Time Synchronization Over Networks, IEEE 1588 and Applications

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Agenda

- Applications of IEEE 1588
- Background on clocks, timescales, time transfer
- Very short tutorial on IEEE 1588 and its profiles
- What does the future hold?
  - Alignment of 1588 and 802.1as- the layered architecture
  - High accuracy, redundancy, wireless, security, management
- Conclusions- why this is important
Applications of IEEE 1588: Telecommunications

**Target Applications**

<table>
<thead>
<tr>
<th>Level of Accuracy</th>
<th>Time Error Requirement (with respect to an ideal reference)</th>
<th>Typical Applications</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>500 ms</td>
<td>Billing, Alarms</td>
</tr>
<tr>
<td>2</td>
<td>100 μs</td>
<td>IP Delay monitoring</td>
</tr>
<tr>
<td>3</td>
<td>5 μs</td>
<td>LTE TDD (cell &gt;3km)</td>
</tr>
<tr>
<td>4</td>
<td>1.5 μs</td>
<td>UTRA-TDD, LTE-TDD (cell ≤ 3Km) Wimax-TDD (some configurations)</td>
</tr>
<tr>
<td>5</td>
<td>1 μs</td>
<td>Wimax-TDD (some configurations)</td>
</tr>
<tr>
<td>6</td>
<td>&lt; x ns (x ffs)</td>
<td>Location Based services and some LTE-A features (Under Study)</td>
</tr>
</tbody>
</table>

Small cells coordination features generally addressed by Class 4!

Stefano Ruffini, Ericsson WSTS 2014

PTP deployment roadmap in CMCC

**Four phases in China Mobile:**

- **2008~2009 Experimental study**
  - Number of hops
  - reconfiguration
  - Signal degradation
  - Temperature
  - Frequency sync
  - PDV
  - Asymmetric delay

- **2009~2011 Large Scale Trial**
  - Over 1000 NBs as working source
  - Trial for over 1 year

- **2012~2014 Commercial Deployment as backup**
  - GPS as working source
  - PTP as backup
  - Part of NBs (ex. small cells) have only PTP source

- **Future Full-scale Commercial Deployment**
  - PTP as working source
  - GPS as backup

Over 6 years’ period for study and deployment: scientific, systematic and cautious process

Han Li, China Mobile. ISPCS-2014

John C. Eidson, UC Berkeley
Applications of IEEE 1588: Power

Synchrophasors’ future

The synchrophasor standard is being revised by a joint IEEE/IEC working group:
- considering new applications
- expects to publish a joint synchrophasor standard: IEEE/IEC 60255-118-1 sometime before 2018
- applications which require better than 1% TVE are being considered

A Department of Energy ARPA-E program is investigating applications for a “micro-PMU” (μPMU):
- extremely precise time-stamping of measurements to allow comparisons of voltage phase angle down to small fractions of a degree
- may be beneficial in distribution networks where the phase differences between nodes are smaller
- μPMU technology is expected to discern angle differences to significantly better than ±0.05 deg (aiming for ±0.01 deg)
- the maximum timing error would need to be less than 0.453 μs for a 50 Hz system or 0.557 μs for a 60 Hz system

Power system applications

GE uses 1588 in the Mark™VIe control system for large generators, turbines, wind farms, and other DCS applications. (reduce wiring, save bandwidth, manage complexity and scaling)

One project needs 50ns!!

 Courtesy of General Electric
Data Acquisition: Sound, vibration, ..., machine condition monitoring

Acquisition devices with 1588 clock, ~1 µs

Hull Vibration Monitoring System

Network Router
- Precision Time Protocol Synchronization (PTP)
- Power over Ethernet (PoE)
- Data Transfer from LAN-XI Systems

Pulse DAQ-H Central Control System
- Data Storage and Analysis
- Interactive Customer User Interface
- Automated and user initiated scans
- Ability to listen to any signal
- Warning/Alarms
- Troubleshooting

COTS Accelerometers
- Off the shelf product
- Designed for Health Usage Monitoring Systems (HUMS)
- High Frequency, High Temperature
- EMI/Radiation Resistant

Distributed LAN-XI A/D Front-Ends
- Dual 24bit A/D Technology (160dB Dynamic Range)
- Extremely low Noise Floor
- Single LAN cable operation (PoE, PTP, Data Transfer)
- 1000+ Channels in a single system

Embedded Hydrophones
- Cavitation Noise
- Integration of permanent hydrophones (Monitoring of Cavitation Noise)
- Listening to signals

Slide courtesy of Bruel and Kjaer
Applications of IEEE 1588: Finance

The need for Sync in Financial Networks

• High-Frequency Trading (HFT) requires accurate time stamping of trades for:
  • Accurate records of transactions during playback regression to improve trading algorithms
  • Reporting and regulatory purposes, disputes, etc.

• GPS has primarily been used for this but faces issues:
  • Coverage and signal loss is a significant and expensive issue
  • Security - a US$20 device can jam GPS signals

• 1588v2 PTP is getting a lot of interest
  • Time can be delivered via the Ethernet network
  • However, accuracy needs to be verified during trials and monitored in-service

Annand Ram, Calnex, WSTS 2014  
John C. Eidson, UC Berkeley
Applications of IEEE 1588: TV Broadcast

SMPTE has gone to ballot on an IEEE 1588 profile for use in TV Broadcast

• Increasingly, studio equipment connected via Ethernet
• Digital TV studio needs synchronization to within 1μs

Annand Ram, Calnex, WSTS 2014

Scientific applications (e.g. LHC at CERN - the White Rabbit project: 1588 + SyncE)

© 2008 CERN
Background: Clock basics

Oscillators characterized by:
- Frequency drift => degrades clock accuracy
- Noise => degrades clock precision

Common LSB values are 40 ns and 8 ns corresponding to 25 MHz and 125 MHz frequencies typical of Ethernet PHY chips.

Background: Timescales

Time is relative but to what?
- Isolated systems: relative to some local oscillator’s frequency and the local epoch (zero point of counter)
- Traceable system, e.g. to UTC or TAI: relative to a national laboratory. In the US this is USNO
UTC-UTC(SP) and UTC – UTC(USNO) from 1 June 2012 to 26 February 2015


Background: Time transfer

- One-way protocols: e.g. GPS, Loran, IRIG-B

- Two-way protocols: e.g. NTP, IEEE 1588 and profiles, Two-way satellite time and frequency transfer (TWSTFT)
Two-way protocols depend on knowing both $\Delta_{MS}$ and $\Delta_{SM}$

Time transfer precision degraded by path jitter

Time transfer accuracy degraded by path asymmetry

Path asymmetry must either be modeled or determined by calibration measurements other than the two-way messages

PHYs, bridges and routing are major sources of asymmetry

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Short tutorial on IEEE 1588

IEEE Standard for a Precision Clock Synchronization Protocol for Networked Measurement and Control Systems

- Editions: 2002 (V1), 2008 (V2)
- P1588 Working Group working on new edition (V2.1): target date 2017

Who has written profiles?

- 802.1AS,
- ITU-T G.8265.1, G.8275.1, (G.8275.2)
- SMPTE, IETF, LXI Consortium, ????
IEEE 1588 (PTP) has three principal functions:

- Pick the best clock, the grandmaster, as the root of a spanning tree (Best Master Clock Algorithm) to form a master-slave hierarchy
- Synchronize each clock to its parent, i.e. the next upstream clock in the spanning tree
- Management

IEEE 1588 Best Master Clock Algorithm:

- Based on pair-wise exchange of “Announce” messages
- Ordered comparison of: priority1, clockClass, accuracy, variance, priority2, clockIdentity
- Loop breaking based on stepsRemoved (from GM)
- Port state: Master, Passive, Slave
Short tutorial on IEEE 1588

IEEE 1588:
Two-way time transfer

What does the future hold?
(what mischief is P1588 up to this time?)

- The layered architecture:
  - Alignment of 1588 with 802.1AS and other profiles
  - Enable easier future addition of links using different time transfer mechanisms, e.g. 802.11

- High accuracy:
  - Technology based on CERN’s White Rabbit
  - Enables accuracy and precision to sub-nanosecond
  - Will be optional
White Rabbit Performance:
Sub-nanosecond synchronization error over three 5km fiber optic Ethernet links!

What does the future hold?
(what mischief is P1588 up to this time?)

Redundancy:
- Still in hot contention in P1588
- Protection against grandmaster and/or path failure
- Current discussion is based on the use of multiple independent domains
  - Distinguished by domainNumber
  - Specify external interface to configure port state (as an option instead of using the BMCA)
  - Would allow external creation of disjoint spanning trees
What does the future hold?
(what mischief is P1588 up to this time?)

Security:
- PTP Integrated: e.g. key management, message authentication
- External Transport Security Mechanisms: e.g. hop-by-hop using MACsec
- Architectural Guidance: e.g. use of redundant masters or paths
- Monitoring and Management Guidance

Management: (current thoughts in P1588)
- Will retain the native management option of clause 15 (lots of users)
- Will specify a standard MIB
Conclusions

The most important aspect of all the current standards and implementation activity:

- There is a growing understanding that time-aware techniques and technology are needed
- We have taken the first of many needed steps to converge the technologies

Thank you for your attention