Ubiquitous Authentication Using Random Keys

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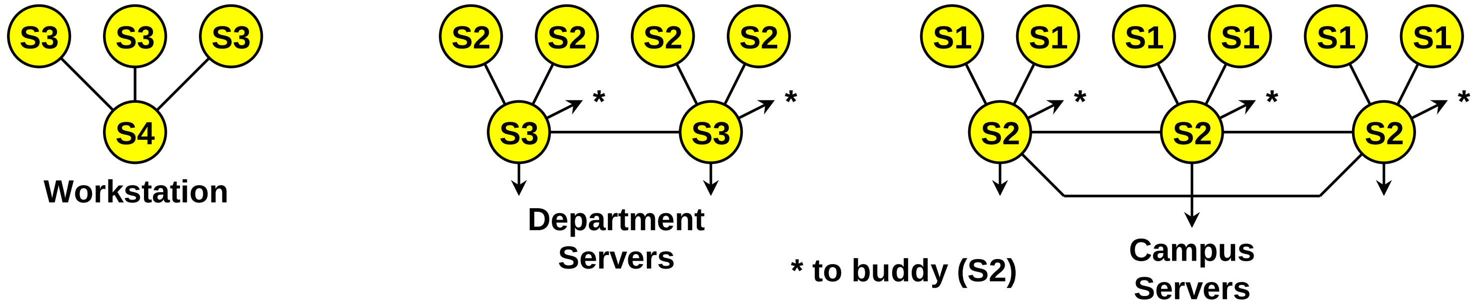
PostScript and PowerPoint versions of this presentation are available at http://www.eecis.udel.edu/~mills

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

Introduction

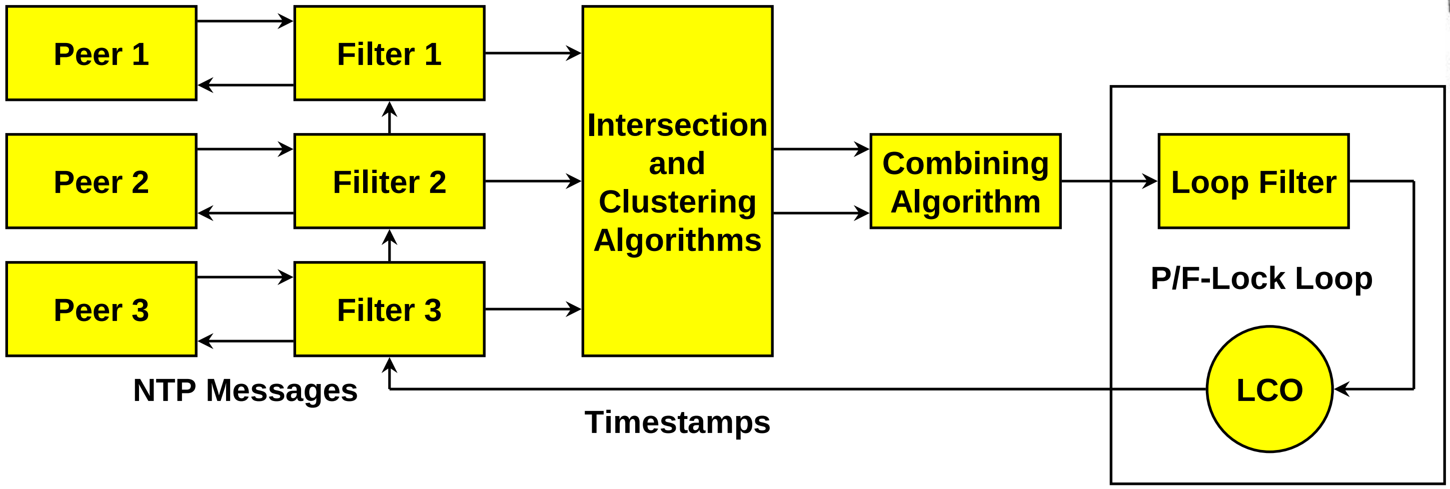


- Network Time Protocol (NTP) synchronizes clocks of hosts and routers in the Internet
- Provides submillisecond accuracy on LANs, low tens of milliseconds on WANs
- Unix NTP daemon ported to almost every workstation and server platform available today - from PCs to Crays
- Well over 100,000 NTP peers deployed in the Internet and its tributaries all over the world

Goals

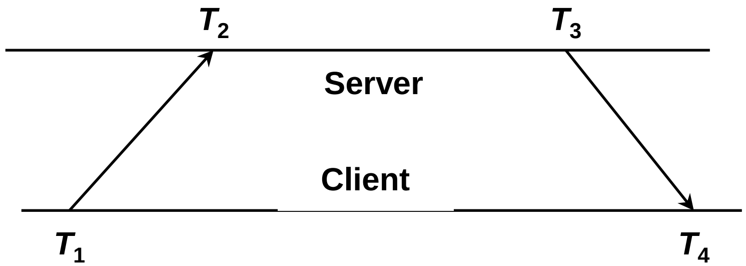
- Robustness to many and varied kinds of failure, including Byzantine disagreements, malicious attacks and implementation bugs.
  - Our approach is based on diverse network paths, redundant servers and a suite of intricately crafted mitigation algorithms.
- Autonomous server and client configuration to optimize performance under resource constraints.
  - Our approach is based on Internet multicasting and manycasting, together with engineered drop-add heuristics.
- Autonomous authentication using a combination of public-key and private-key cryptography.
  - Our approach uses automatically generated and managed random keys with controlled lifetimes and engineered algorithms designed to avoid loss of accuracy due to encryption delays.

NTP architecture



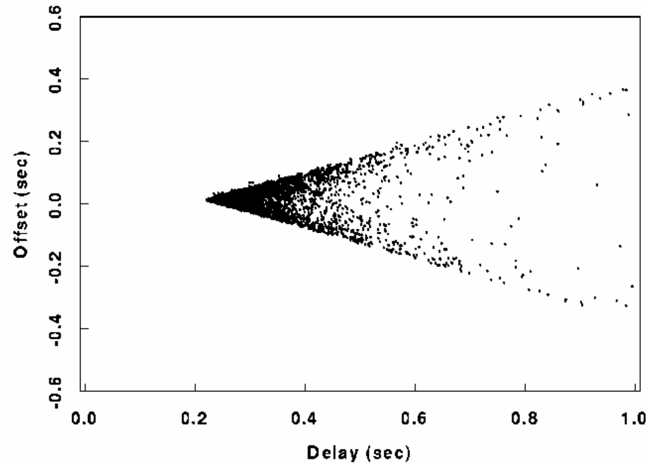
- Multiple synchronization peers for redundancy and diversity
- Clock filters select best from a window of eight clock offset samples
- Intersection and clustering algorithms pick best subset of peers and discard outlyers
- Combining algorithm computes weighted average of offsets for best accuracy
- Loop filter and local clock oscillator (LCO) implement hybrid phase/frequency-lock feedback loop to minimize jitter and wander

Clock filter algorithm



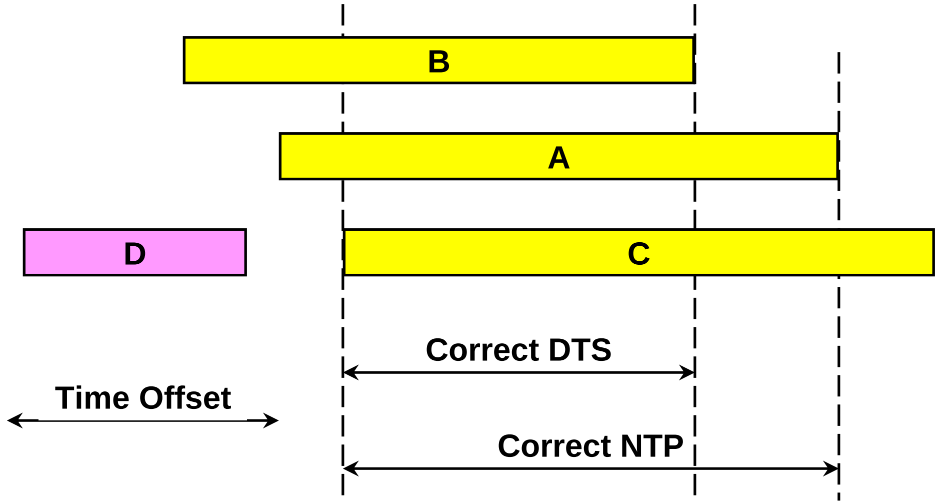
$$\text{Offset} \quad \theta = \tfrac{1}{2}[(T_2 - T_1) + (T_3 - T_4)]$$

$$\text{Delay} \quad \delta = (T_4 - T_1) - (T_3 - T_2)$$



- Most accurate clock offset θ is measured at the lowest delay δ (apex of the wedge diagram)
- Phase dispersion ε_r is weighted average of offset differences over last eight samples - used as error estimator
- Frequency dispersion ε_f represents clock reading and frequency tolerance errors - used in distance metric
- Synchronization distance $\lambda = \varepsilon_f + \delta/2$ - used as distance metric and maximum error bound, since correct time θ_0 must be in the range $\theta - \lambda \le \theta_0 \le \theta + \lambda$

Intersection algorithm



m = number of clocks
f = number of presumed falsetickers
A, B, C are truechimers
D is falseticker

- Initially, set falsetickers *f* and counters *c* and *d* to zero
- Scan from far left endpoint: add one to *c* for every lower endpoint, subtract one for every upper endpoint, add one to *d* for every midpoint
- If $c \geq m - f$ and $d \geq m - f$, declare success and exit procedure
- Do the same starting from the far right endpoint
- If success undeclared, increase *f* by one and try all over again
- if $f \leq m/2$, declare failure

Clustering algorithm

Sort survivors of intersction algorithm by increasing synchronization distance. Let *n* be the number of survivors and n_{min} a lower limit.

For each survivor s_i, compute the select dispersion (weighted sum of clock differences) between si and all others.

Let s_{max} be the survivor with maximum select dispersion (relative to all other survivors) and s_{min} the survivor with minimum sample dispersion (clock differences relative to past samples of the same survivor).

$s_{max} \le s_{min}$ or $n \le n_{min}$?

yes

no

Delete the survivor s_{max}; reduce *n* by one

The resulting survivors are processed by the combining algorithm to produce a weighted average used as the final offset adjustment

NTP autonomous configuration - approach

- Dynamic peer discovery schemes
  - Primary discovery vehicle using NTP multicast and manycast modes
  - Augmented by DNS, web and service location protocols
  - Augmented by subnet search using standard NTP monitoring tools, including *ntpq* and *ntpdc*
- Automatic optimal configuration
  - Distance metric designed to maximize accuracy and reliability
  - Constraints due to fanout limitations and maximum distance
  - Complexity issues require intelligent heuristic
- Candidate optimization algorithms
  - Multicast mode with or without initial propagation delay calibration
  - Manycast mode with administrative and/or TTL delimited scope
  - Distributed, hierarchical, greedy add/drop heuristic

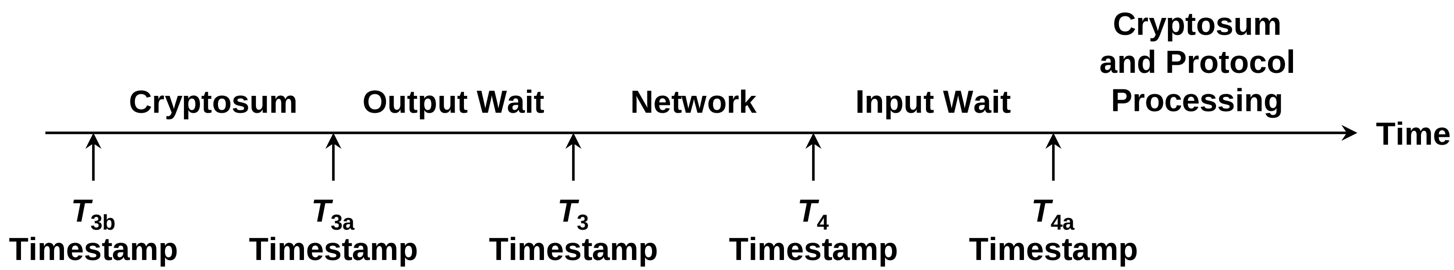
NTP configuration scheme implementation

- Multicast scheme (moderate accuracy)
  - Servers flood local area with periodic multicast response messages
  - Clients use client/server unicast mode on initial contact to measure propagation delay, then continue in listen-only mode
- Manycast scheme (highest accuracy)
  - Initially, clients flood local area with a multicast request message
  - Servers respond with multicast response messages
  - Clients continue with servers as if in ordinary configured unicast client/server mode
- Both schemes require effective implosion/explosion controls
  - Expanding-ring search used with TTL and administrative scope
  - Excess network traffic avoided using multicast responses and rumor diffusion
  - Excess client/server population controlled using NTP clustering algorithm and timeout garbage collection

NTP autonomous authentication - approach

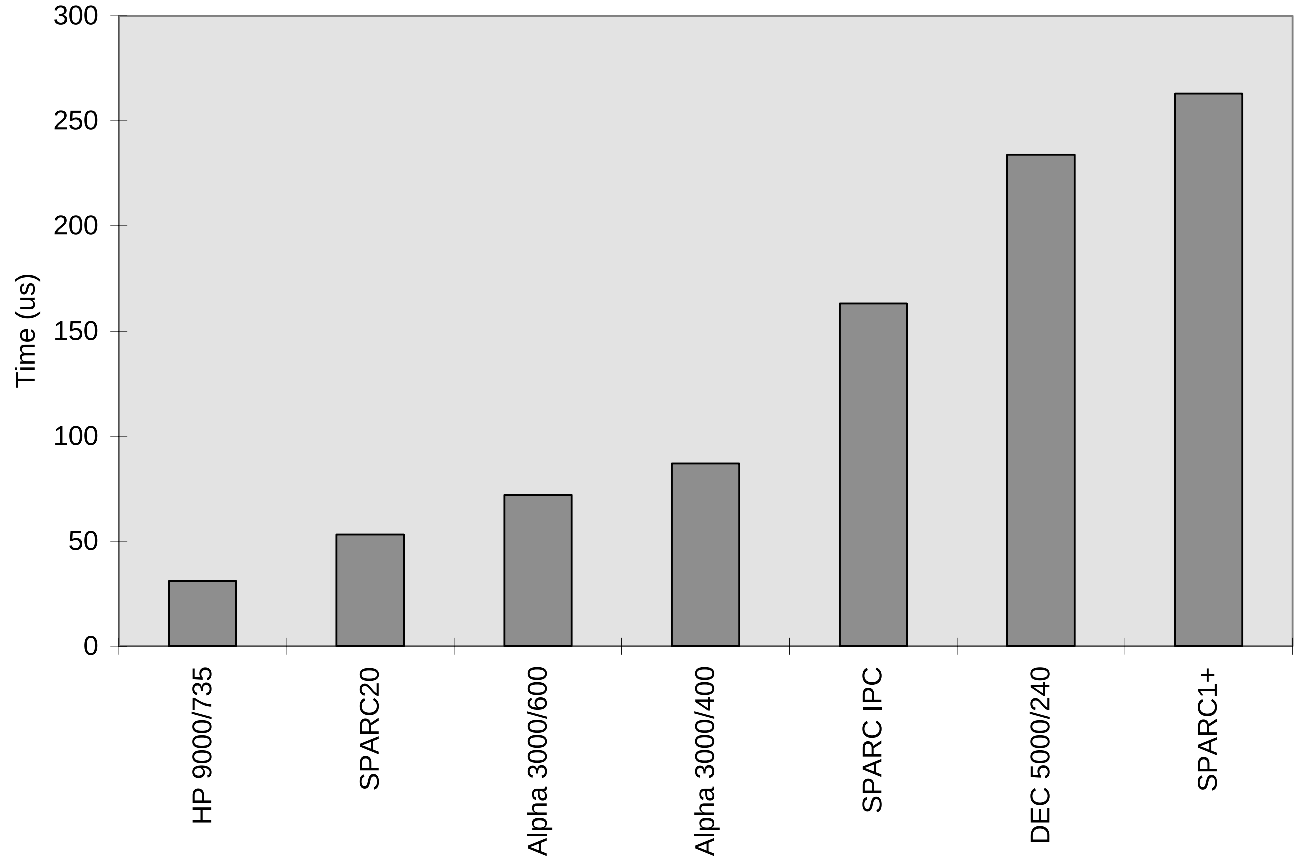
- The circular dilemma:
  - Cryptographic keys must not endure beyond enforced lifetimes
  - Enforced lifetime requires secure timekeeping
  - Secure timekeeping requires cryptographic authentication
- Authentication and synchronization protocols work independently for each peer, with each allowed to reach a tentative outcome
- When both authentication and synchronization are complete, the peer is admitted to the population used to synchronize the system clock
- Complicating this scheme are requirements that the lifetimes of all public keys, including those used to sign certificates, must be enforced as well
- However, public-key cryptography is too slow for good timekeeping
- Our approach combines public-key signed credentials, together with pseudo-random key sequences and keyed cryptosums

Message propagation time budget



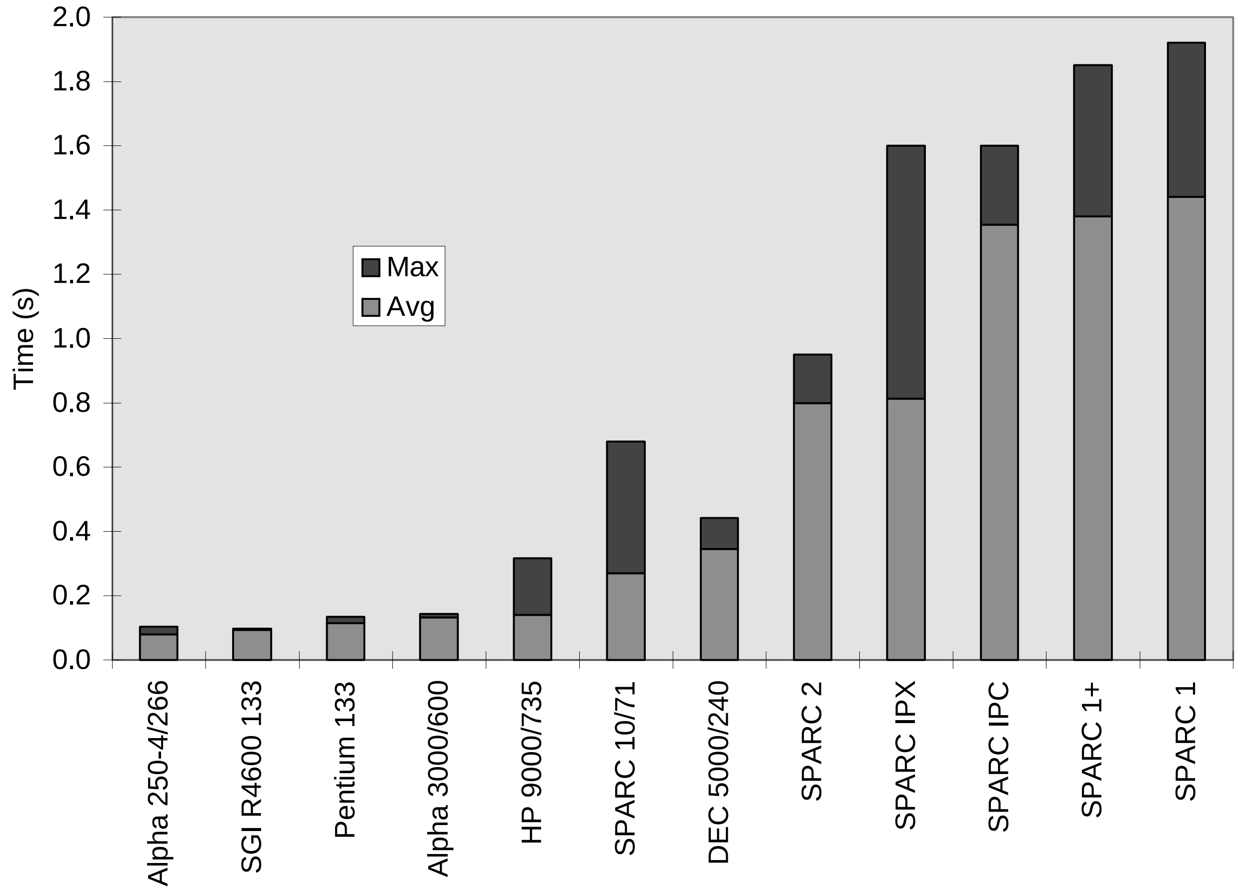
- We want T_3 and T_4 timestamps for accurate network calibration
  - If output wait is small, T_{3a} is good approximation to T_3
  - T_{3a} can't be included in message after cryptosum is calculated, but can be sent in next message; use T_{3b} as best approximation to T_3
  - T_4 captured by most network drivers at interrupt time; if not, use T_{4a} as best approximation to T_4
- Largest error is usually output cryptosum
  - Private-key algorithms (MD5, DES-CBC) running times range from 10 μs to 1 ms, depending on architecture, but can be predicted fairly well
  - Public-key algorithms (RSA) running times range up to 100 ms, depending on architecture, but are highly variable and depend on message content

MD5 message digest



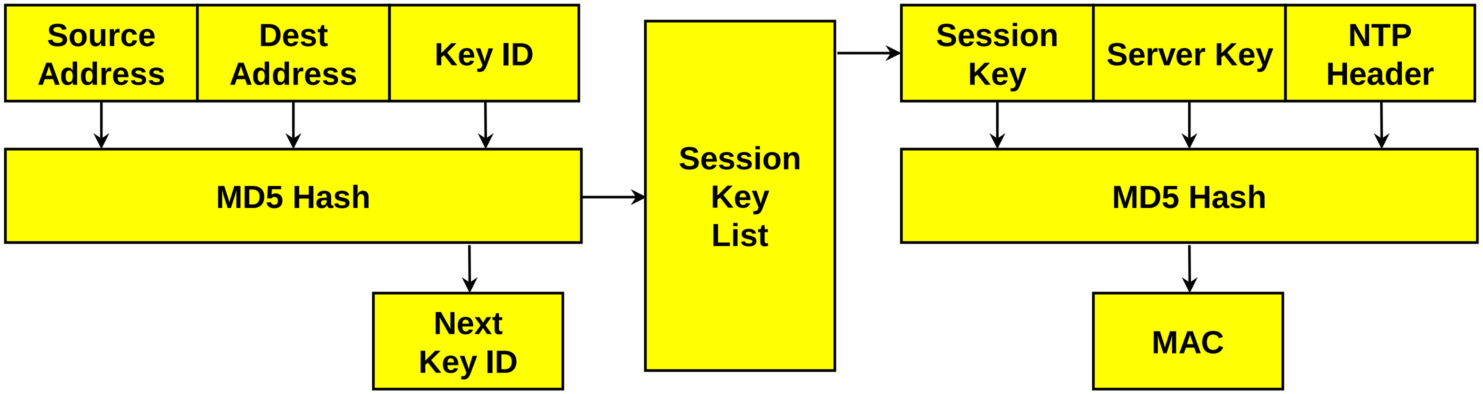
- Measured times to construct 128-bit hash of 48-octet NTP header using MD5 algorithm in RSAREF

MD5/RSA digital signature



- Measured times (s) to construct digital signature using RSAREF
- Message authentication code constructed from 48-octet NTP header hashed with MD5, then encrypted with RSA 512-bit private key

NTP autonomous authentication scheme (Autokey)



- Session keys are generated using IP addresses and key identifiers
- Initial key identifier is random; each succeeding one is hashed from the previous one
- Session key list is used in reverse order; clients verify hash of current session key matches most recent session key identifier
- At intervals, the server generates a pseudo-random session key sequence from a private random seed and a known hash function
- Session keys are used in reverse order, so clients cannot predict the next one, but can verify the current one is valid using known hash

Initial testing and deployment state in NTP Version 4

- NTP Version 4 alpha rollout now generally deployed
  - Improved clock discipline accuracy and stability
  - Autonomous configuration and authentication algorithms
  - Revised protocol model to plug security holes
  - Precision time kernels now in Digital Unix 4.x and Solaris 2.6
- Testing in local environment
- Stability problems with certain hardware and software systems remain to be resolved
- Autonomous configuration greedy add/drop heuristic not yet complete
- Autokey scheme has problems with Unix socket semantics, especially in multicast configurations
- Autokey birthday attacks and small key sizes may be a problem

Future plans

- Complete NTP Version 4 protocol testing and validation project
  - Deploy, test and evaluate NTP Version 4 daemon in local network
  - Deploy and test in DARPA testbeds (DARTnet and CAIRN)
  - Deploy and test at friendly sites in the US, Europe and Asia
- Prosecute standards agendae in IETF, ANSI, ITU, POSIX
  - Revise the NTP formal specification and launch on standards track
  - Participate in deployment strategies with NIST, USNO, others
- Develop scenarios for other applications such as web caching, DNS servers and other multicast services

NTP online resources

- Internet (Draft) Standard RFC-1305 Version 3
  - Simple NTP (SNTP) Version 4 specification RFC-2030
  - Designated SAFEnet standard (Navy)
  - Under consideration in ANSI, ITU, POSIX
- NTP web page http://www.eecis.udel.edu/~ntp
  - NTP Version 3 release notes and HTML documentation
  - List of public NTP time servers (primary and secondary)
  - NTP newsgroup and FAQ compendium
  - Tutorials, hints and bibliographies
- NTP Version 3 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