Synchronization in Packet Networks

NTPv4 and IEEE 1588

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Objectives

- Provide a brief introduction to NTP and IEEE 1588 (PTP)
- Highlight some basic similarities and differences in the two solutions
- Provide information for the further investigation of either or both NTP and IEEE 1588 (PTP)

Acknowledgements

- This effort draws heavily upon the work of:
  - Dr. David Mills and the NTP development community
  - Mr. John Eidson and the IEEE 1588 Working Group

Network Time Protocol (NTP)

- NTP grew out of work done by Dr. David Mills at the University of Delaware
  - Previous versions: 1985 - NTPv0 (RFC 958), 1988 - NTPv1 (RFC 1059), 1989 - NTPv2 (RFC 1119)
  - Current version: 1992 - NTPv3 (RFC1305)
  - The NTP architecture, protocol and algorithms have been evolved over the last twenty plus years
- The initial objective was to synchronize clocks over the global Internet
- Status: Millions of NTP peers deployed worldwide
  - Well managed NTP provides accuracies of:
    - Low tens of milliseconds on WANs,
    - Submilliseconds on managed LANs, and
    - Submicroseconds possible using a precision time source, hardware assists, and a managed/engineered infrastructure
  - NTP daemon ported to almost every workstation and server platform available today
    - All primarily based on the code distribution from ntp.org

IEEE 1588 - Precision Time Protocol (PTP)

- IEEE 1588 – PTP evolved out of the industrial automation and test and measurement communities
  - Version 1 published as IEEE 1588™ - 2002
- Primary objectives included:
  - Sub-microsecond synchronization of real-time clocks
  - Targeted for relatively localized systems.
  - Applicable to local areas networks supporting multicast communications (including but not limited to Ethernet™)
  - Simple, administration free installation
  - Supports heterogeneous systems of clocks with varying precision, resolution and stability
  - Minimal resource requirements on networks and host components.
- Status
  - Multiple independent implementations (products) emerging
    - Successful plug-fest held in conjunction with ISPCS in October 2007

NTP – Standardization Status

- NTP developed outside the structure of the IETF
  - Current definitive documents (RFC 1305 and RFC 4330) were independent submissions from Dr. Mills
- The Internet Engineering Task Force (IETF) NTP WG was chartered in March 2005 to develop an NTPv4 specification to include:
  - Updated NTPv4 algorithms, IPv6 support, Enhanced Security
  - SNTP (Simple Network Time Protocol)
  - An NTP MIB (for monitoring and management via SNMP)
- Status:
  - Protocol and Algorithms -07 draft released in July 2007.
    - draft is 108 pages
  - Plan to complete by 1Q 2008
  - MIB, Autokey, and NTP Control protocol drafts also underway
- Future efforts:
  - IETF is currently discussing potential future development work for NTP.

IEEE 1588 – Standardization Status

- IEEE 1588 Version 2 PAR (Project Authorization Request) approved in March 2005.
  - Scope included Layer 2 mapping, Transparent Clocks, Short Frames, IPv6, Security
  - Version 2 Technical Work completed February 2007.
  - Version 2 Sponsor Ballot completed August 2007
    - sponsor ballot version is 275 pages
- Status
  - Work underway to complete sponsor ballot and proceed to recirculation ballot
  - Target completion 1Q 2008
- Future efforts:
  - IEEE 802, ITU, and the LXI Consortium are currently discussing potential IEEE 1588 profiles
  - The IETF is currently discussing potential future development work for IEEE 1588.

Similarities at a Glance

- NTP and PTP both:
  - Exchange time information over a packet switched network for the purposes of clock synchronization
  - Use this exchanged time information to determine the offset between two independent clocks
  - Form a hierarchical tree structure as the basis for the distribution of time information
  - Assume symmetric network paths
  - Are somewhat resilient in the presence of packet loss
  - Use methods to reduce the impact of non-deterministic delays

Time stamp format and timescale

NTP

- Timestamp Format
  - 32-bit unsigned seconds
  - 32-bit fractions of a second (resolving to 232 picoseconds)
- Timescale
  - UTC
    - Prime Epoch
      - 0 hour 1 January 1900

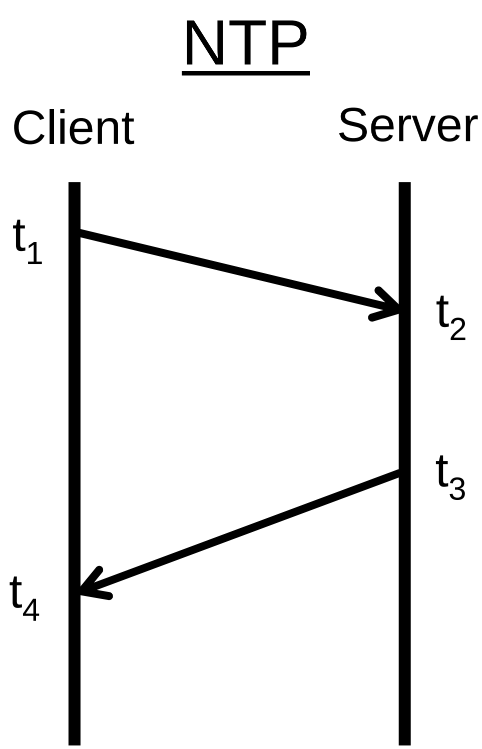
PTP

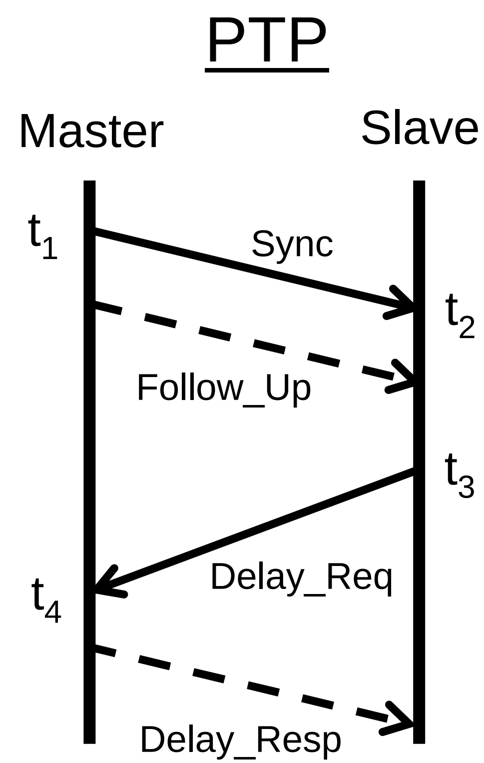
- Timestamp Format
  - 48-bit unsigned seconds
  - 32-bit unsigned nanoseconds
- Timescale(s)
  - TAI
  - Allows for alternate timescales

Clock Types

- NTP
  - Clock (Does not distinguish amongst different types of clocks)
- IEEE 1588
  - Ordinary Clock (OC)
    - Has a single PTP port in a domain and maintains the timescale of the domain
  - Boundary Clock (BC)
    - Has multiple PTP ports in a domain and maintains the timescale of the domain
  - Transparent Clock
    - Measures the time taken for a PTP event message to transit the device
      - Peer-to-peer transparent clocks (P2P TC) provide corrections for the propagation delay of the link in addition to the transit time
      - End-to-end transparent clock (E2E TC)

Time Information Exchange
Returnable Time Approach





Key differences:
- Client/Server versus Master/Slave
- Additional messages (follow_up and delay_resp)

NTP Message

NTP Protocol Header Format (32 bits)

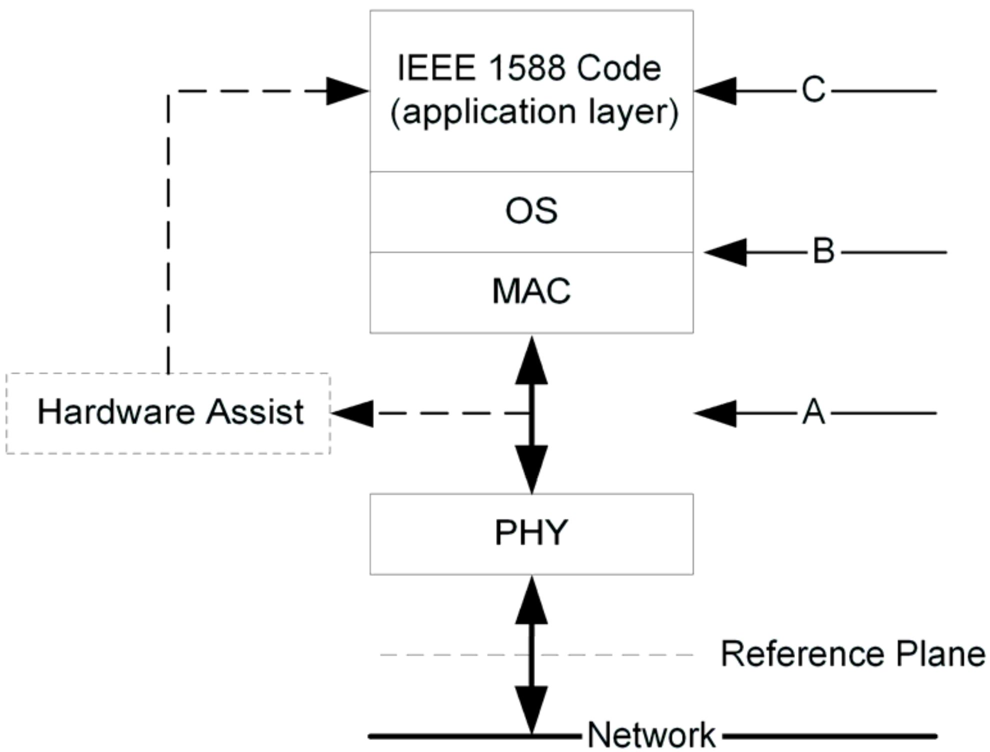
LI	VN	Mode	Strat	Poll	Prec
Root Delay					
Root Dispersion					
Reference Identifier					
Reference Timestamp (64)					
Originate Timestamp (64)					
Receive Timestamp (64)					
Transmit Timestamp (64)					
Extension Field 1 (optional)					
Extension Field 2… (optional)					
Key/Algorithm Identifier					
Message Hash (64 or 128)					

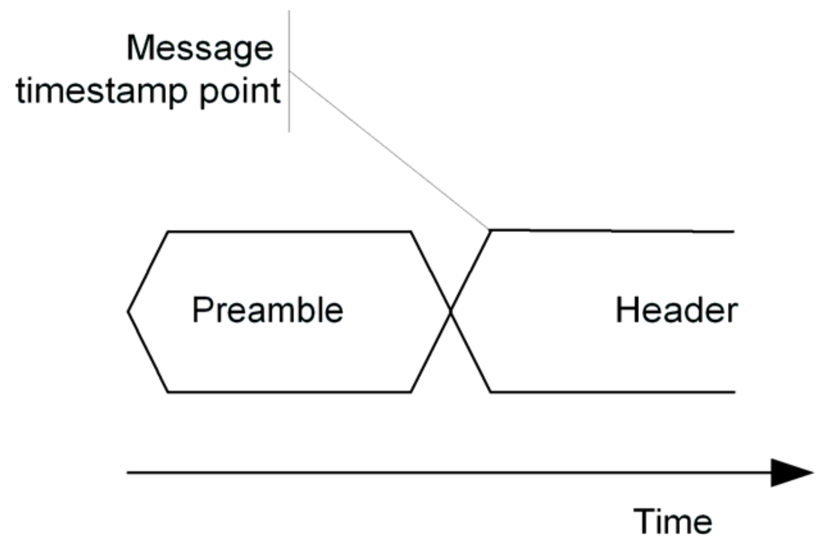
- NTP has a single message type
- NTP Modes of Operation
  - Symmetric Active
  - Symmetric Passive
  - Client
  - Server
  - Broadcast Server
  - Broadcast Client

PTP Messages

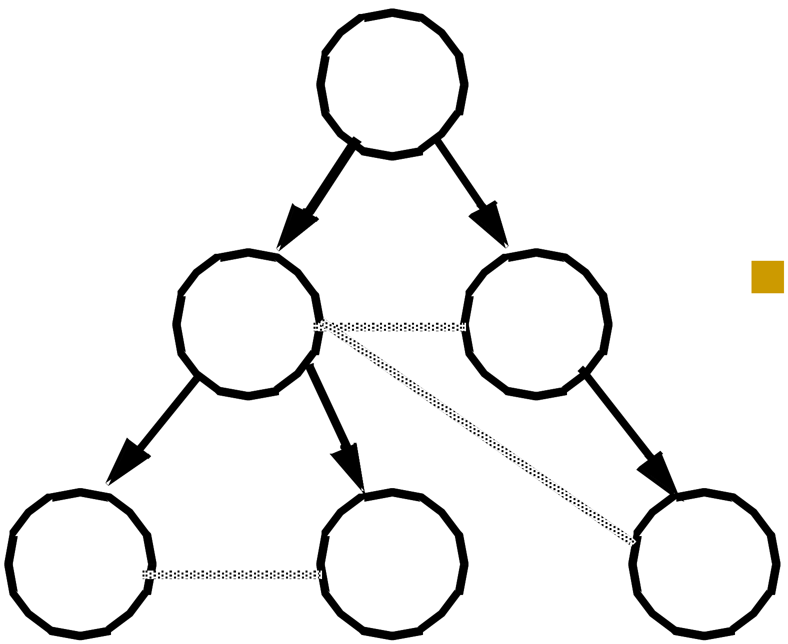
- PTP Event Messages (timestamped)
  - Sync
  - Delay_Req
  - Pdelay_Req
  - Pdelay_Resp
- PTP General Messages (not timestamped)
  - Follow_Up
  - Pdelay_Resp_Follow_Up
  - Announce
  - Management
  - Signaling

IEEE 1588 (PTP) - Hardware Time Stamping



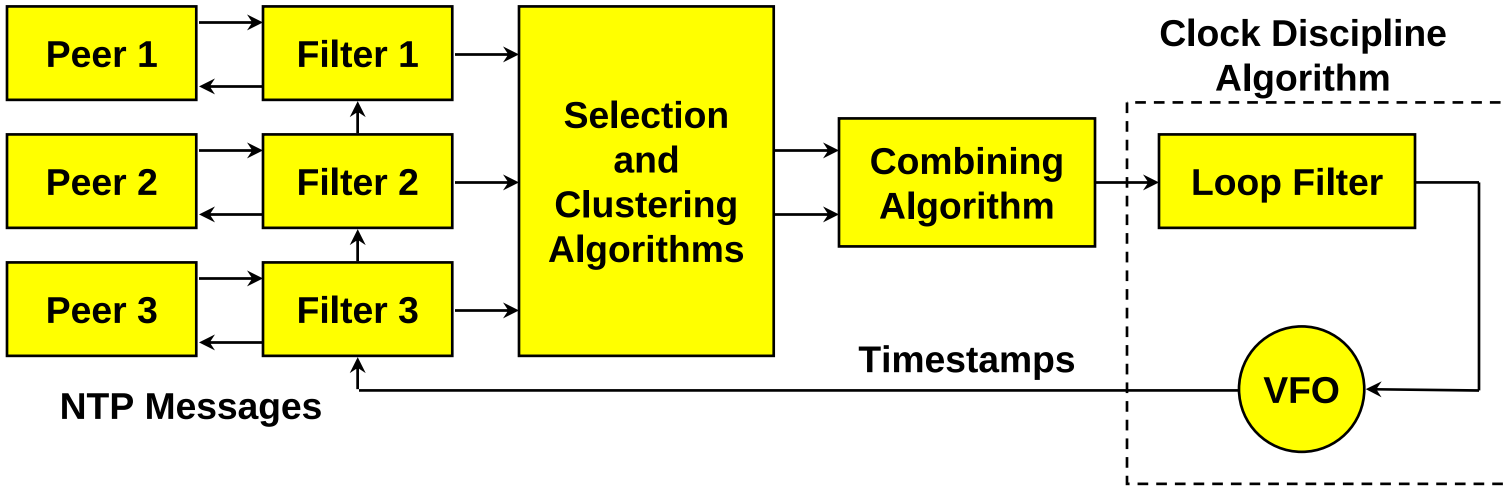


Hierarchical Structure



- NTP and PTP both:
  - Utilize a hierarchical structure
  - Provide for reconfiguration of the hierarchy
- However:
  - PTP has two defined protocol phases:
    - 1) First, organize clocks into master-slave hierarchy
    - 2) Then, each slave synchronizes to master
  - NTP clients continuously monitor multiple servers and identify *truechimers* and *falsetickers*

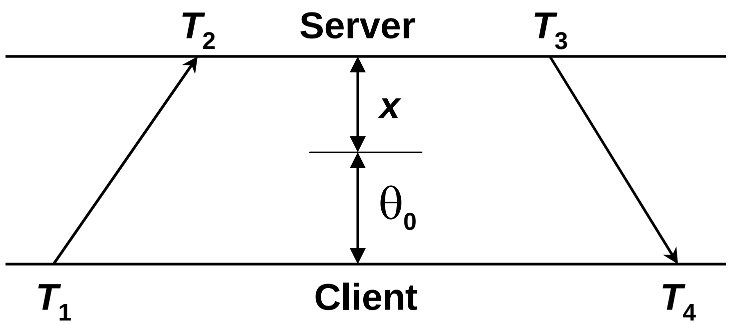
NTP - Architecture



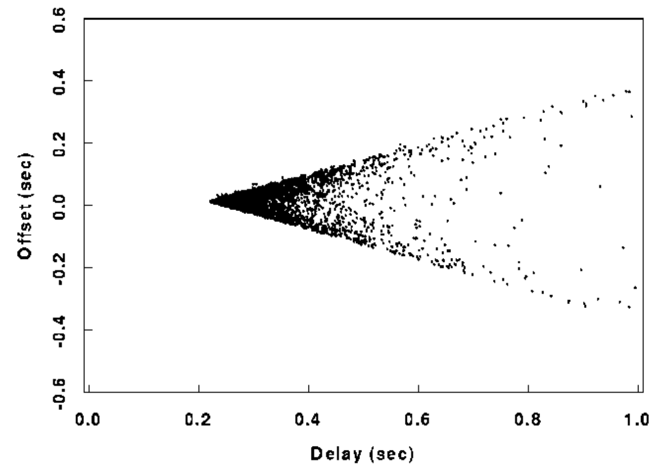
- Multiple servers/peers provide redundancy and diversity.
- Clock filters select best from a window of eight time offset samples.
- Intersection and clustering algorithms pick best *truechimers* and discard *falsetickers.*
- Combining algorithm computes weighted average of time offsets.
- Loop filter and variable frequency oscillator (VFO) implement hybrid phase/frequency-lock (P/F) feedback loop to minimize jitter and wander.

From http://www.eecis.udel.edu/~mills/ntp.html

NTP - 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 (δ_0, θ_0) becomes the offset and delay output.
  - Each output can be used only once and must be more recent than the previous output.

From http://www.eecis.udel.edu/~mills/ntp.html

Summary of Basic Differences

NTP

- Client/server architecture
  - Sophisticated client
- Dynamic and ongoing server selection
- Strictly layer 3 solution
- Clock filter algorithms for local clock behavior
- UDP/IPv4 and UDP/IPv6 only allowable transports
- Designed as a unicast protocol with broadcast/multicast functionality added

PTP

- Master/slave architecture
  - Simple slave
- Static master selection (Best Master Clock algorithm)
- Hardware timestamp capability (layer violation)
- No clock filter algorithms
- Multiple transports allowed:
  - UDP/IPv4, UDP/IPv6, IEEE 802.3, DeviceNET, ControlNET, and IEC 61158 Type 10 currently defined)
- Designed as a multicast protocol with unicast functionality added

NTP and PTP Trade-offs

IETF (NTP)

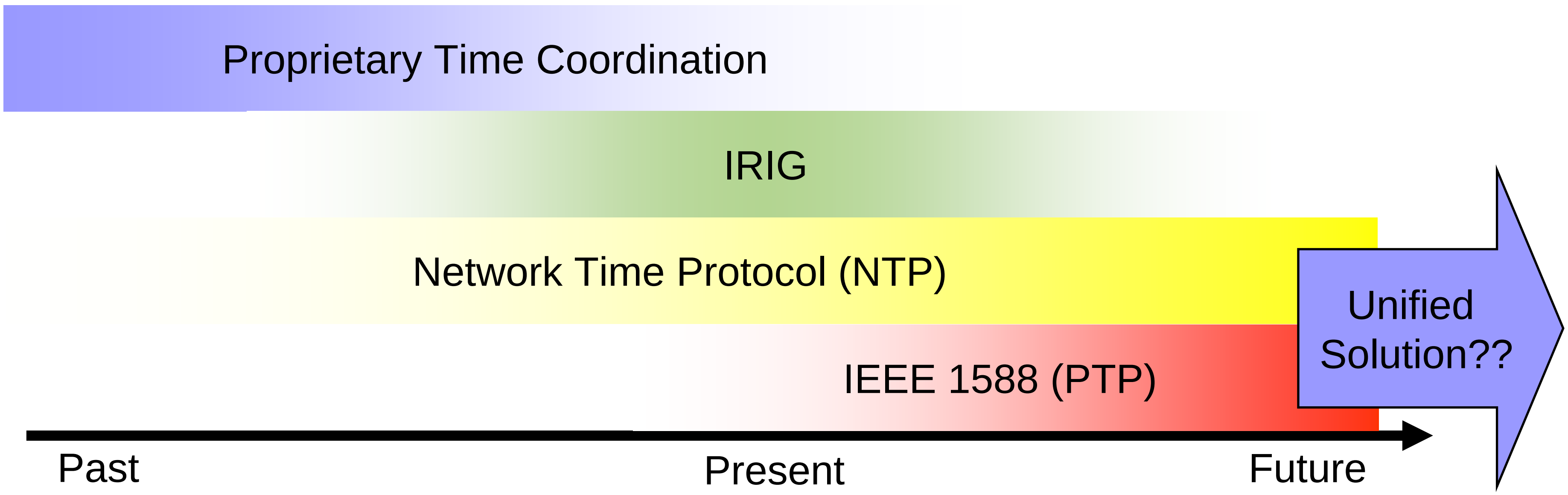
- Pros
  - Scalable and robust
  - Subnet technology independent
  - Represents the generic computing equipment market
  - Wide scale deployment and years of experience
- Cons
  - Does not address high end synchronization requirements in an open standards based manner

IEEE 1588 (PTP)

- Pros
  - Designed for high precision applications
  - Industrial automation and telecom industries have real time requirements
- Cons
  - Lacks the robustness and deployment experience of NTP
  - Currently represents a niche market relative to generic computing equipment

Note: Each of these solutions has some overlap and addresses some unique aspects of the problem (not an apples to apples comparison).

Clock Coordination Service Trends



Multiple independent time distribution systems

Multiple uncorrelated timescales per platform

Unique and specialized platform time distribution solutions

GPS primary time distribution system

Some migration to UTC and GPS timescales

Migration to standards based time distribution solutions (IRIG, NTP)

Next generation robust GPS time distribution system

Only one or a limited few coordinated timescales

Standards based time distribution solutions using existing and emerging network infrastructure

NTP References

- NTP Published Specifications
  - RFC 4330 -- Simple Network Time Protocol (SNTP) Version 4 for IPv4, IPv6 and OSI, January 2006, Informational. Obsoletes RFC 2330, 1769.
  - RFC 1305 -- Network Time Protocol (Version 3) Specification, Implementation and Analysis, March 1992, Draft Standard. Obsoletes RFC958, RFC1059, RFC1119.
- NTPv4 Draft Specification
  - draft-ietf-ntp-ntpv4-proto-07.txt (shortly to be -08)
- Books
  - Computer Network Time Synchronization: The Network Time Protocol, David L. Mills, CRC Press, 2006.
- Websites
  - www.ietf.org
  - www.eecis.udel.edu/~mills/
  - www.ntp.org

IEEE 1588 (PTP) References

- IEEE 1588 Version 1 – Published specification
  - IEEE Std 1588™-2002 IEEE Standard for a Precision Clock Synchronization Protocol for Networked Measurement and Control Systems.
- IEEE 1588 Version 2 – Draft specification
  - IEEE P1588 D2.1 Draft Standard for a Precision Clock Synchronization Protocol for Networked Measurement and Control Systems, July 2007.
- Books
  - Measurement, Control and Communication Using IEEE 1588, John C. Eidson, Springer-Verlag, 2006.
    - Documents Version 1 and provides application examples.
- Websites
  - www.ieee1588.nist.gov (NIST website with previous 1588 conference information)
  - www.ispcs.org

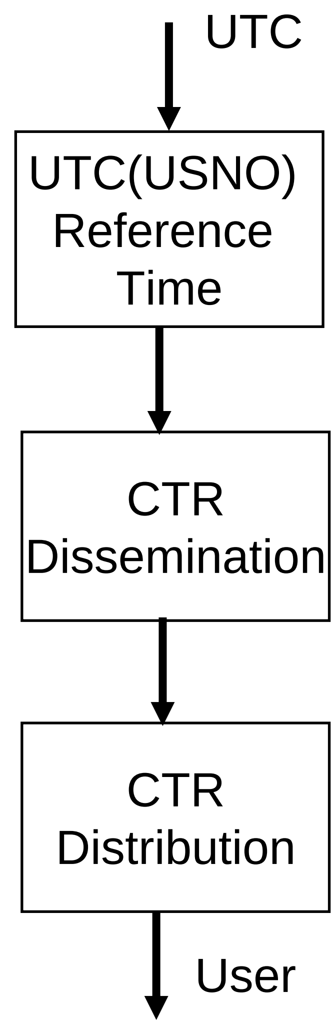
Questions?

International Standards Activities
IEEE 802.1AS

- IEEE 802.1AS Standard for Time Sensitive Applications in Bridged LANs
  - Project Authorization Request (PAR) approved in July 2006
- Status
  - Draft in development based on IEEE 1588
- Opportunity for market beyond AVB
  - Potential for hardware time synchronization support in all IEEE 802 type interfaces (including Ethernet and wireless)
  - Leveraging IEEE 1588 could result in more general hardware availability and market acceptance of technology.
  - Affordable mainstream products that support precise time synchronization.

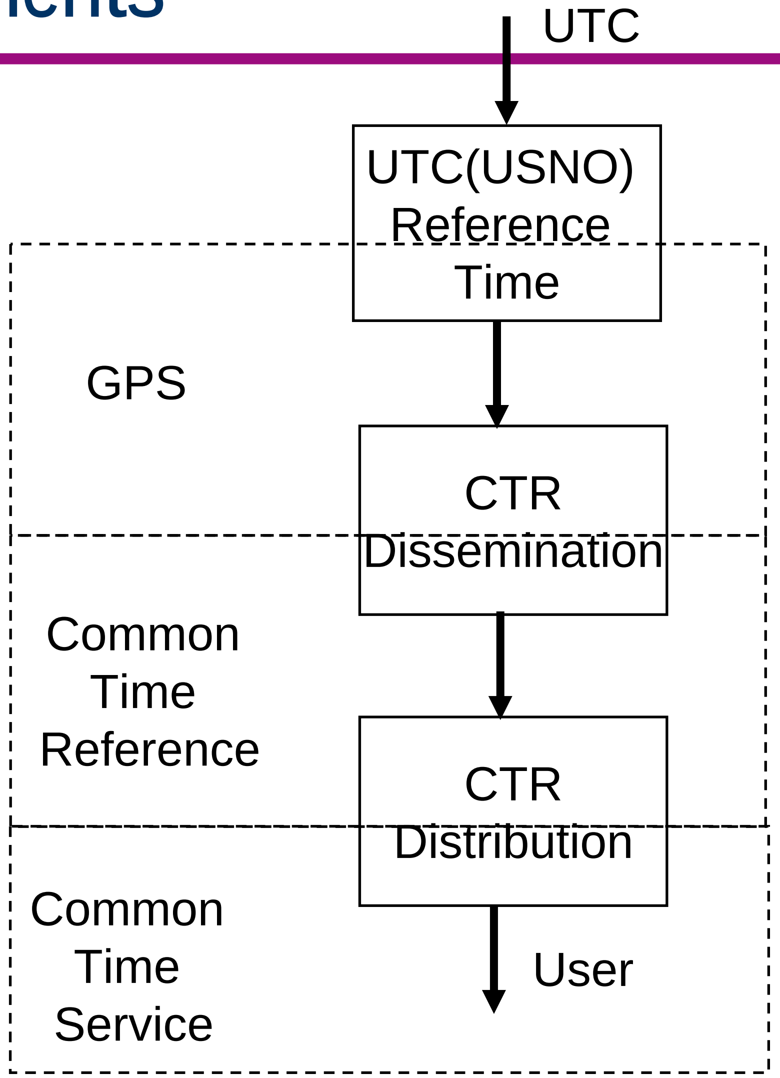
Common Time Reference Architecture

- Functional Architecture
  - Time Reference
    - Provides a time source traceable to a national or international reference (UTC(USNO))
  - Time Dissemination
    - Distribution of time and frequency information to sites, campuses, or platforms
    - GPS is a key enabling technology
  - Time Distribution
    - Distribution of time and frequency to users and applications via an assortment of interfaces



Mapping of Architecture to Components

- GPS
  - Most common means to distribute UTC to platform/site
- Common Time Reference
  - Coordinates an ensemble including external inputs (GPS) and platform standards (Cesium) to provide a single coordinated time for the platform/site
- Common Time Service
  - Distributes time to customers
    - NTP, PPS and IRIG are common examples
  - Manages time in local systems



Notional Common Time Service Architecture