PTP: The Key to ST 2110 Timing

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Precision Time Protocol – History

- Designed to synchronize clocks via a computer network, with much higher accuracy than NTP

- Widely used in industries such as telecom and finance, now being adopted for video applications to replace analog sync

- Version 1 published as IEEE 1588-2002, not used for video

- Version 2 published as IEEE 1588-2008
  - Updated with IEEE 1588-2019 ("Version 2.1")

- Augmented with standards such as SMPTE ST 2059-2 (since 2015)

- Some terminology has changed: Master/Slave → Leader/Follower

PTP over IPv4

- User Datagram Protocol (UDP) used for transport
  - Port 319 for Event messages
  - Port 320 for General messages
- Multicast group address for most messages: 224.0.1.129
- Exchange of PTP messages may be multicast, unicast, or a mix of both

Common PTP Message Types

- Event message class
  - Sync
  - Delay_Req
- General message class
  - Announce – used to establish the synchronization hierarchy
  - Delay_Resp
  - Follow_Up
  - Management – used to query and update "data sets" used by PTP instances
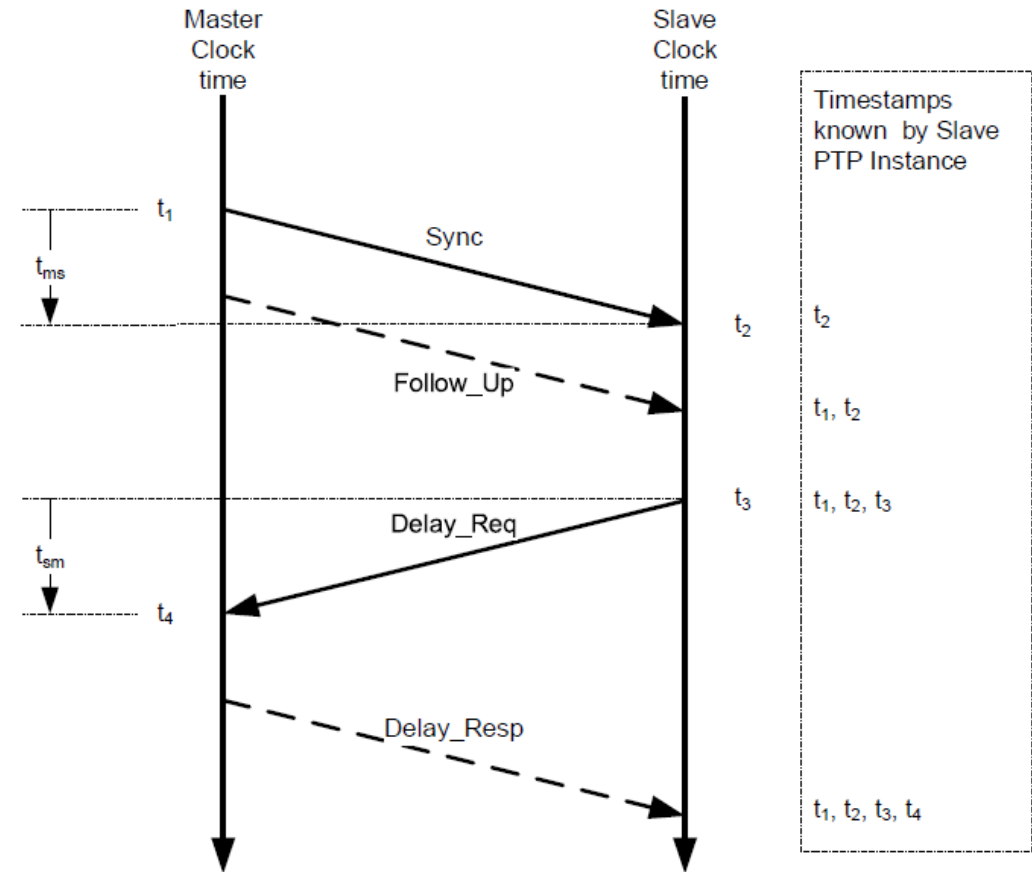- Differentiated Services used by switches to enforce high priority for event messages

Clock Synchronization

- Sync messages sent periodically (e.g. 8 per second) from leader to followers

- Follow_Up message needed only if Sync timestamp is not included in the Sync message

- Followers send Delay_Req, typically at same rate as Sync

- After complete exchange, followers have all 4 timestamps
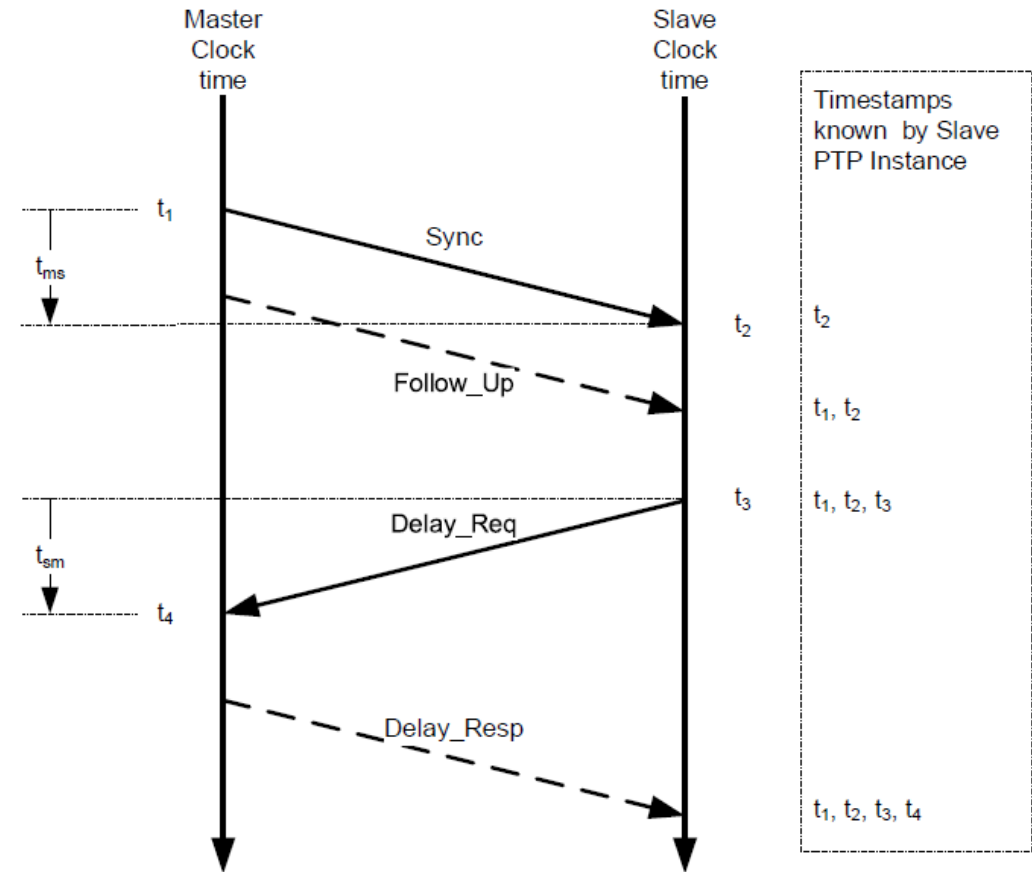
Clock Synchronization

- $t_{ms} = t_2 - t_1$
- $t_{sm} = t_4 - t_3$
- $meanDelay = \dfrac{t_{ms} + t_{sm}}{2}$
- $offset = \dfrac{t_{ms} - t_{sm}}{2}$
- Follower clock can be adjusted using these values
- There is also a provision for asymmetric network delays

- Ordinary Clock
  - PTP nodes with a single port on the network
  - Can be either a follower or a leader
  - Typically in video networks, we have grandmaster (GM) clocks that are leader-only and devices (cameras, etc.) that are follower-only

- Boundary Clock
  - Multi-port device (i.e. switch) with one follower (synced to the GM) and many leaders on all other ports
  - Provides scalability in large PTP networks

- Transparent Clock
  - Switch that updates timestamps in PTP messages but does not assume a role

Media Network Architecture
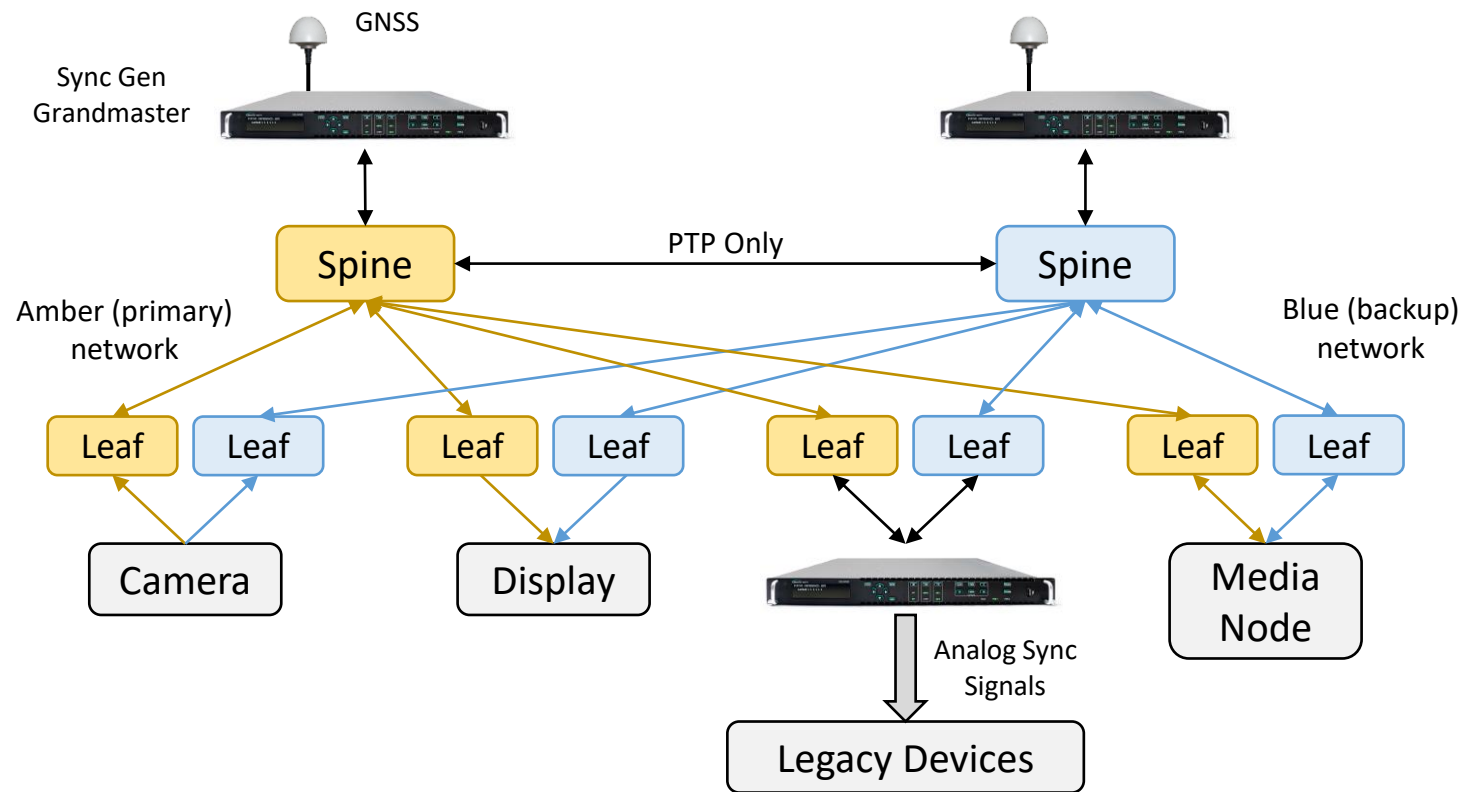
- Redundant network for resiliency
- Leaf/Spine switches (boundary clocks) for scalability
- Hybrid facility with PTP → analog to support legacy devices

Lead Clock Determination

- Announce messages are sent periodically (typ. 1 per second) and include (in priority order):
    1. Priority 1 – user-configured
    2. Clock Class – GNSS locked, holdover, free-running, etc.
    3. Clock Accuracy – estimate based on time source, e.g. "within 25 ns"
    4. Clock Variance – computed stability of local clock
    5. Priority 2 – user-configured
    6. Clock Identity – (tie-breaker) based on MAC address

- Potential leaders use the Best Master Clock Algorithm (BMCA) to decide which node is the sync source

Best Master Clock Algorithm

- Leader clocks listen for other Announce messages

- Start sending Announce when better than received Announce
  - Or when no Announce received (timeout is usually 3s)

- Stop sending Announce (go to Passive) when a better leader is seen
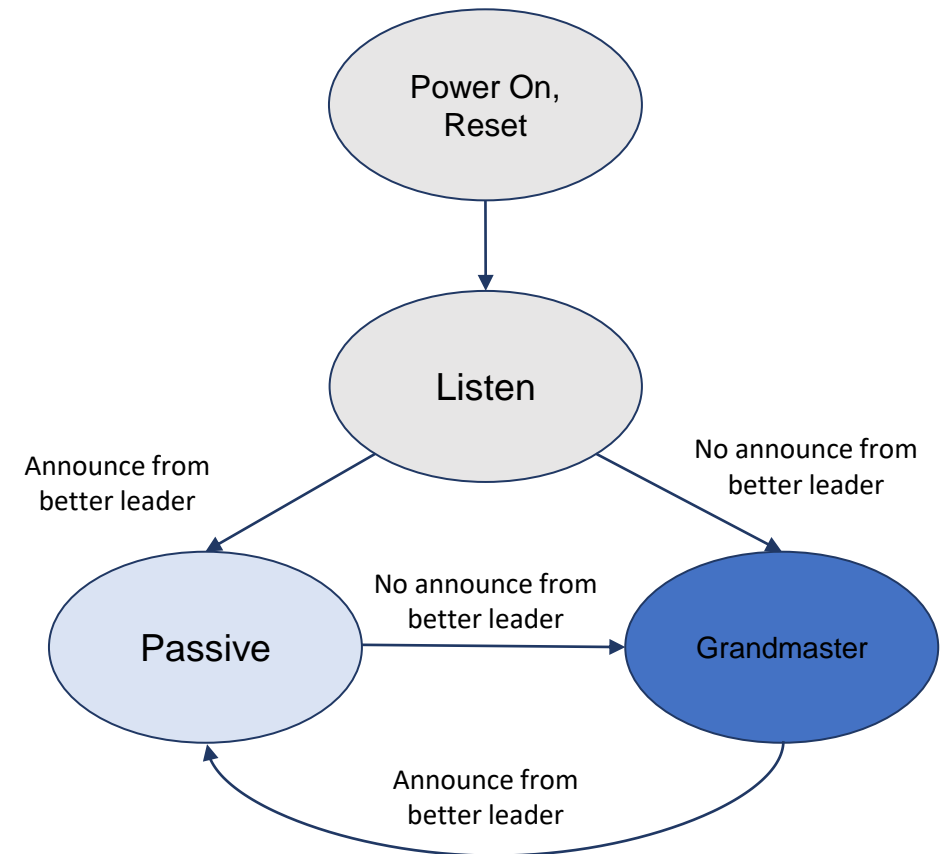
PTP Domains

- Domain is simply a numeric identifier (0-255) for a logical PTP network

- Multiple domains can co-exist on a physical network
  - For example, separate audio (AES67) and ST 2110 domains

- Every PTP message includes the domain number so nodes can accept or discard the message as appropriate

PTP Profiles

- A profile is a set of PTP options and attributes for a given application
  - Message rate defaults and permitted limits (Announce, Sync, etc.)
  - Communication models (e.g. multicast, unicast, mixed)
- IEEE 1588-2019 specifies the "Delay Request-Response Default PTP Profile"
- SMPTE 2059-2:2021 specifies the "SMPTE profile for synchronization in a professional broadcast environment"
- AES67-2018 specifies the "PTP profile for media applications"
- Other profiles for telecom and other applications

- Specifies the PTP profile used by ST 2110

- Permits three communication models:
  - Multicast for all messages
  - Unicast for all messages. Followers are configured with a list of potential leaders and use a "grant" mechanism to request that the leader send unicast Announce, Sync, and Delay_Resp messages
  - Mixed – Announce, Sync (& Follow_Up) and Management messages are sent by multicast. Delay_Req/Delay_Resp are sent by unicast (without grant)

- Adds a synchronization metadata TLV in Management messages to signal time code information to media nodes (e.g. next jam time)

Best Practices

- Create a solid network plan
  - Redundant amber/blue networks
  - Switches that support PTP, ideally Boundary Clock mode
  - Scalable switch architecture – Spine/Leaf
- Use PTP-only link between amber/blue networks so that GMs can see each other's Announce messages
  - All devices see the same GM on both networks
- Configure switch ports "role master" to prevent rogue leaders
- Use SMPTE 2059-2 profile and default message rates
  - Use Mixed Multicast/Unicast communication model

Troubleshooting Tools

- PTP monitoring and measurements

- Wireshark packet captures for offline analysis

Any Questions?