Advancements in Time Synchronization for TSN

The IEEE 802.1AS Profile of IEEE 1588

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TSN
How we got to Now
Where we're headed

TSN and the IEEE 1588 (PTP) Family of Protocols

IEEE 1588 Precision Time Protocol (PTP)

IEEE 1588 PROFILES

- Default L2/L3/ P2P/HA
- ITU-T
- IETF
- SMPTE
- AES
- IEC 61850
- AUTO-SAR
- GIGE VISION
- 802.1AS

IEEE 802.1 TSN

- Latency
- Reliability
- Config

Certification: Avnu Alliance

IEEE 1588 defines a *family of protocols*

Profiles select among the (numerous) options

Profiles of 1588 are not generally interoperable

2019 adds High Accuracy (White Rabbit) and Security

TSN Defines a Profile of PTP — IEEE 802.1AS

The TSN Profiles

Like a PTP/IEEE 1588 profile, the TSN profiles select among options, add additional requirements for their application area.

The Focus: Cyber-Physical Systems

TSN Profile	IEEE Designation	Status
Audio/Video Bridging (AVB)	802.1BA	Published
Fronthaul/Backhaul	802.1CM	Published
Automotive In-Vehicle	802.1DG	(Published)
Industrial Automation	60802 (IEC/IEEE)	Draft
Service Provider Networks	802.1DF	Draft
Aerospace	802.1DP	Draft

Profiles Also Defined for TSN

802.1AS: Original Requirements (2005→2011)

Assumptions:

1. Inexpensive crystal oscillator (XO), +/- 100 PPM)
2. Contains a profile of IEEE 1588 / PTP

Requirements:

1. Deterministic clock error (e.g. 1us worst-case)--dramatically enhanced subsequently
   a. Audio and video regeneration, and potential for many network hops
2. Plug-and-play (no administrative configuration required)
3. Support beyond Ethernet: 802.11 Wi-Fi, EPON, and others
4. Fast Clock Lock (as fast as 1 second from power-on)

Concessions:

1. No support for IP/UDP headers, no automatic IP routing of gPTP
2. Time-transfer *ends* at the switch/bridge where 802.1AS is not supported

Unique Requirements drove Enhancements

802.1AS: Boundary Clock (BC) or Transparent Clock (TC)?

Looking from the outside:

- Switches run BTCA (Best Master Clock Algorithm), filter Announce messages, like BCs
- SYNC messages transmitted either:
  1. Synchronously, after receiving SYNC, or
  2. Asynchronously, as if in holdover, until Announce Timeout

Internally:

- Timestamps use a free-running clock (like a TC)
- But compensates for rate-ratio WRT GM (like a BC, but using computational syntonization)

These Switches are BC/TC Hybrids

Quickly establish end-to-end “Rate Ratio”

Neighbor Rate Ratio is computed continuously

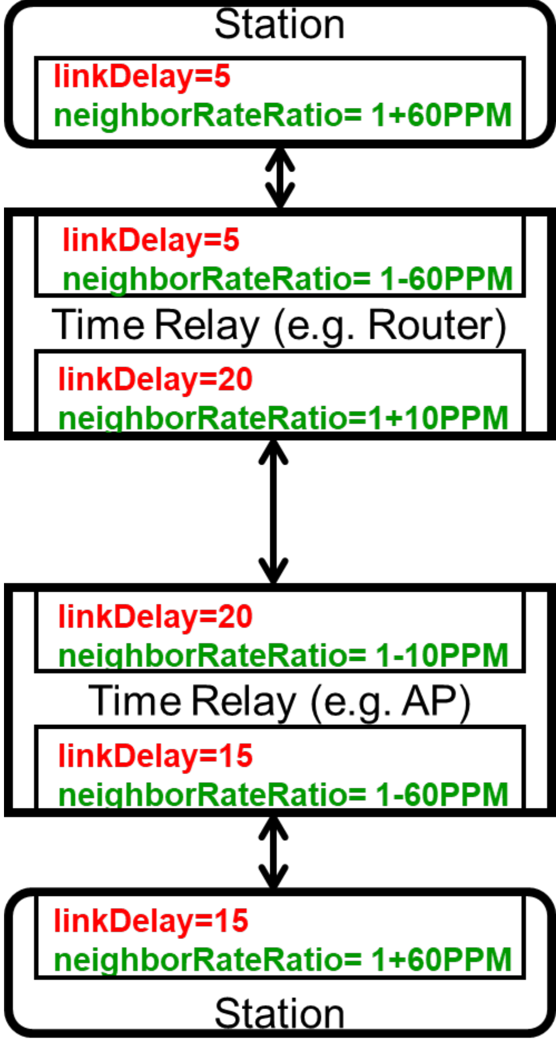
..on every link

..in both direction

Then accumulated end-to-end in a Follow-Up Field

⇒ Upon reconfiguration of the clock tree or new GM, endpoints know their PPM WRT the GM after a single (SYNC) message

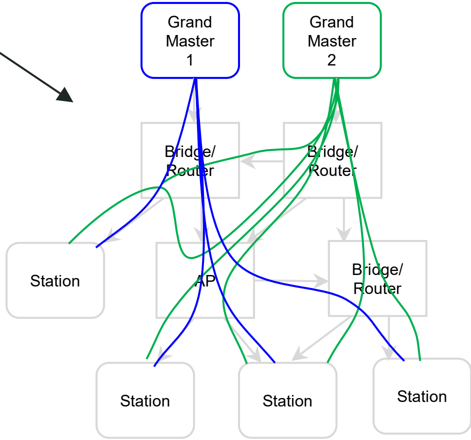
Cheap XOs Requires Fast Re-Syntonization



802.1AS (2011→Future): Recent and Future Enhancements

Major:

1. Administratively-defined clock trees, redundant GMs (e.g. Hot Standby)
2. **Fault Tolerant Timing / Timing Integrity for Aerospace (802.1DP)**
3. Long-Chains (e.g. 128 nodes) for Industrial (60802)



Less Major:

1. Use Sync to compute Rate Ratio
2. One-step tolerant
3. Inclusive Terminology (Time Transmitter, Time Receiver)
4. Support for half-duplex (10 Mbps) Ethernet MACs

Major Focus on Larger, Safety-Critical Systems

Zooming out…

Synchronized ***clocks*** are used by **sensors**, **actuators**, and to schedule the real-time **software application**

..and sometimes by the **network itself**, for ensuring bounded latency

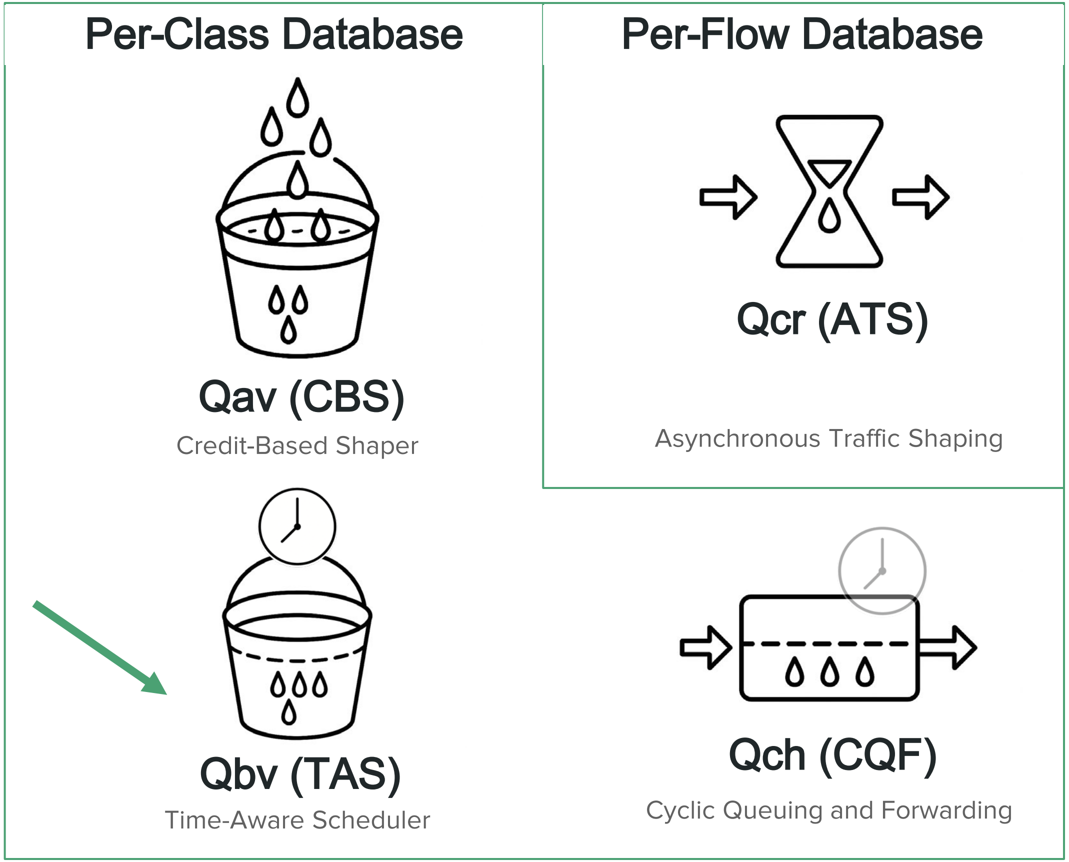
TSN Traffic Shaping

Goal: Provide Latency Bound

Trade Offs:

1. **Need for clock-sync**
2. Per-Flow Database
   a. In Talker
   b. In Talker and Bridge
3. Implementation complexity
4. Worst-case latency

All require Admission Control



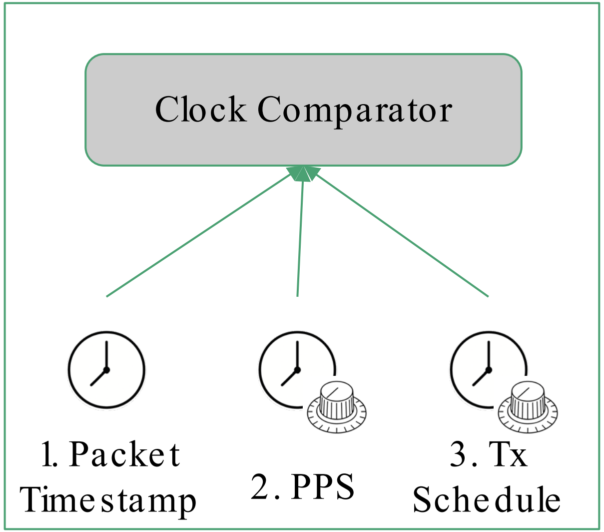
\+ **Preemption and Cut-Through**

Uses of a Synchronized Clock within the Ethernet NIC

1. Timestamp PTP and other frames (up to *all* Rx and Tx frames)
    a. Using a Free Running clock for this is almost always better
        i. Eliminate dynamics from the fundamental measurement
        ii. Arbitrary number of PTP domains
        iii. Improved “Gain peaking” over long chains of switches

2. Generate PPS and other periodic signals

3. Transmit frames on a schedule
    a. According to a SW-programmed schedule, per queue (e.g. for 802.1Qbv / TAS)
    b. At a software-specified “Launch Time”, on a per-packet basis



Conclusions

The 802.1 TSN group defined a profile of 1588 tailored for Cyber-Physical Systems

802.1AS addresses unique challenges in AV, Automotive, Industrial, Aerospace, …

Traffic Shaping can bound the worst-case network latency

..and some traffic shaping algorithms requires clock synchronization

[And please, let's limit the further proliferation of additional PTP Profiles as much as possible]

Kevin's Time Lab on Youtube