NTP Clock Discipline Modelling and Analysis

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

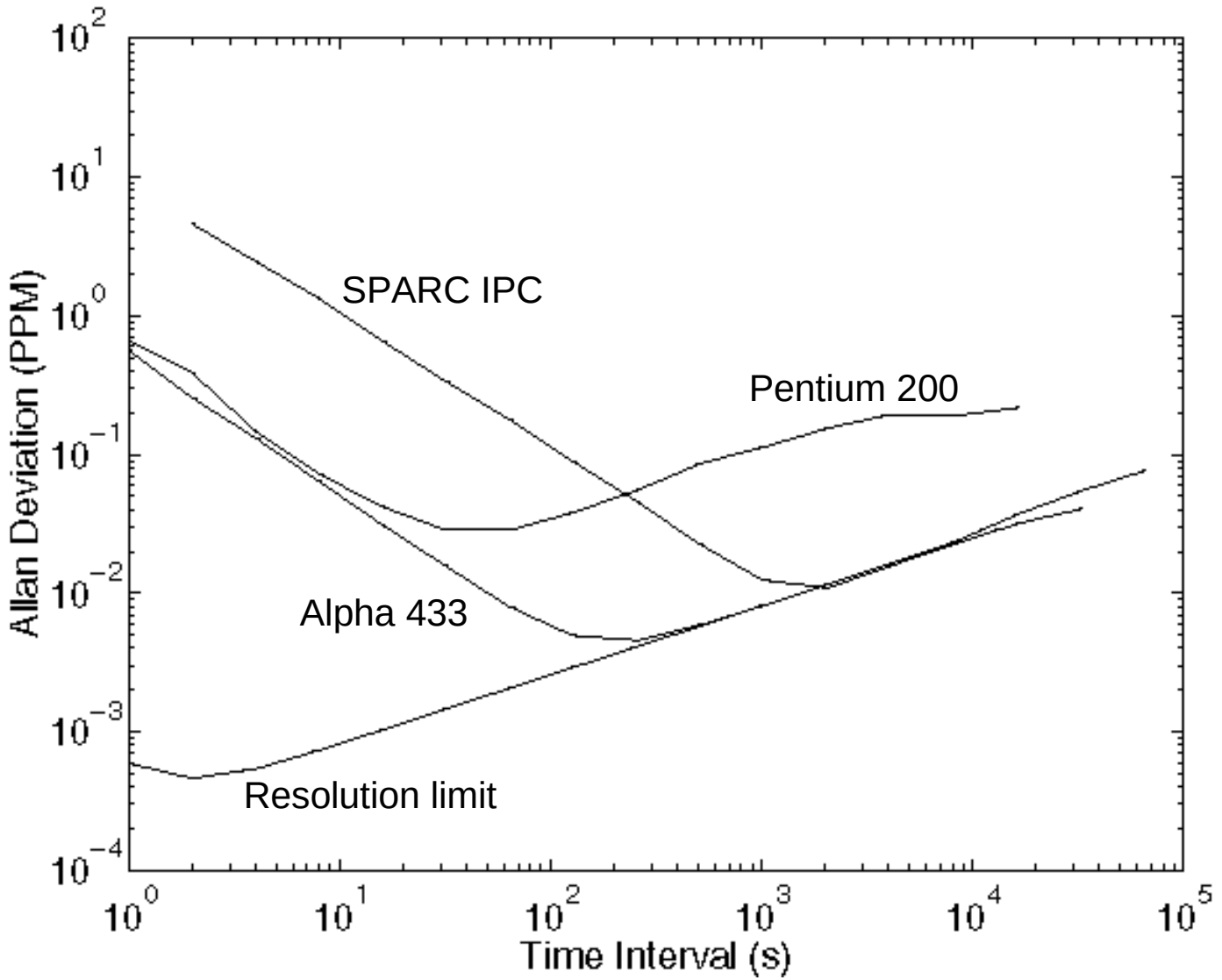
Clock discipline error modelling

- Errors due to network jitter
  - Jitter process is modelled by an exponential distribution with parameter σ.
  - Jitter estimator is the square root of the average of time difference squares.
  - Jitter characteristic appears as a straight line with slope –1 on the Allan deviation plot.
- Errors due to oscillator wander
  - Wander process is modelled by the integral of a zero-mean normal distribution with parameter σ.
  - Wander estimator is the square root of the average of frequency difference squares.
  - Wander characteristic appears as a straight line with slope +0.5 on the Allan deviation plot.
- The Allan intercept is defined as the intersection of the jitter and wander characteristics.
  - The intersection coordinates define the optimum averaging interval and poll interval.

Constructing the Allan deviation plot

- Time differences between the system clock and an external standard are measured at 1-s intervals over several days
- For a given time interval τ the frequency $y(\tau)$ is determined as the time difference between the beginning and end of the interval divided by τ
- The Allan deviation $\sigma_y(\tau)$ is defined as the average of successive frequency differences $\Delta y(\tau)$ as τ varies from 1 s to several days.
- The Allen deviation plot appears in log-log coordinates as two intersecting lines determined by the jitter and wander characteristics
- The following graph shows $\sigma_y(\tau)$ for three architectures and operating system, plus a synthesized characteristic with nanosecond resolution and assumed “good” frequency stability.
  - Alpha 433 has nanokernel modifications and 2.3-ns resolution.
  - Pentium 200 has nanokernel modifications and 5-ns resolution.
  - SPARC IPC has microkernel modifications and 1000-ns resolution.

Allan deviation characteristics compared



Allan intercepts compared

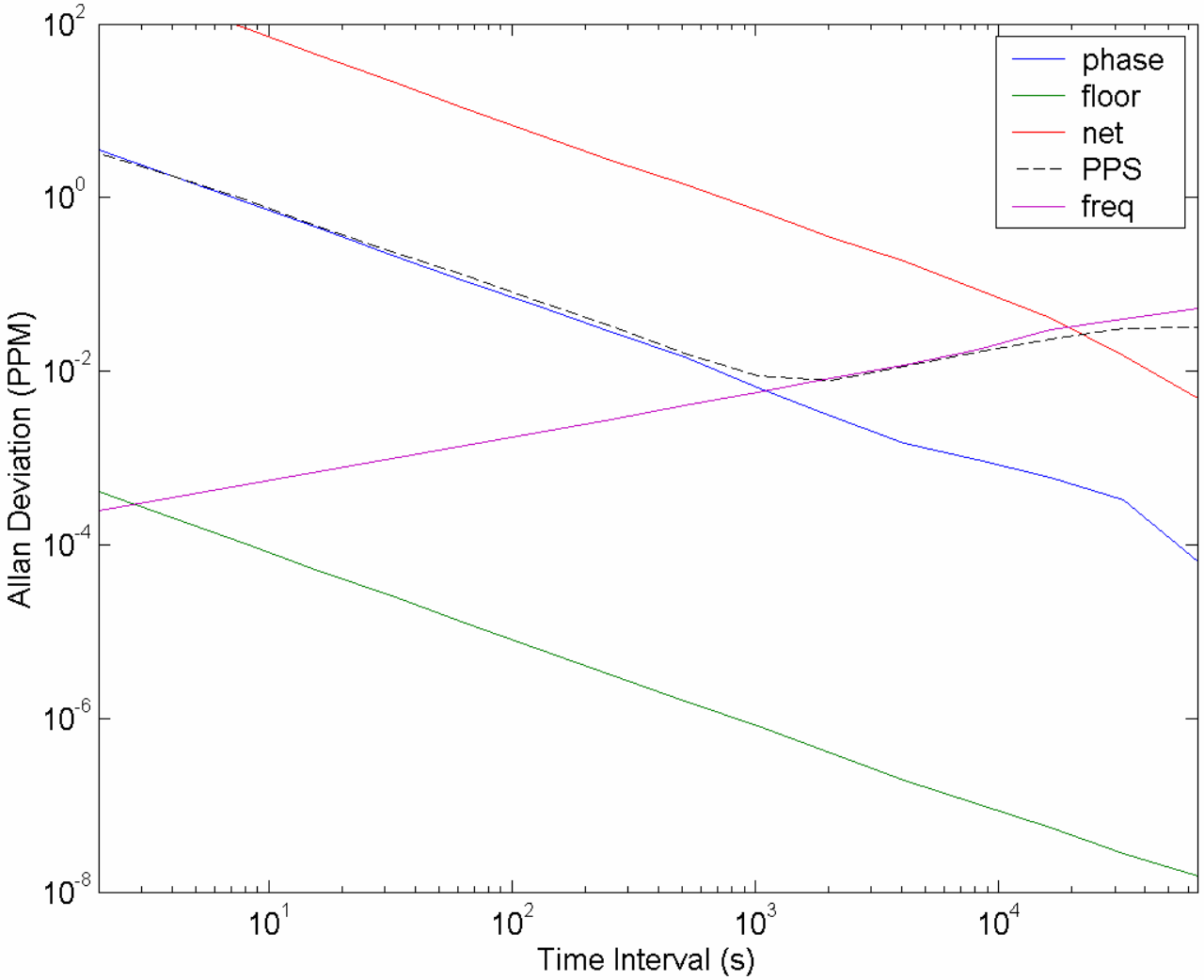
System	Resolution	Precision	Stability	*x* Intercept	*y* Intercept	Range *
SPARC IPC	1000 ns	1000 ns	good	2000 s	.01 PPM	600 - 5000 s
Pentium 200	1 ns	5 ns	poor	50 s	.03 PPM	10 - 300 s
Alpha 433	1 ns	2.3 ns	good	200 s	.005 PPM	50 - 2000 s
Resolution limit	1 ns	1 ns	good	2 s	.0004 PPM	1 - 10 s

* For stability no worse than twice *y* intercept

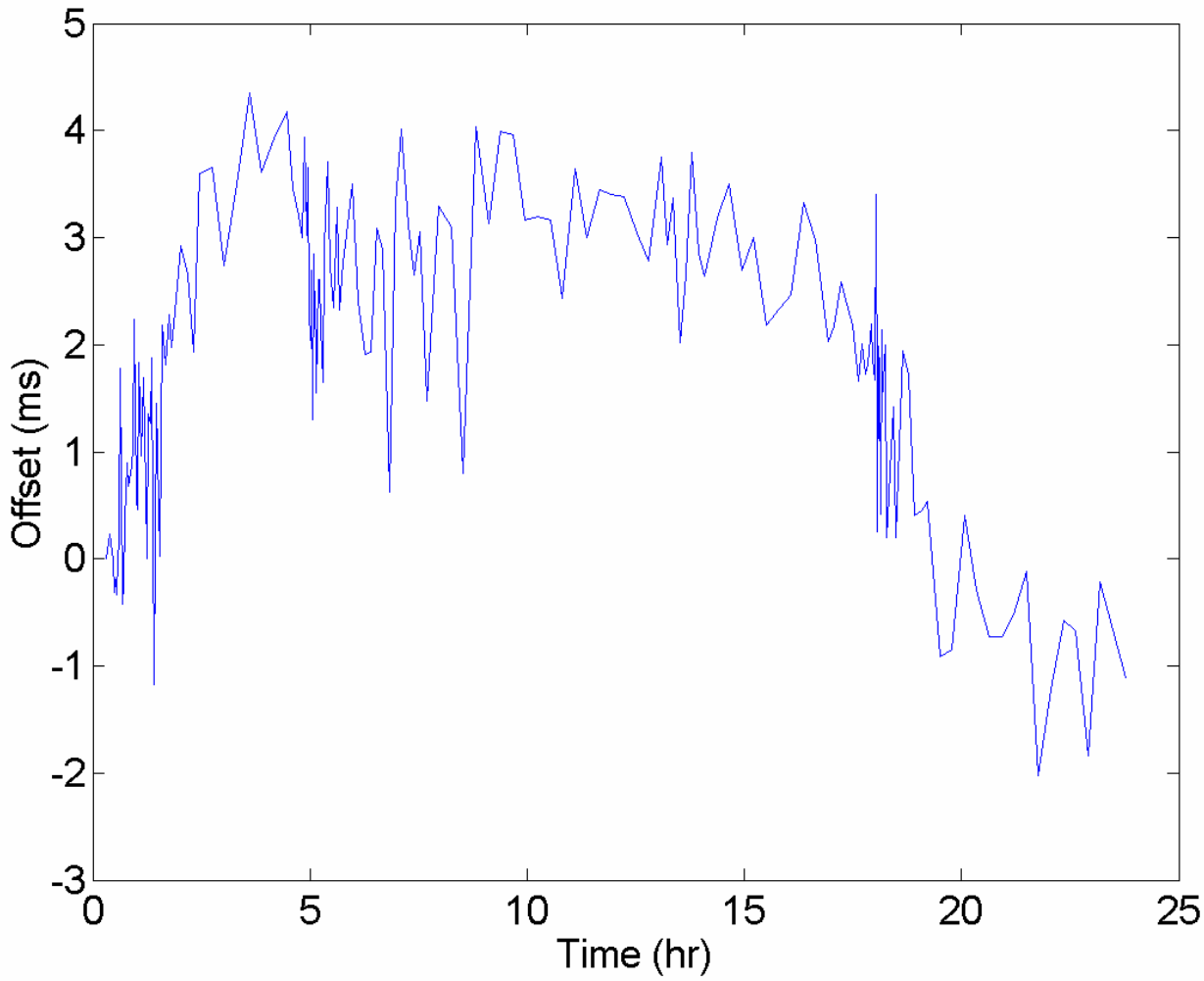
Allan deviation cont.

- A useful performance predictor can be constructed from Allan deviation plots and synthetic noise sources. The graph on the next page compares the Allan deviation of a PPS source to pseudo-random noise sources.
  - The PPS signal is connected to a Sun SPARC IPC running SunOS 4.1.3.
  - Trace *PPS* shows the measured combined phase (slope -1) and frequency (slope +0.5) noise.
  - Trace *net* is generated from an exponential distribution with parameter 500e-6. This is typical of a workstation synchronized to a primary time server over the Internet.
  - Trace *phase* is generated from an exponential distribution with parameter 5e-6. Note how closely this matches the *PPS* phase characteristic.
  - Trace *floor* is generated from a uniform distribution between 0 and 2 ns. This may represent the best achievable with modern workstations.
  - Trace *freq* is generated from the integral of a zero-mean normal distribution with parameter 5e-10. This represents the random-walk characteristic of typical computer oscillators.

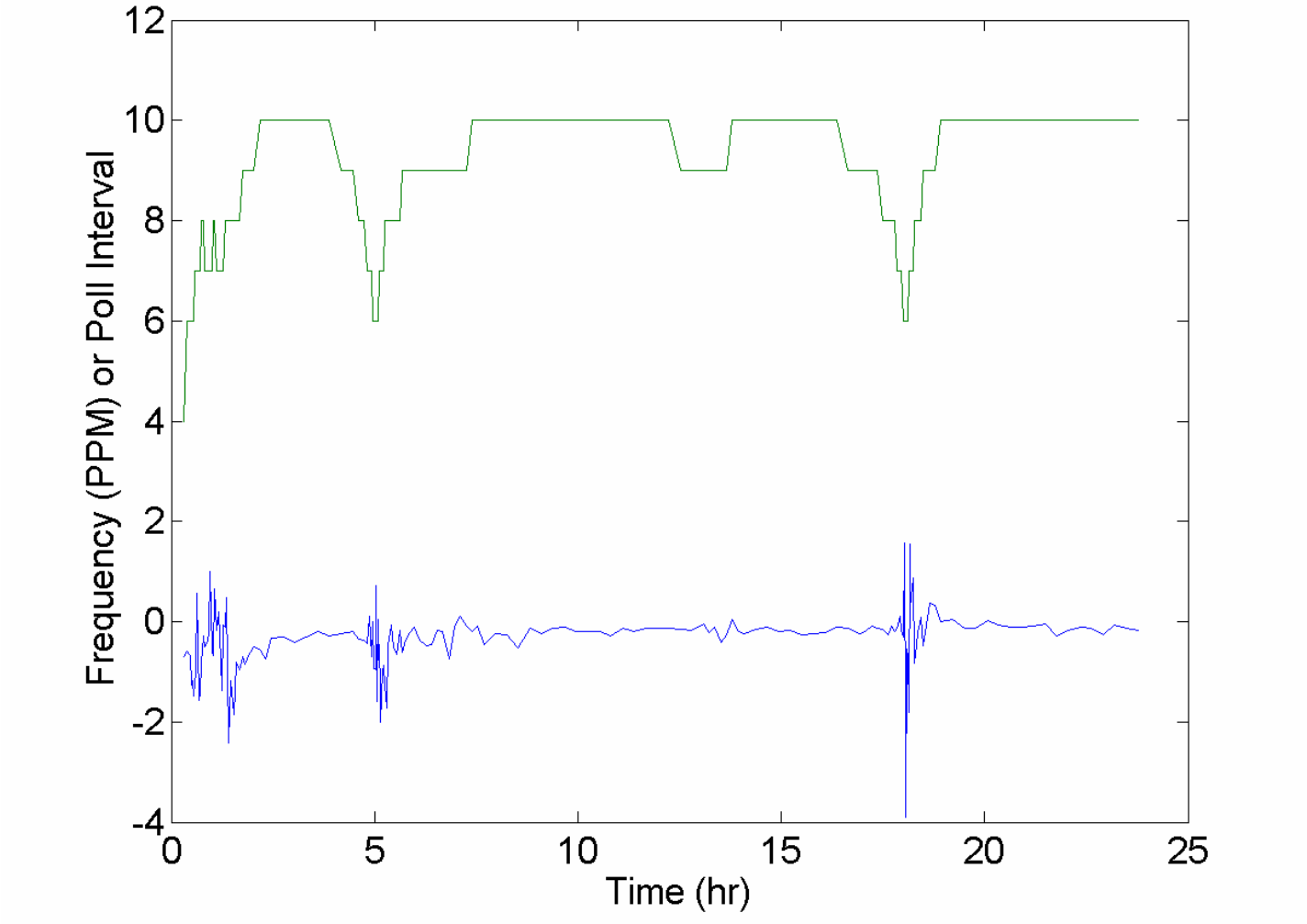
Allan deviation calibration



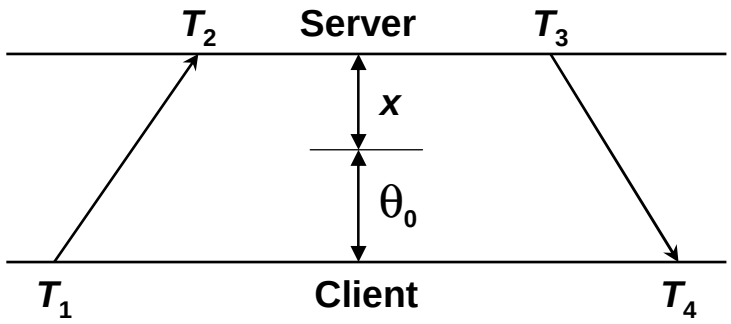
Clock offset from simulator



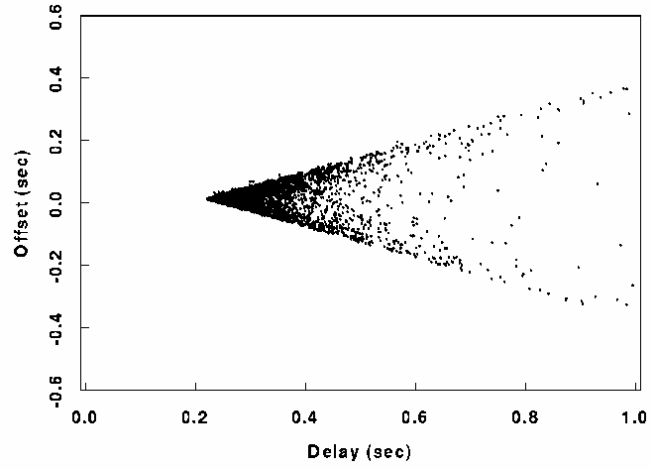
Frequency offset and poll interval from simulator



Clock filter algorithm



$$\theta = \tfrac{1}{2}[(T_2 - T_1) + (T_3 - T_4)]$$
$$\delta = (T_4 - T_1) - (T_3 - T_2)$$

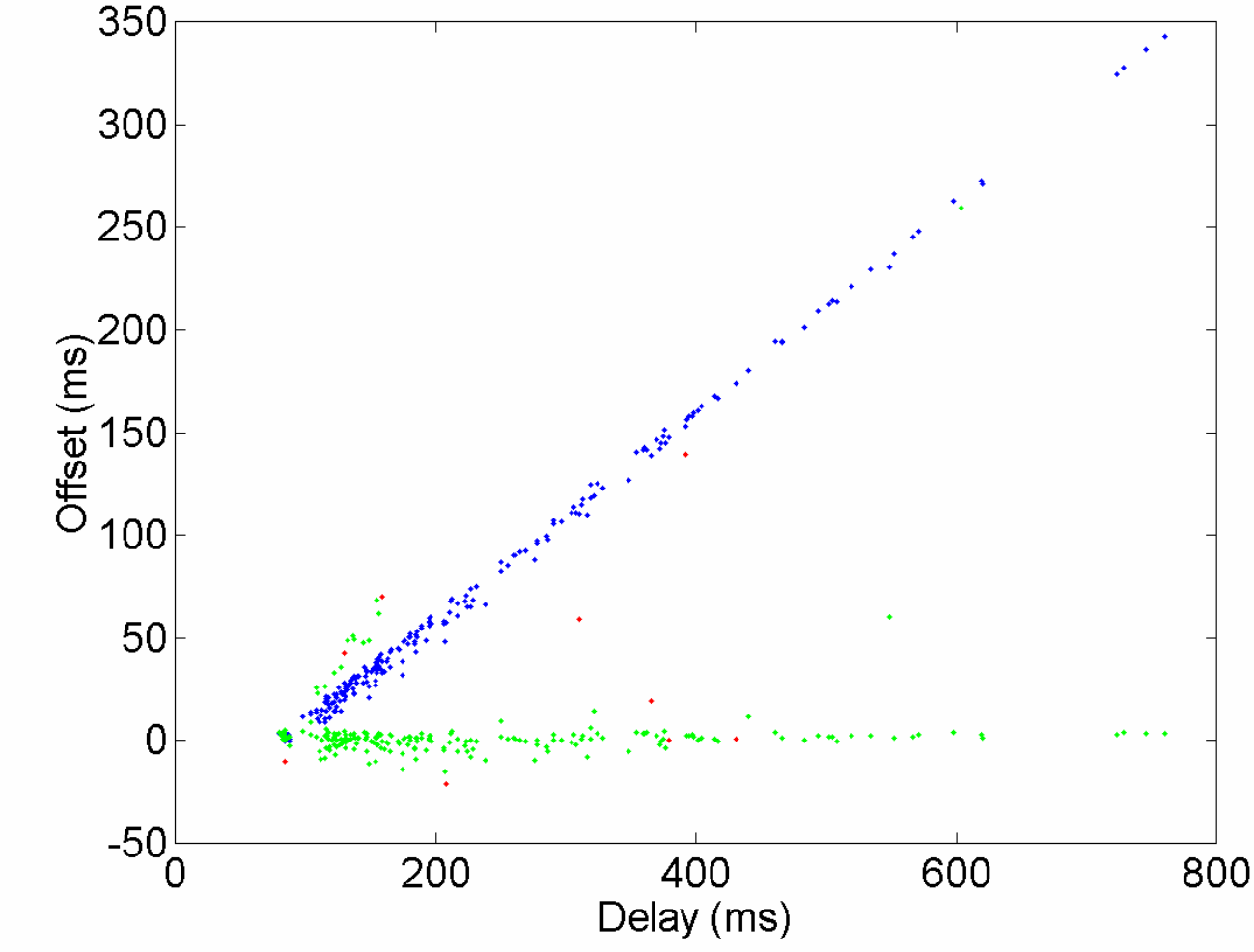


- The most accurate offset θ_0 is measured at the lowest delay δ_0 (apex of the wedge scattergram).
- The correct time θ must lie within the wedge $\theta_0 \pm (\delta - \delta_0)/2$.
- The δ_0 is estimated as the minimum of the last eight delay measurements and (θ_0, δ_0) becomes the peer update.
- Each peer update can be used only once and must be more recent than the previous update.

Huff&puff filter

- Many network paths show large delays and delay variations on one direction of transmission but not the other.
- These conditions often prevail only during some period of the workday.
- A wedge scattergram plotting offset versus roundtrip delay samples is shown in the next slide:
  - Blue dots represent the clock filter output.
  - Green dots represent the huff&puff filter output.
  - Red dots are discarded by the popcorn spike suppressor.
- Let (θ_0, δ_0) be the apex coordinate at the minimum roundtrip delay and (θ, δ) the coordinate of a blue dot on the positive limb. Then, (θ', δ), where $\theta' = \theta - (\delta - \delta_0) / 2$, is the coordinate of the corresponding green dot and θ' is the corrected offset produced by the huff&puff filter.
- A similar argument holds for the negative limb.

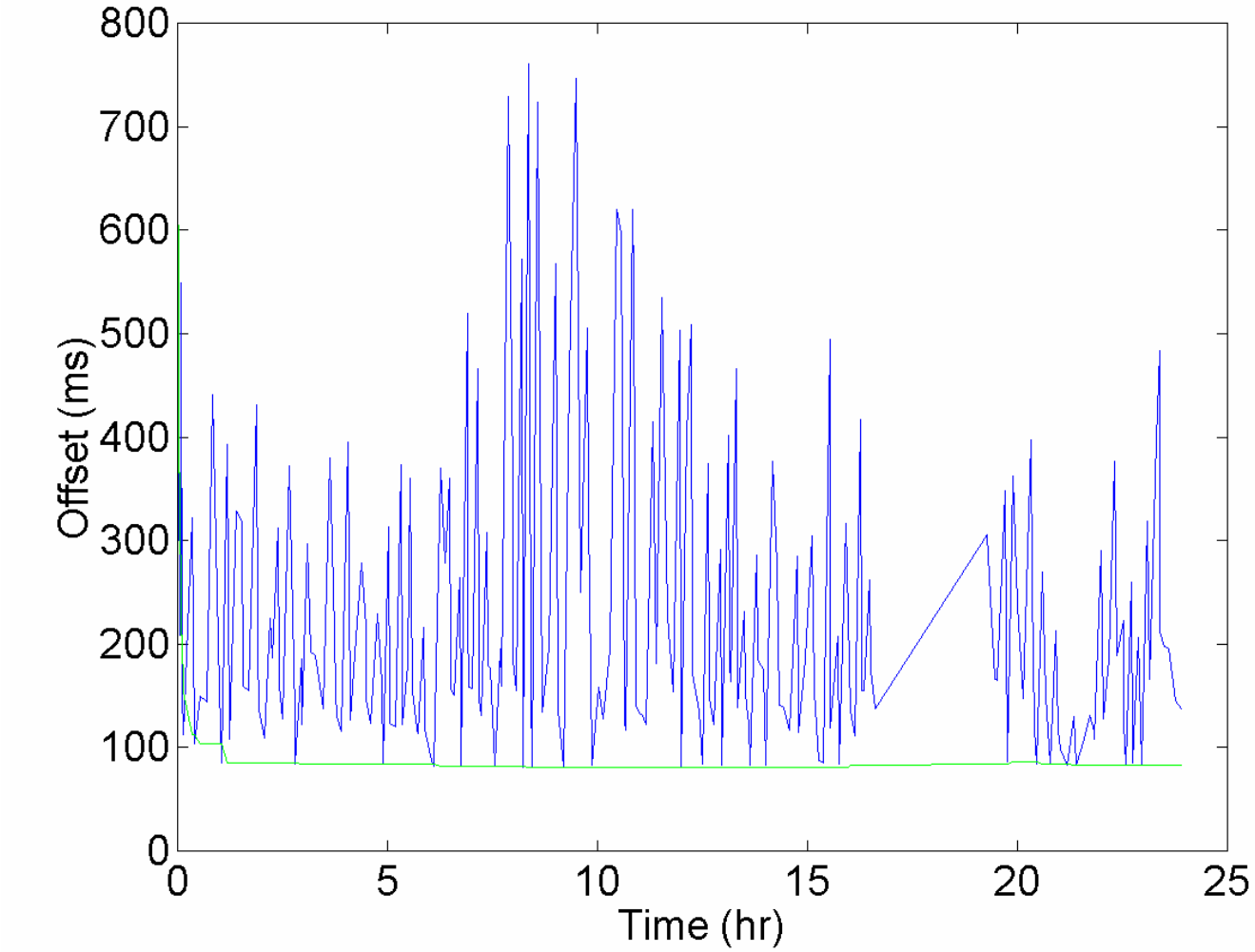
Huff&puff wedge scattergram



Huff&puff minimum delay estimator

- The time series graph shown on the following slide shows the sample delay (blue trace) together with the minimum delay over a window extending four hours in the past (green trace).
- This is typical behavior for a moderately loaded network link, whether or not asymmetrical delays are present.
- The server was apparently unreachable between hours 16-19.

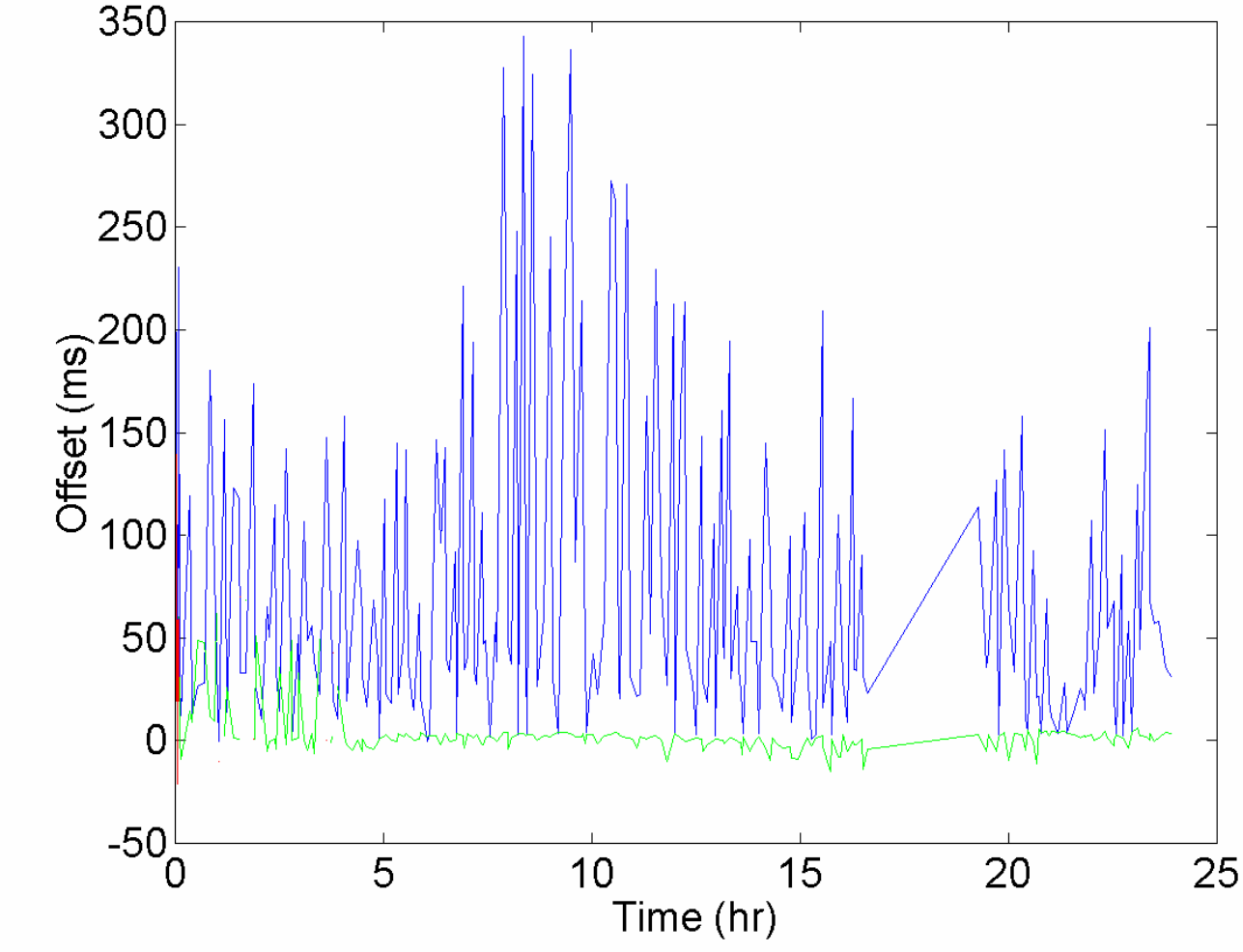
Huff&puff delay time series



Huff&puff filter performance

- The time series graph shown on the following slide shows the clock filter output (blue trace) and corresponding huff&puff filter output (green trace).
- The popcorn spike suppressor discards samples where the absolute sample-sample offset difference exceeds the running average of RMS jitter in the clock filter output.
- While this particular scenario shows a dramatic reduction in jitter and improvement in accuracy, other scenarios show less improvement, including:
  - The minimum delay statistic cannot be reliably determined if the most recent minimum delay sample is beyond the window.
  - The delays are large and more symmetric, so the sample point does not occur on a positive or negative limb.
  - The popcorn spike suppressor fails to detect and discard the outlyers.

Huff&puff offset time series



Further information

- NTP home page 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 home page 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
- Udel FTP server: ftp://ftp.udel.edu/pub/ntp
  - Current NTP Version software, documentation and support
  - Collaboration resources and junkbox
- Related projects http://www.eecis.udel.edu/~mills/status.htm
  - Current research project descriptions and briefings