The Hitchhiker's Guide to Precision Time Synchronization

HPTS v14
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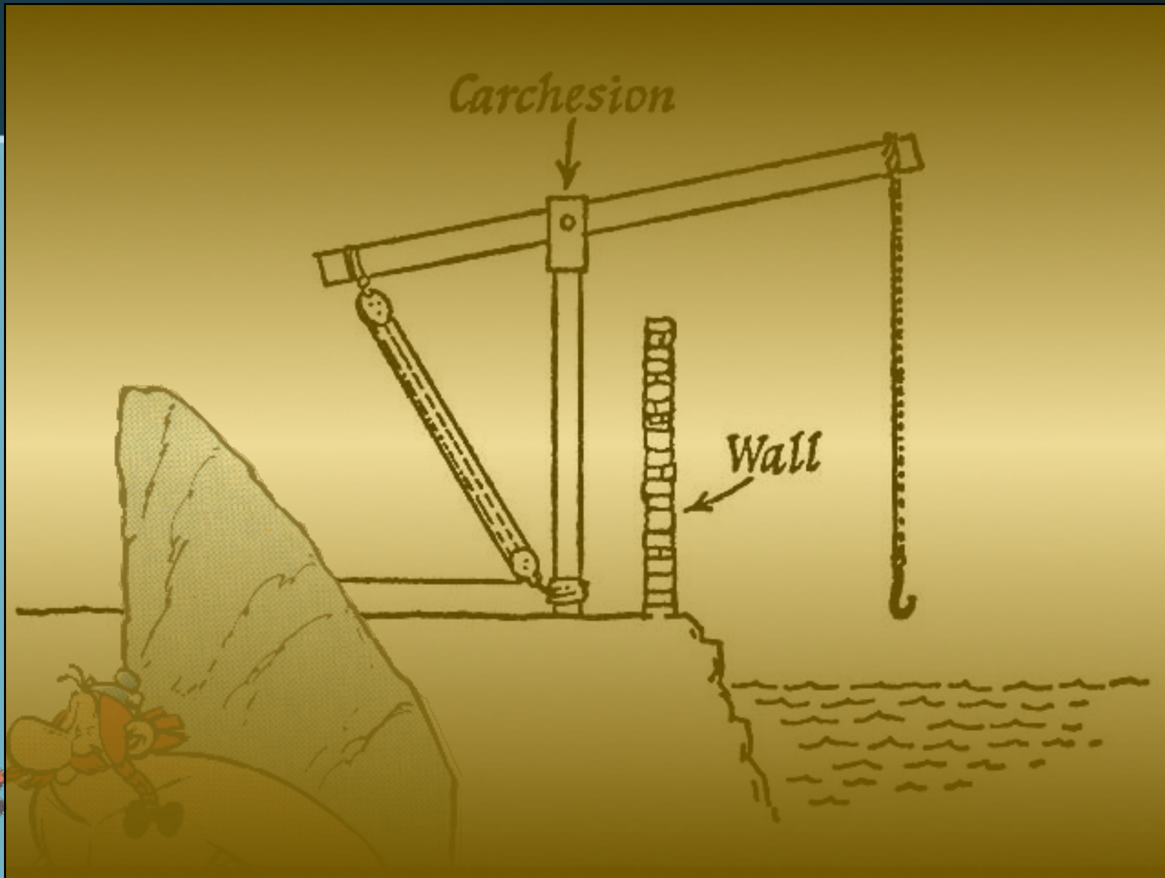
PRECISION TIME SYNCHRONIZATION

THE FUTURE IS AN OBSESSION … AN ATTRACTION … AN INVENTION … AN INVITATION

It does not matter where the train is going, what matters is it's direction and your decision to get on …



"Give me a lever long enough & a fulcrum on which to place it, & I shall move the world."

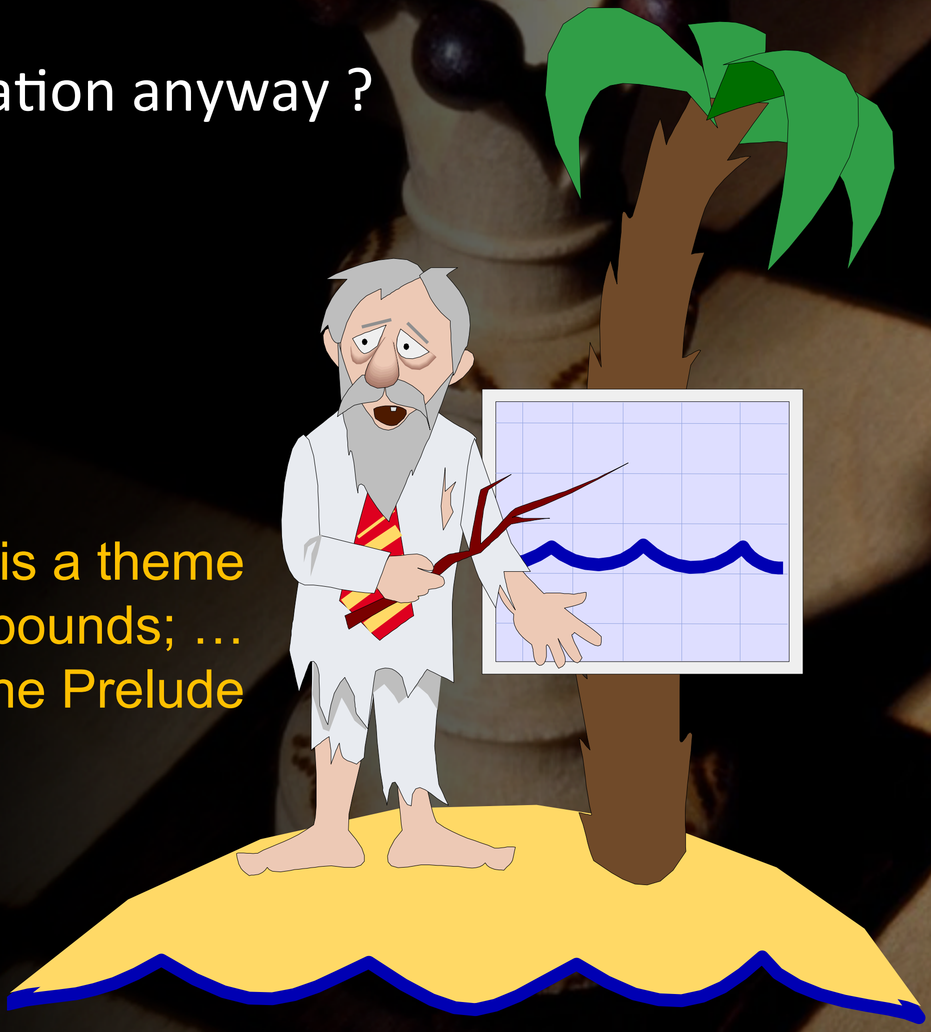
A *carchesion* is a kind of swivel or universal joint

About me

- Krishna Sankar, Lead Architect, Egnyte.com – Cloud Storage
- Past Life ; Distinguished Engineer
  - Chief subordinate to Assistant to Chief of Staff to CTO to the CEO of Cisco, Focusing on Cloud Computing & Data Clouds
  - C3L Project on Storage Overlay Network Fabric for Big Data (Hadoop)
- Co-chair : DMTF Cloud Incubator
- ETSI STF (Electronic Digital Signatures), W3C, OASIS (TAB, SAML et al)
- Writing a Book on Cloud Computing
  - "Building Clouds with Amazon Web Services"; Editor Michael Swaine
- Working on
  - Stanford MMDS (Mining Massive Data Sets Post Graduate Certificate Course
  - MS Bioinformatics - John Hopkins Advanced Biotechnology Studies(Started)
- OSCON'10 "Building a Bog data Cloud"[Link], Available now as a video [Link]
- Author : Enterprise Web 2.0 Fundamentals, Wireless LAN Security
  - Written a few Java books. Don't buy them – they are very old
- Member: Scala Expert group on STM/July 2010
- Writing code for SNIA CDMI Ref Impl – File based Object Store SPI
- Lego Robotics : Technical Judge FLL World Festivals

Agenda

- What is Time Synchronization anyway ?
- IEEE 1588 v2
- IETF TicToc
- ISPCS 2012
- Q&A …

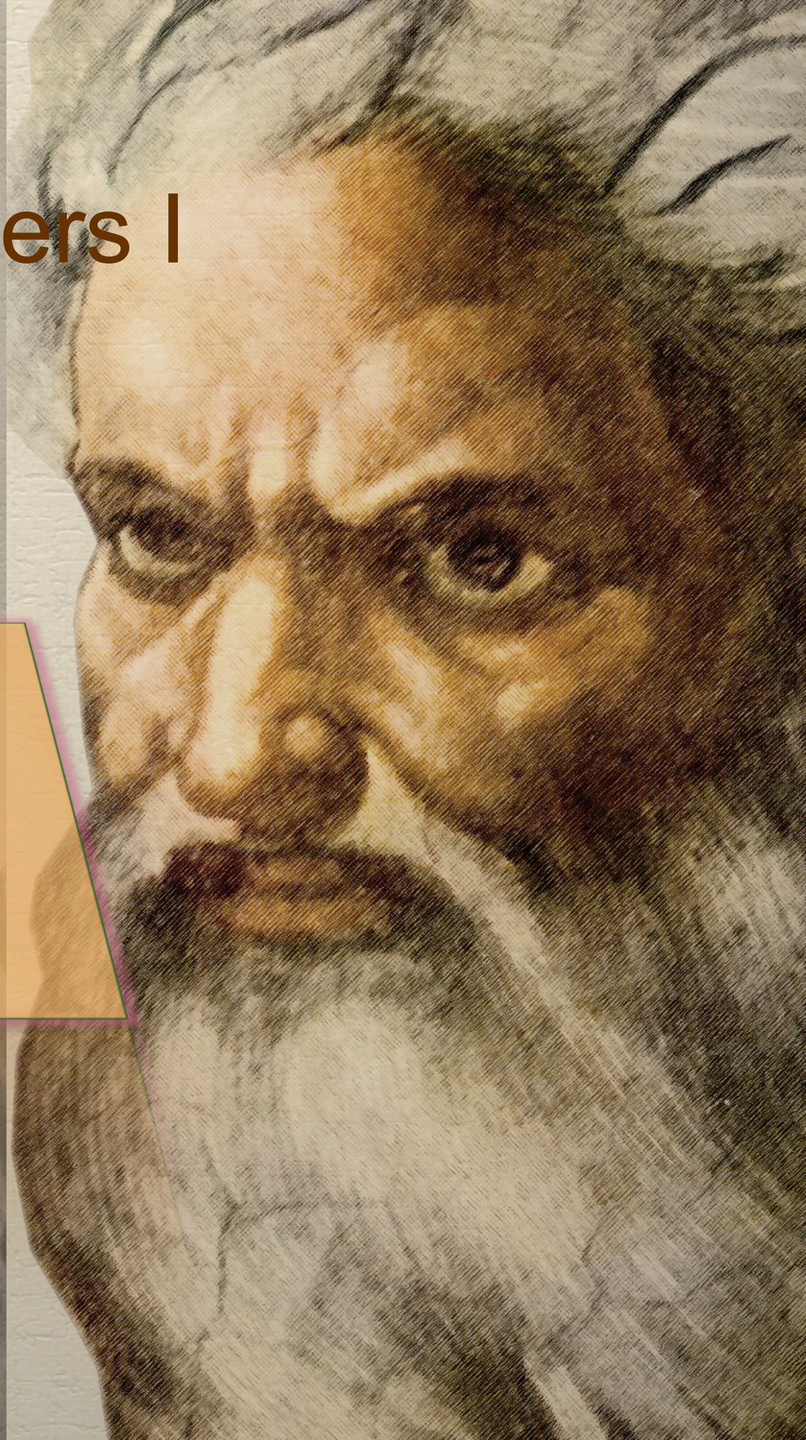


The road lies plain before me;--'tis a theme
Single and of determined bounds; …
- Wordsworth, The Prelude

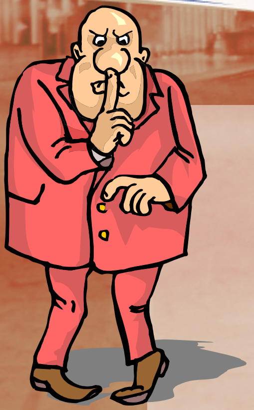
Thanks to …

The giants whose shoulders I am standing

- HPTS Programming Committee
- Pranta Das
- John Edison
- IEEE 1588 WG
- IETF Tictoc WG
- Others I have forgotten …



What is Time Synchronization Anyway ?



I am monarch of all I survey;
My right there is none to dispute;
From the centre all round to the sea
I am lord of the fowl and the brute
- Cowper, The Solitude Of Alexander SelKirk

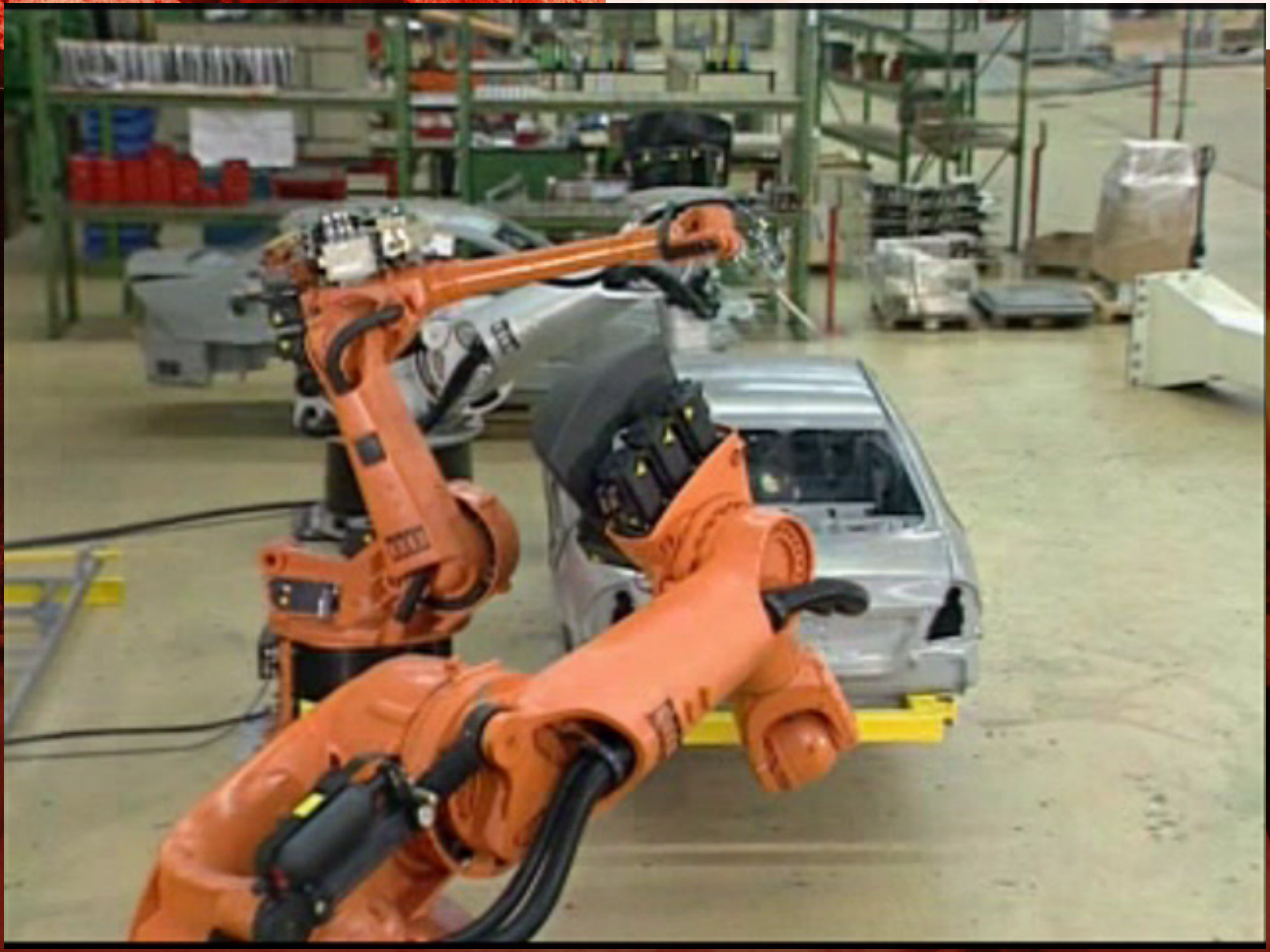
Time Synchronization

- Different than Time Distribution
- Across a set of machines for a specific application
  - The value proposition of providing precision time to an application is enormous…
  - …and has the potential to change the fundamental characteristics of applications
- Slowly finding it’s way into routers & blade server fabrics

Applications

- Ocean observatory networks
- Digital substation automation
- Industrial Automation
- Stock Trading Desks
  - Borgs trading based on arbitrage
  - Based on δt
- Cloud Computing/Storage Clouds
- Telecommunications
- Cellular/Network frequency, …

Industrial: RoboTeam in Action: Process Relative Motion (IEEE 1588 establishes timing coordination)



T&M: data acquisition

- IEEE 1588 time stamping data at the sensor for aircraft stress testing

Symmetricom GPS-linked IEEE 1588 master clock

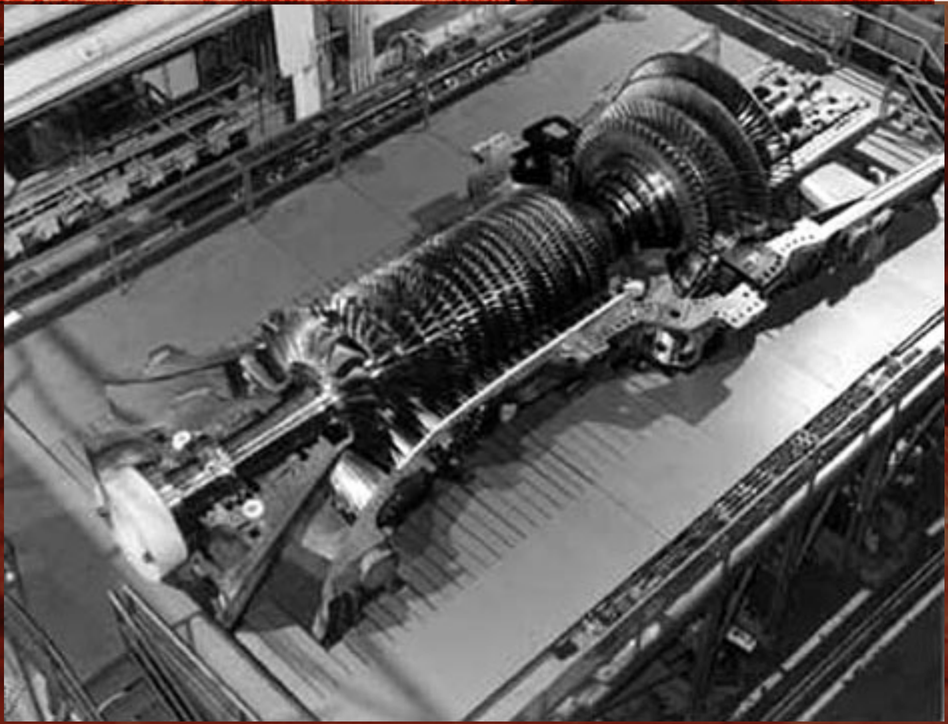
T&M: data acquisition

- Teletronics: In-flight Monitoring- IEEE 1588 time stamping data at source

T&M/Military: System instrumentation

- Agilent RF and high speed digital instruments (each has an IEEE 1588 clock)

Power Generation:



General Electric: Distributed Ethernet-based control system with IEEE 1588 used for timing coordination

When I think of my own native land,
In a moment I seem to be there;
But, alas! recollection at hand
Soon hurries me back to despair.
- Cowper, The Solitude Of Alexander SelKirk

IEEE1588v2 PTP
(Precision Time Protocol)

Objectives of IEEE 1588

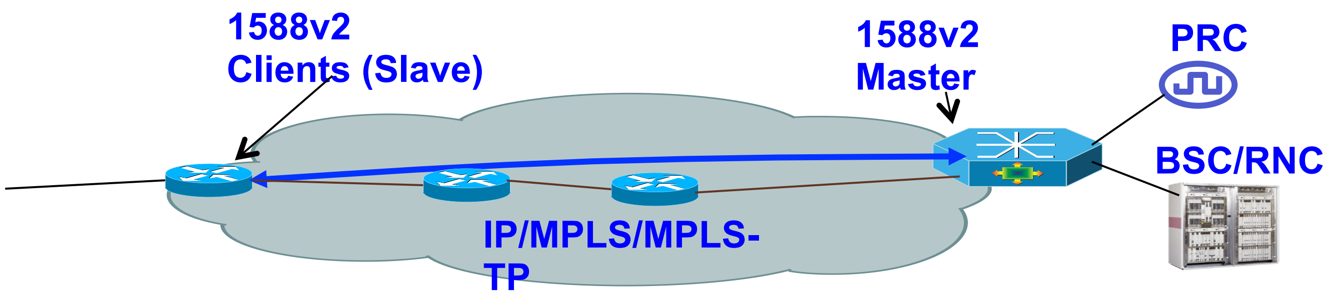
- Sub-microsecond synchronization of real-time clocks in components of a networked distributed measurement & control system
- Intended for relatively localized systems typical of financial, cloud & industrial automation/test & measurement environments.
- Applicable to local area networks supporting multicast communications (including but not limited to Ethernet)

Objectives of IEEE 1588

- Simple, administration free installation
- Support heterogeneous systems of clocks with varying precision, resolution and stability
- Minimal resource requirements on networks and host components.

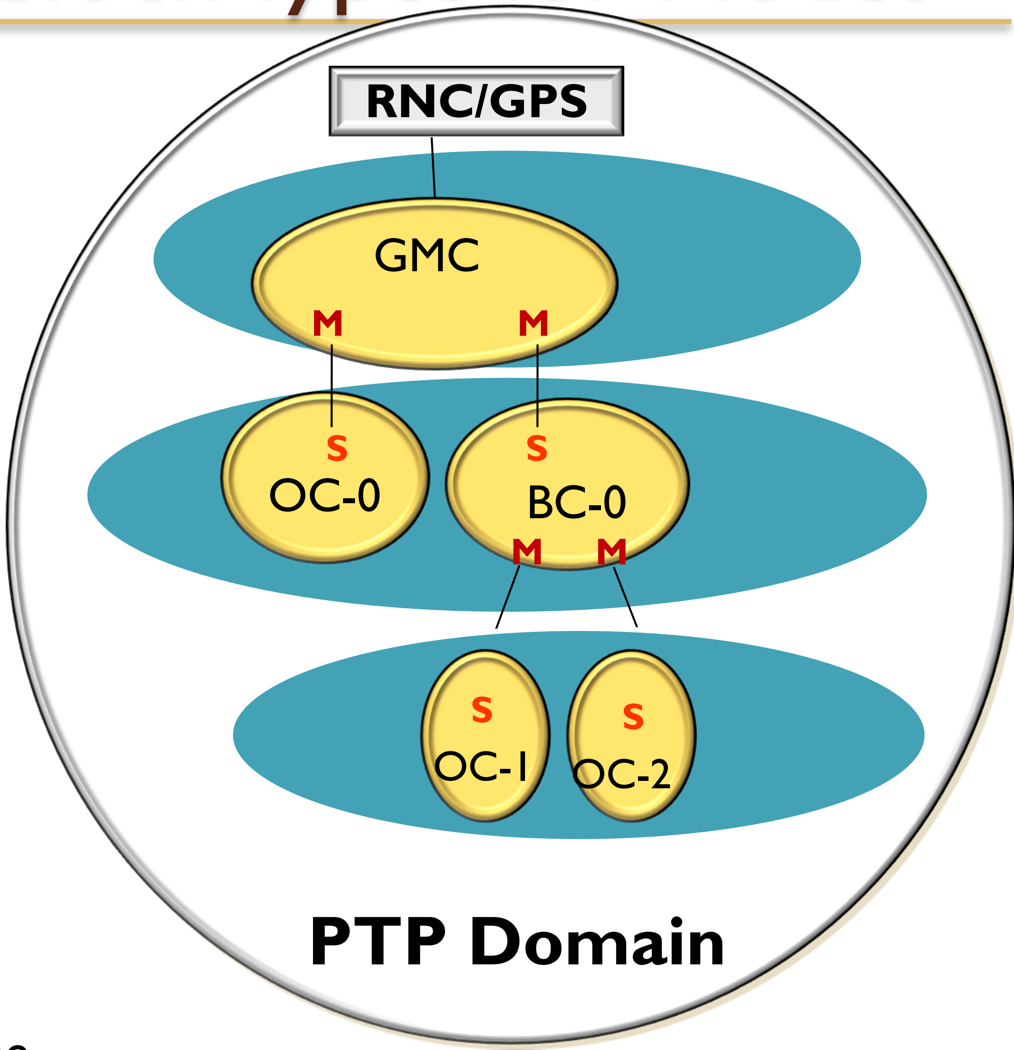
PTP Communication Ports on PTP Devices

- PTP uses Master-Slave model to provide packet based clock synchronization over Unicast and/or Multicast transport
- Timing distribution uses a series of messages between Master and Slave PTP devices to achieve synchronization
- PTP capable devices exchange messages through logical ports
- There are three types of PTP port states:
    - –PTP Master Port/clock (M): has the best quality & distributes timing info to Slaves.
    - –PTP Slave Port/clock (S): Synchronizes its clock with a Master port.
    - –PTP Passive Port: not a Master port, doesn't synchronize to a Master port to avoid loops



Device Roles: Clock Types for Nodes

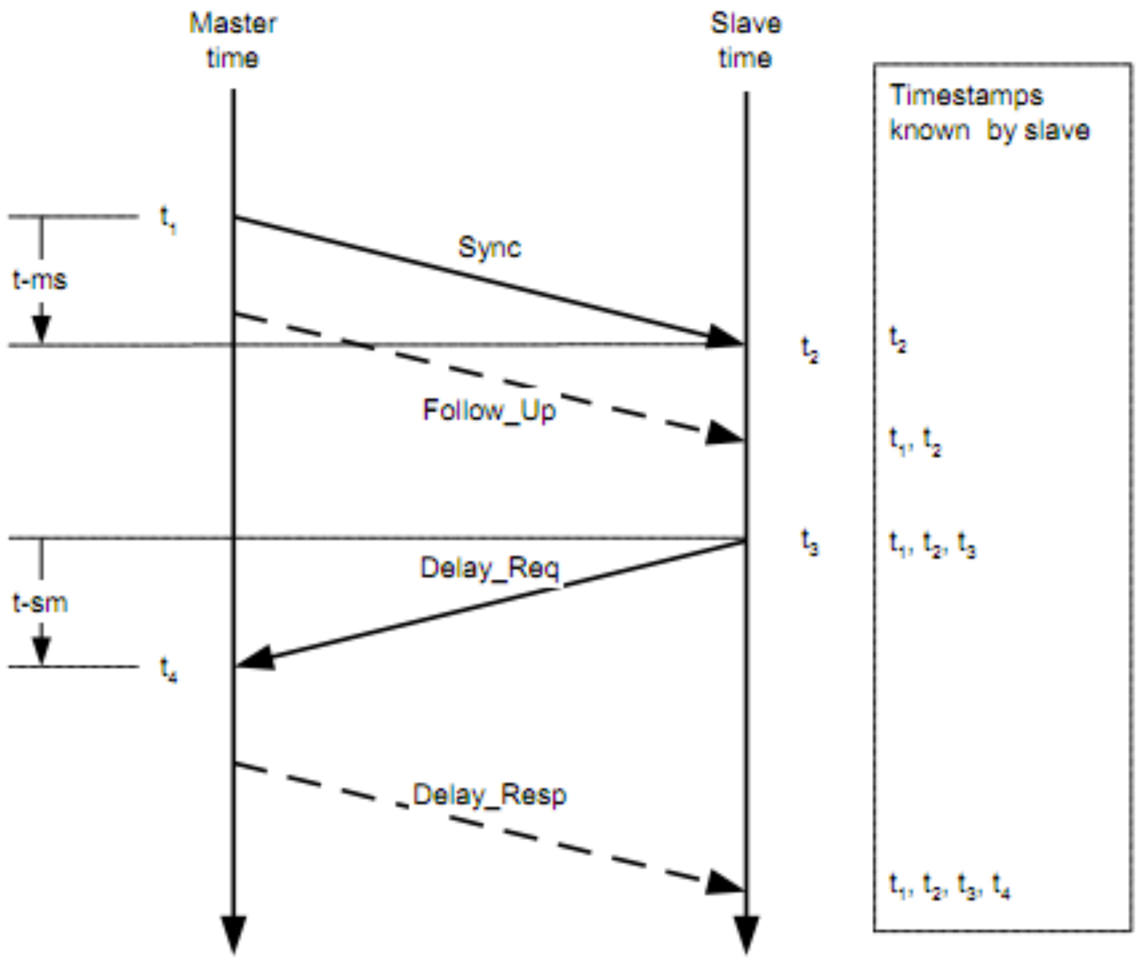
- There are five basic PTP devices of which four are PTP clocks:
  - –Ordinary Clock (OC)
  - –Boundary Clock (BC)
  - –End-to-End Transparent Clock
  - –Peer-to-Peer transparent Clock
  - –Management node
- Grand Master Clock (GMC)
  - –Ultimate source of time within a domain (OC or BC)



RNC, GPS = External Primary Reference Clock

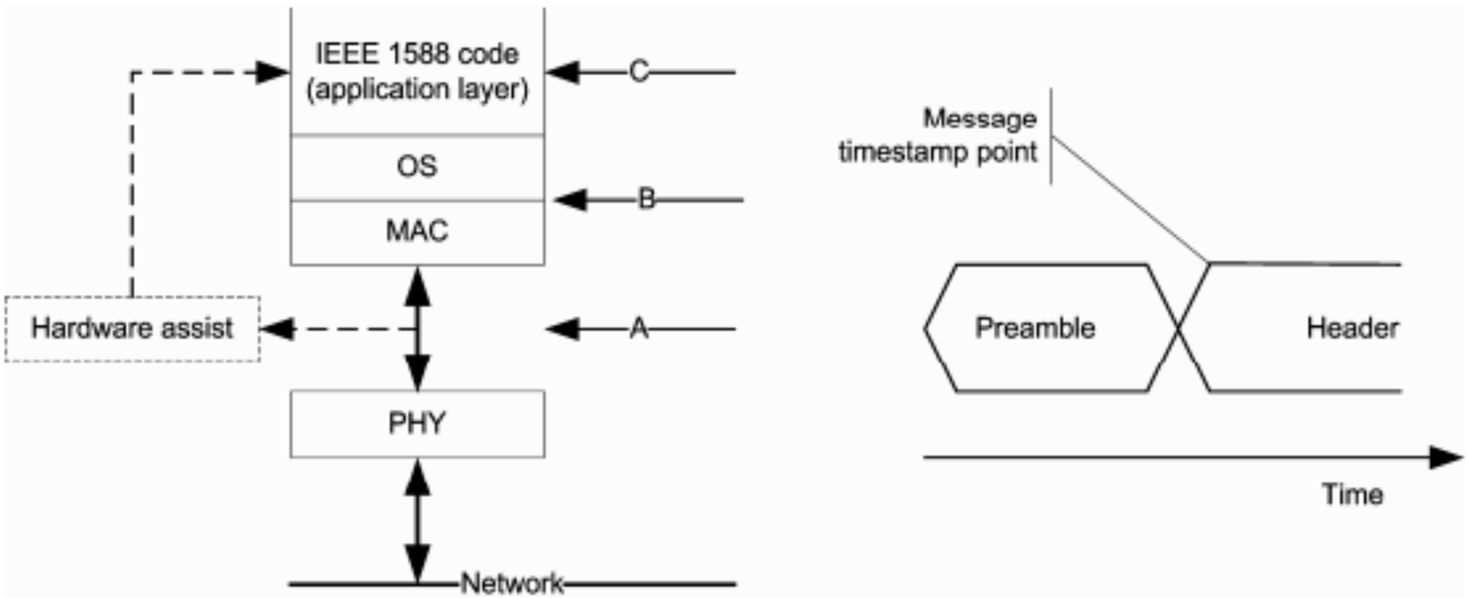
PTP Device Communication Messages

- PTP devices communicate using a set of General messages and Event Messages to achieve synchronization
- General Messages play important role in synchronization and used to discover PTP devices, build & maintain PTP session, are not time stamped and consist of:
  - –Follow_up: also generate timing information
  - –Delay_Response: also generate timing information
  - –Pdelay_Resp_Follow_Up: used in measuring link delay
  - –Announce: establishes synchronization hierarchy/Device Discovery
  - –Management: query & update
  - –Signaling: for communication between clocks
- Event Messages are time stamped by hardware and used for freq/time/phase synchronization, and consist of:
  - –Sync
  - –Delay_Req
  - –Pdelay_Req and Pdelay_Resp



Master time
Slave time
Timestamps known by slave
t1
Sync
t-ms
t2
Follow_Up
t1, t2
t3
t1, t2, t3
Delay_Req
t-sm
t4
Delay_Resp
t1, t2, t3, t4

Message Stamps



Hardware assisted time stamping increases accuracy to ns level

But not that easy

How Clock port role is determined

- Best Master Clock Algorithm (BMCA)specifies how a PTP port state transitions to different roles (Master, Slave, Passive)
  - –Each clock determines the best master clock in its domain out of all clocks it can see including itself – Grand Master clock is defined
  - –Best clock is selected based upon multiple parameters including user defined priority, clock class, accuracy and stability of the local clock
  - –If there’s a tie, the decision is made upon Universally Unique Identifier Device (UUID) of the port
  - –Port states (M/S/Pare defined
- Port roles can be controlled dynamically for ex: default IEEE 1588 BMCA or provisioned statically on a PTP device using alternate BMCA

7.6.3.2 Variance algorithm

The PTP variance, from which offsetScaledLogVariance and observedParentOffsetScaledLogVariance are derived, is based on the theory of Allan deviation as follows.

The Allan deviation $\sigma_y(\tau)$ is estimated as follows (see ITU-T Recommendation G.810 [B19]):

$$\sigma_y(\tau)=\left[\frac{1}{2(N-2)\tau^2}\times\sum_{k=1}^{N-2}(x_{k+2}-2x_{k+1}+x_k)^2\right]^{\frac{1}{2}}$$

where x_k, x_{k+1}, and x_{k+2} are time residual measurements made at times t_k, $t_k+\tau$, and $t_k+2\tau$. τ is the sample period between measurements, and N is the number of data samples. The term "residual" implies that any consistent systematic effects have been removed from the data.

The Allan deviation as stated is a second-order statistic on the variation of the frequency of the oscillator used as the basis of the time base.
The PTP variance is defined by

$$\sigma_{PTP}^2=\tau^2\times\frac{1}{3}\sigma_y^2$$

An unbiased estimate of the PTP variance shall be computed as follows:

$$\sigma_{PTP}^2=\frac{1}{3}\left[\frac{1}{2(N-2)}\times\sum_{k=1}^{N-2}(x_{k+2}-2x_{k+1}+x_k)^2\right]$$

where x_k, x_{k+1}, and x_{k+2} are time residual measurements, made at times t_k, $t_k+\tau$, and $t_k+2\tau$, between the time provided by the measured clock and a local reference clock, and N is the number of data samples. For a PTP variance, the quantity τ, the sample period, shall be the value defined in the applicable PTP profile. Subclauses 8.2.1.3.1.3 and 8.2.3.4 specify variances to be computed using the specifications in this clause. If these variances are computed during execution, data are only available in multiples of the syncInterval; see 7.7.2.3. In this case, τ should be a multiple of the syncInterval.

Implementation

M600 uses OCXO HQ

	TCXO	OCXO LQ	OCXO MQ	OCXO HQ	OCXO DHQ	Rubidium (only available for 3U models)
short term stability (τ = 1 sec)	$2 \cdot 10^{-9}$	$1 \cdot 10^{-9}$	$2 \cdot 10^{-10}$	$5 \cdot 10^{-12}$	$2 \cdot 10^{-12}$	$2 \cdot 10^{-11}$
accuracy of PPS (pulse per sec)	< ±250 nsec	< ±250 nsec	< ±100 nsec	< ±100 nsec	< ±100 nsec	< ±100 nsec
phase noise	1Hz -60dBc/Hz 10Hz -90dBc/Hz 100Hz -120dBc/Hz 1kHz -130dBc/Hz	1Hz -60dBc/Hz 10Hz -90dBc/Hz 100Hz -120dBc/Hz 1kHz -130dBc/Hz	1Hz -75dBc/Hz 10Hz -110dBc/Hz 100Hz -130dBc/Hz 1kHz -140dBc/Hz	1Hz -100dBc/Hz 10Hz -130dBc/Hz 100Hz -145dBc/Hz 1kHz -155dBc/Hz	1Hz -100dBc/Hz 10Hz -125dBc/Hz 100Hz -140dBc/Hz 1kHz -150dBc/Hz	1Hz -75dBc/Hz 10Hz -89dBc/Hz 100Hz -128dBc/Hz 1kHz -140dBc/Hz
accuracy free run, one day	$\pm 1 \cdot 10^{-7}$ ±1Hz (Note1)	$\pm 2 \cdot 10^{-8}$ ±0.2Hz (Note1)	$\pm 1.5 \cdot 10^{-9}$ ±15mHz (Note1)	$\pm 5 \cdot 10^{-10}$ ±5mHz (Note1)	$\pm 1 \cdot 10^{-10}$ ±1mHz (Note1)	$\pm 2 \cdot 10^{-11}$ ±0.2mHz (Note1)
accuracy free run, one year	$\pm 1 \cdot 10^{-6}$ ±10Hz (Note1)	$\pm 4 \cdot 10^{-7}$ ±4Hz (Note1)	$\pm 1 \cdot 10^{-7}$ ±1Hz (Note1)	$\pm 5 \cdot 10^{-8}$ ±0.5Hz (Note1)	$\pm 1 \cdot 10^{-8}$ ±0.1Hz (Note1)	$\pm 5 \cdot 10^{-10}$ ±5mHz (Note1)
accuracy GPS-synchronous, averaged 24h	$\pm 1 \cdot 10^{-11}$	$\pm 1 \cdot 10^{-11}$	$\pm 5 \cdot 10^{-12}$	$\pm 1 \cdot 10^{-12}$	$\pm 1 \cdot 10^{-12}$	$\pm 1 \cdot 10^{-12}$
accuracy of time free run, one day	± 8.6 msec	± 1.8 msec	± 130 µsec	± 44 µsec	± 10 µsec	± 1.8 µsec
accuracy of time free run, one year	± 32 sec	± 13 sec	± 3.5 sec	± 1.6 sec	± 300 msec	± 16 msec
temperature dependant drift free run	$\pm 1 \cdot 10^{-6}$ (-20...70°C)	$\pm 2 \cdot 10^{-7}$ (0...60°C)	$\pm 5 \cdot 10^{-8}$ (-20...70°C)	$\pm 1 \cdot 10^{-8}$ (5...70°C)	$\pm 2 \cdot 10^{-10}$ (5...70°C)	$\pm 6 \cdot 10^{-10}$ (-25...70°C)

Lessons

- Shallow Networks
- Separate from other networks
- No buffering in routers
- Accuracy depends on Hardware/Software
- Normal Distribution rather than a number
  - Skinny ~50 µsecs possible
- GPS satellite visibility needed for Grand Master Clocks
- Most of financial IT isnin basement !

IETF Tictoc

The woods are lovely, dark, and deep,
But I have promises to keep,
And miles to go before I sleep,
And miles to go before I sleep.
-Frost

Tictoc Status Pages

Timing over IP Connection and Transfer of Clock (Active WG)

Int Area: Ralph Droms, Jari Arkko | 2008-Mar-11 —
Chairs:
Karen O'Donoghue
Yaakov Stein

Working Group Documents:

ePUB

Draft name	Rev.	Dated	Status	Comments, Issues
Active:				
draft-ietf-tictoc-1588overmpls	-02	2011-10-07	Active	
draft-ietf-tictoc-ptp-mib	-00	2011-07-04	Active	
Recently Expired:				
draft-ietf-tictoc-requirements	-01	2011-03-08	Expired	
Expired:				
draft-bryant-tictoc-probstat	-02	2008-04-09	Expired	
draft-stein-tictoc-modules	-03	2008-11-03	Expired	

Related Active Documents (not working group documents):

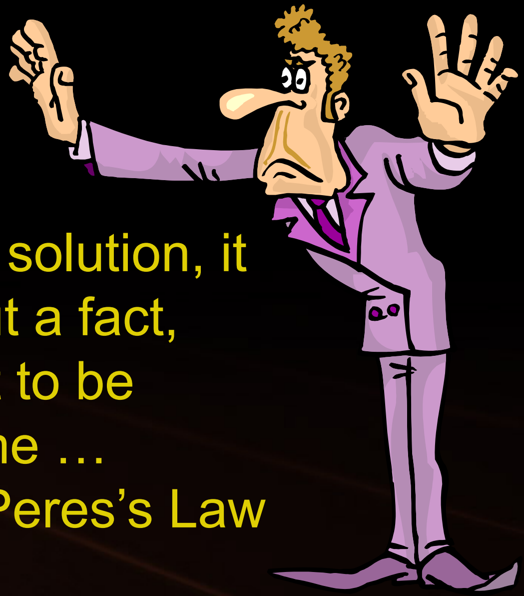
(To see all tictoc-related documents, go to tictoc-related drafts in the ID-archive)

draft-davari-tictoc-1588overmpls	-01		2011-01-15
draft-mizrahi-tictoc-checksum-trailer	-00		2011-07-04
draft-vinay-tictoc-ptp-mib	-00		2011-03-07
draft-xu-tictoc-ipsec-security-for-synchronization	-02		2011-09-16
draft-zhang-tictoc-pdv-lsp	-00	*new*	2011-10-20

Draft dependency graphs

If a problem has no solution, it is not a problem, but a fact, not to be solved but to be coped with, over time …

- Peres’s Law



ISPCS 2012

2007 International IEEE Symposium on Precision Clock Synchronization for Measurement, Control and Communication

ISPCS
Vienna '07

October 1-3, 2007, Austrian Academy of Sciences, Vienna, Austria

The 2007 Proceedings are now online on IEEE Xplore

Sponsored by
Austrian Academy of Sciences, IEEE Instrumentation and Measurement Society, Industrial Electronics Society, IEEE Systems Council, IEEE and the National Institute of Standards and Technology

2012 International IEEE Symposium on Precision Clock Synchronization for Measurement, Control and Communication

Sept. 23th - 28th, 2012: San Francisco, California, USA

Plugfest Sept. 23th - 25th, 2012: SFO Marriott Hotel, Burlingame, CA.

Technical Program Sept 26th-28th, 2012: SFO Marriott Hotel, Burlingame, CA.

Imminent Deadlines:

- April 16, 2012 - Deadline for submission of regular papers
- May 14, 2012 - Deadline for letters of intent for plug-fest

http://www.ispcs.org/2012/index.html

Participation

- Papers
- Requirements
  - For Transaction Systems
  - Cloud Inrastructure
- Sponsorships
- Attend the Symposium

Was it a vision, or a waking dream?
Fled is that music:—do I wake or sleep?

-Keats, Ode to a Nightingale