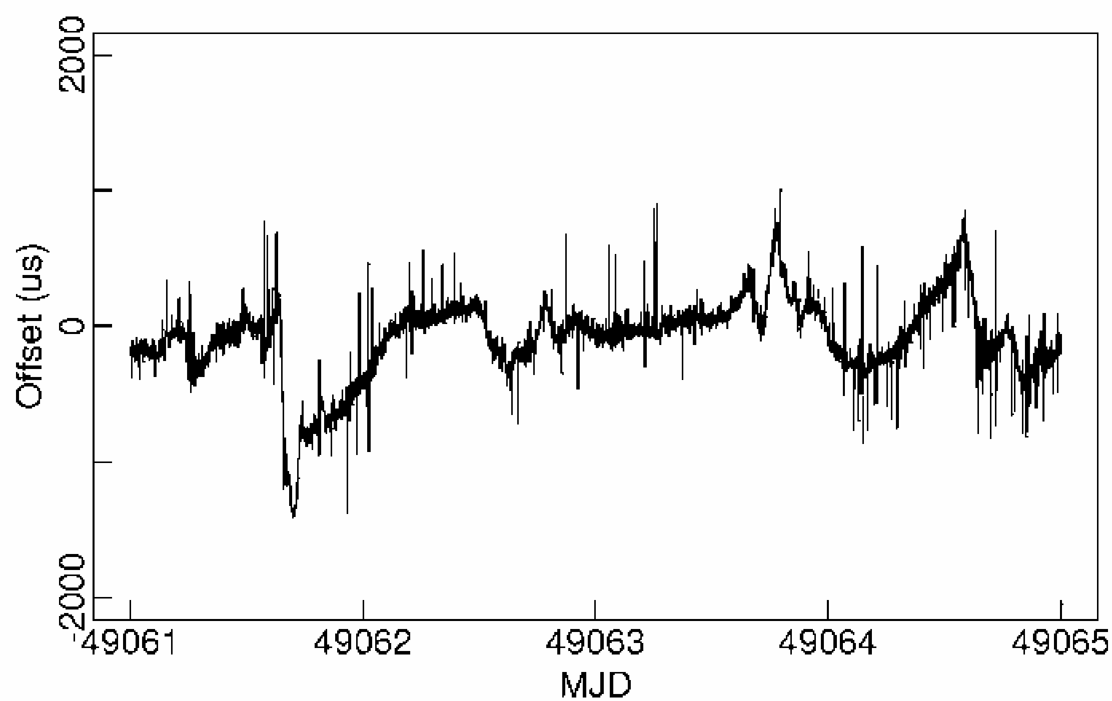
- Type II, adaptive-parameter, hybrid phase/frequency-lock loop estimates LCO phase and frequency
- Phase signal $V_d = \theta_r - \theta_o$ between NTP and local clock oscillator (LCO) computed from timestamps, then filtered to produce control signal V_c
- Auxiliary frequeny-lock loop disciplines LCO frequency y to pulse-per-second (PPS) signal, when available
- Loop parameters automatically optimized for update intervals from 16 s to over 1 d

PPS signal kernel discipline



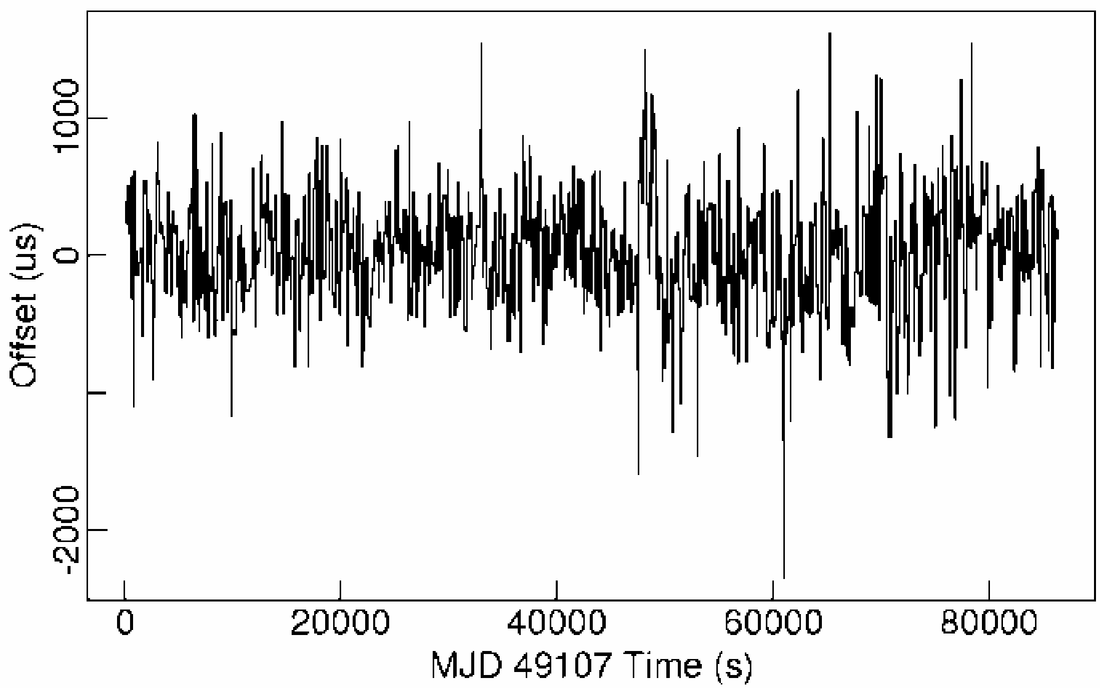
- Graph shows offsets of local clock oscillator relative to PPS signal
- PPS signal disciplines the local clock via kernel interface
- Precision-time kernel modifications are operative

Performance with a secondary server via Ethernet



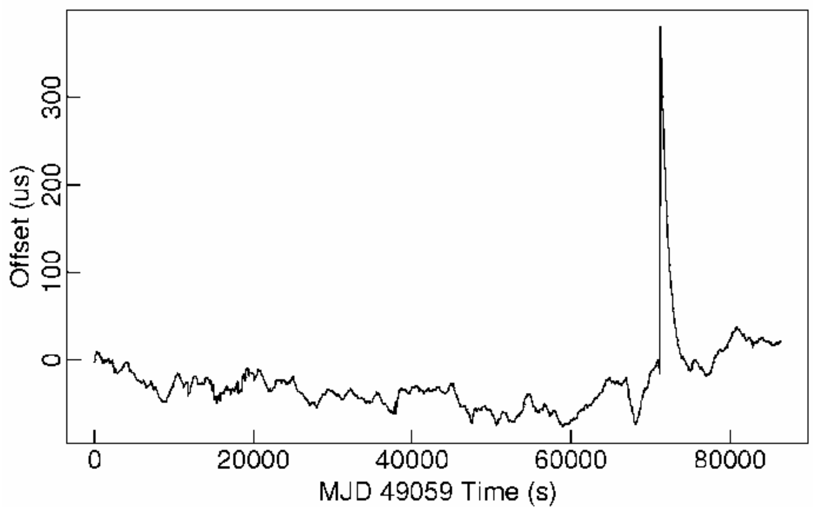
- Clock offsets for Sun SPARC 1+ and SunOS 4.1.1 over four days
  – Primary server synchronized to GPS with PPS
  – Spikes are due to Ethernet jitter and collisions
  – Wander is due to client clock oscillator instability

Performance with a secondary server via T1 line

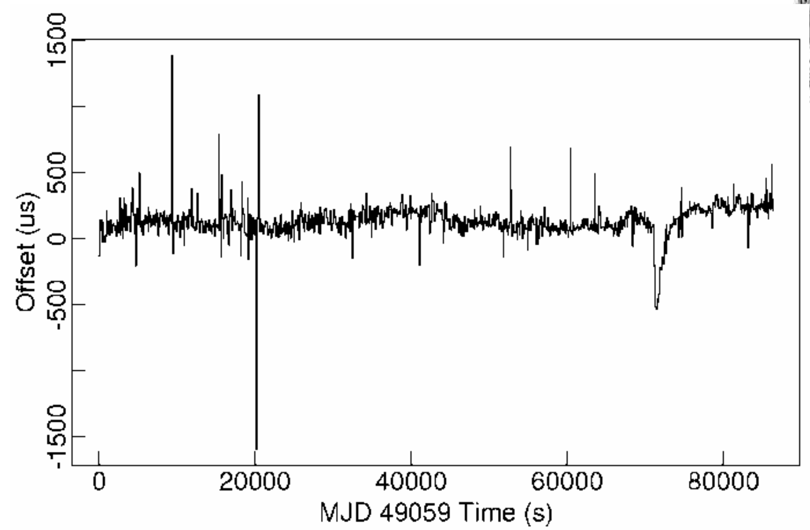


- Clock offsets measured for a NSFnet secondary server running NTP
  - Measurements use NSF server synchronized to a primary server via Ethernets and T1 tail circuit
  - This is typical behavior for lightly loaded T1 circuit

Closed-loop characteristics of primary servers



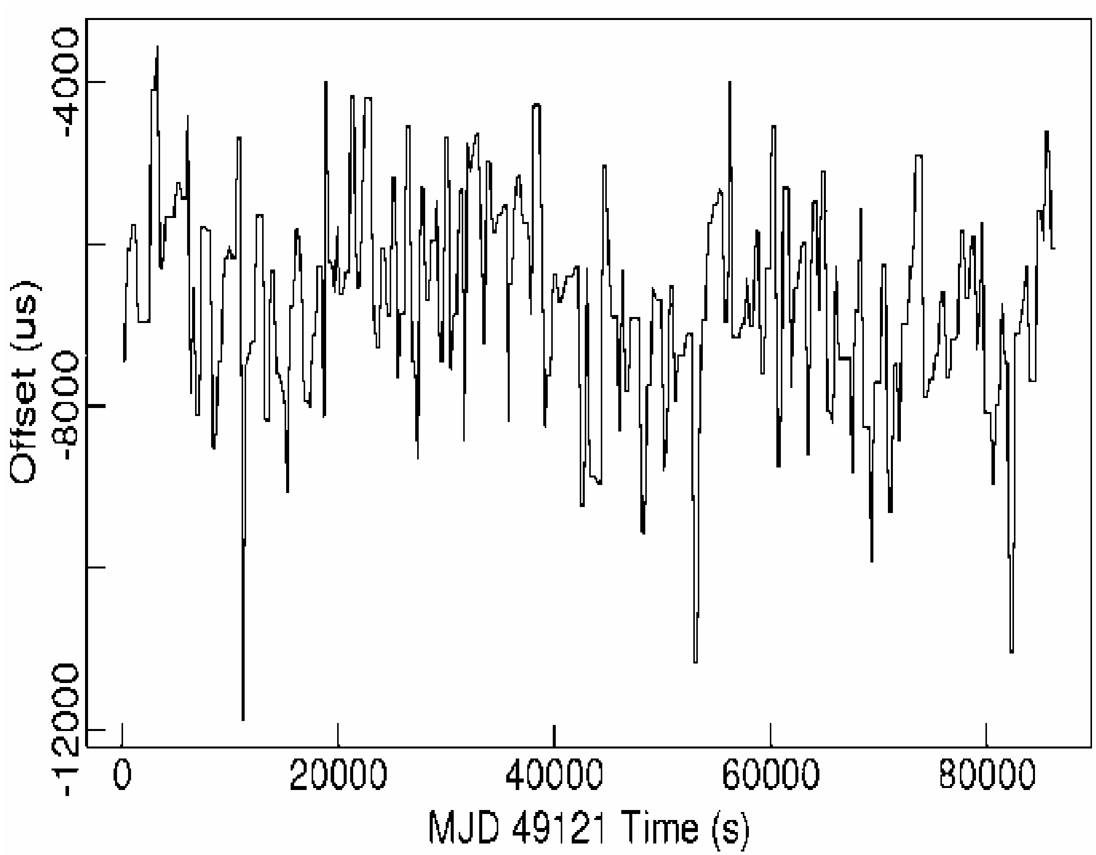
(a) Clock Offset Relative to GPS



(b) Clock Offset between Two Primary Servers

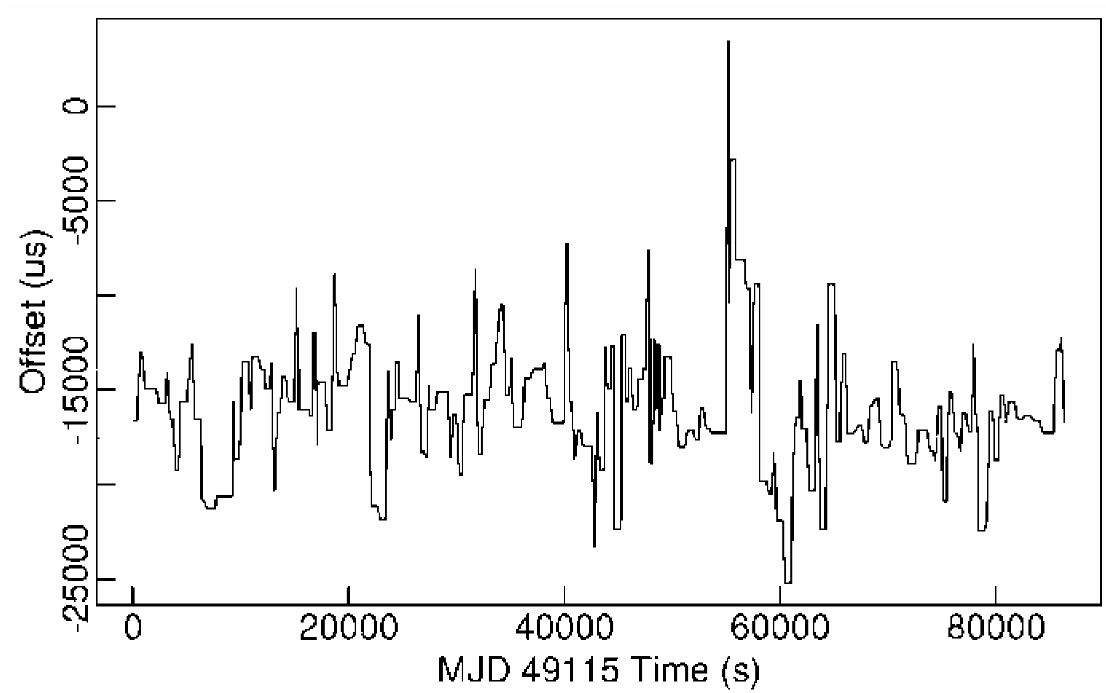
- Clock offsets for Sun SPARC 1+ and SunOS 4.1.1 over one day
  - Two primary servers, both synchronized to the same GPS receiver (no PPS)
  - (a) Measured GPS receiver relative to the local clock of either server
  - (b) Measured one server across the Ethernet relative to the local clock of the other server
  - Note 300-µs spike of unknown cause is visible in both (a) and (b)

Performance with a modem and ACTS service



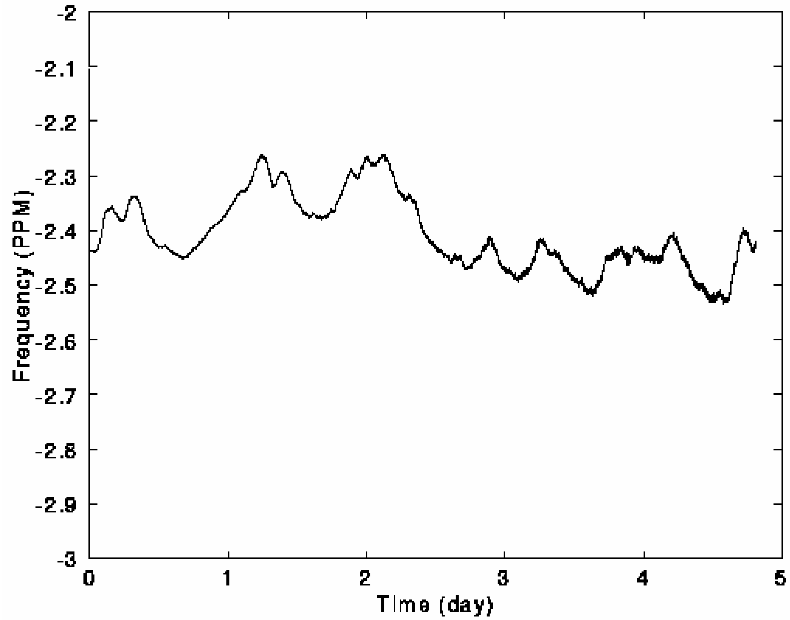
- Measurements use 2300-bps telephone modem and NIST Automated Computer Time Service (ACTS)
- Calls are placed via PSTN at 16,384-s intervals

Time offsets with an Australian primary server

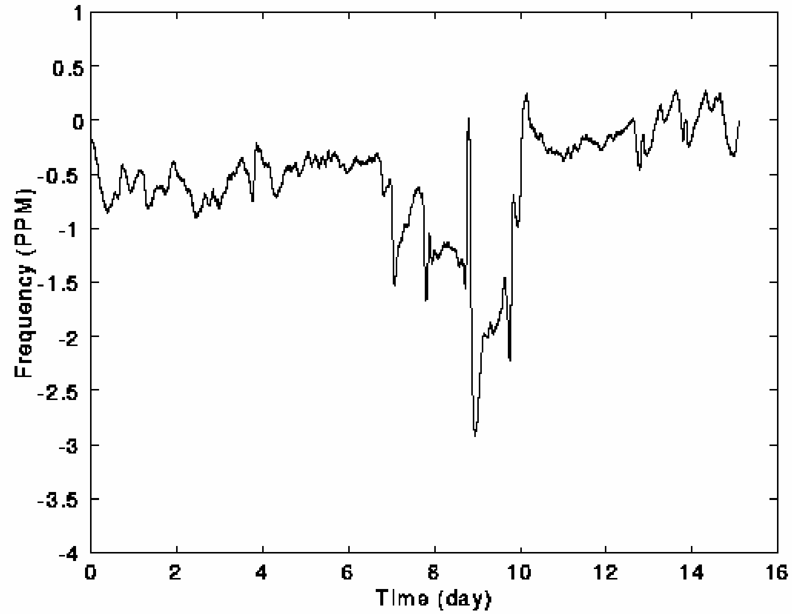


- Transmission path is one way via satellite, the other way via undersea cable
- This surely is an extreme case of network jitter and congestion

Typical frequency variations with temperature



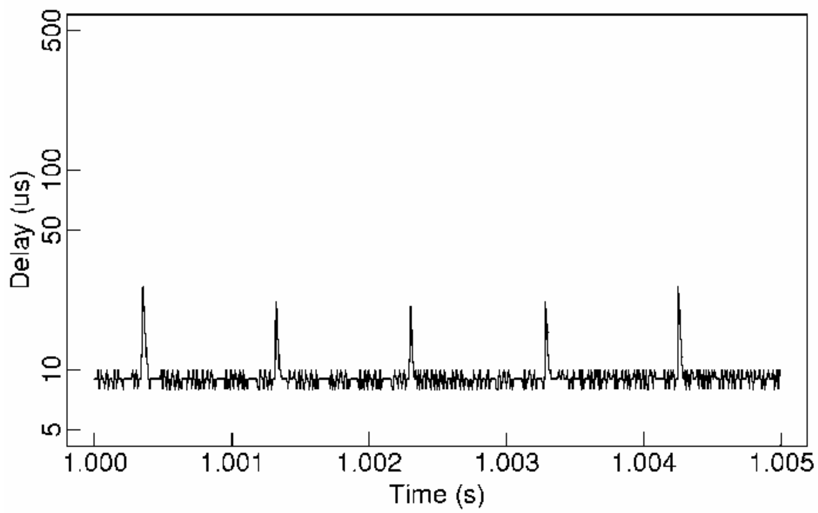
(a) Frequency Offset Measured by PPS



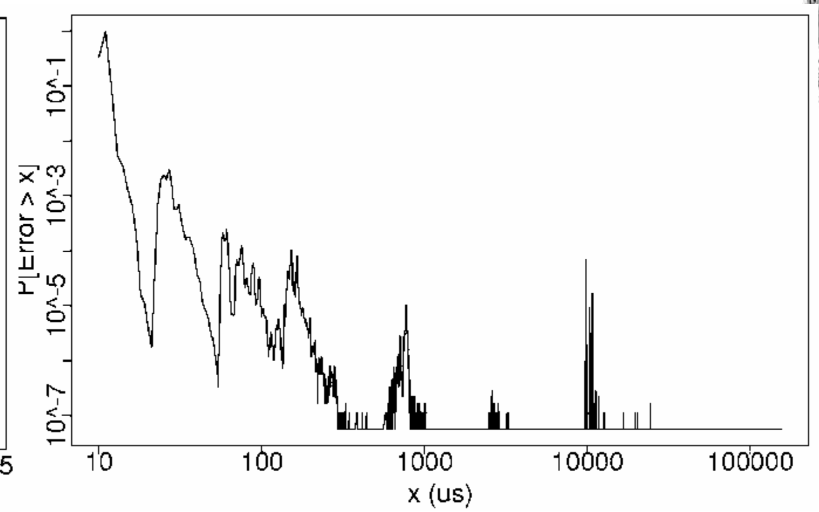
(b) Frequency Offset Measured by NTP

- Measured frequency offsets for free-running local clock oscillator
- (a) Measured directly using PPS signal and `ppsclock` clock discipline
  - Typical room temperature thermostatically controlled in winter
- (b) Measured indirectly using NTP and host synchronized to PPS signal
  - Room temperature follows the ambient in first nice days in spring

Errors due to kernel latencies



(a) Latency for `getimeofday()` Call



(b) Latency Distribution for (a)

- These graphs were constructed using a Digital Alpha and OSF/1 V3.2 with precision time kernel modifications (now standard)
- (a) Measured latency for gettimeofday() call
  - spikes are due to timer interrupt routine
- (b) Probability distribution for (a) measured over about ten minutes
  - Note peaks near 1 ms due timer interrupt routine, others may be due to cache reloads, context switches and time slicing
  - Biggest surprise is very long tail to large fractions of a second

NTP online resources

- Network Time Protocol (NTP) Version 3 Specification RFC-1305
  - NTPv4 features documented in release notes and reports cited there
- Simple NTP (SNTP) Version 3 specification RFC-2030
  - Applicable to IPv4, IPv6 and ISO CNLS
- List of public NTP time servers (as of November 1999)
  - 93 active primary (stratum 1) servers
  - 109 active stratum 2 servers
- NTP Version 4 implementation and documentation for Unix, VMS and Windows
  - Ported to over two dozen architectures and operating systems
  - Utility programs for remote monitoring, control and performance evaluation
  - Complete documentation in HTML format
- Collaboration resources at http://www.eecis.udel.edu/~mills/resource.htm

Further information

- Network Time Protocol (NTP): http://www.ntp.org/
  - Current NTP Version 3 and 4 software and documentation
  - FAQ and links to other sources and interesting places
- David L. Mills: http://www.eecis.udel.edu/~mills
  - Papers, reports and memoranda in PostScript and PDF formats
  - Briefings in HTML, PostScript, PowerPoint and PDF formats
  - Collaboration resources hardware, software and documentation
  - Songs, photo galleries and after-dinner speech scripts
- FTP server ftp.udel.edu (`pub/ntp` directory)
  - Current NTP Version 3 and 4 software and documentation repository
  - Collaboration resources repository
- Related project descriptions and briefings
  - See “Current Research Project Descriptions and Briefings” at http://www.eecis.udel.edu/~mills/status.htm