Joint ITU-T/IEEE Workshop on The Future of Ethernet Transport

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IEEE 802.1AS and IEEE 1588

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Acknowledgment

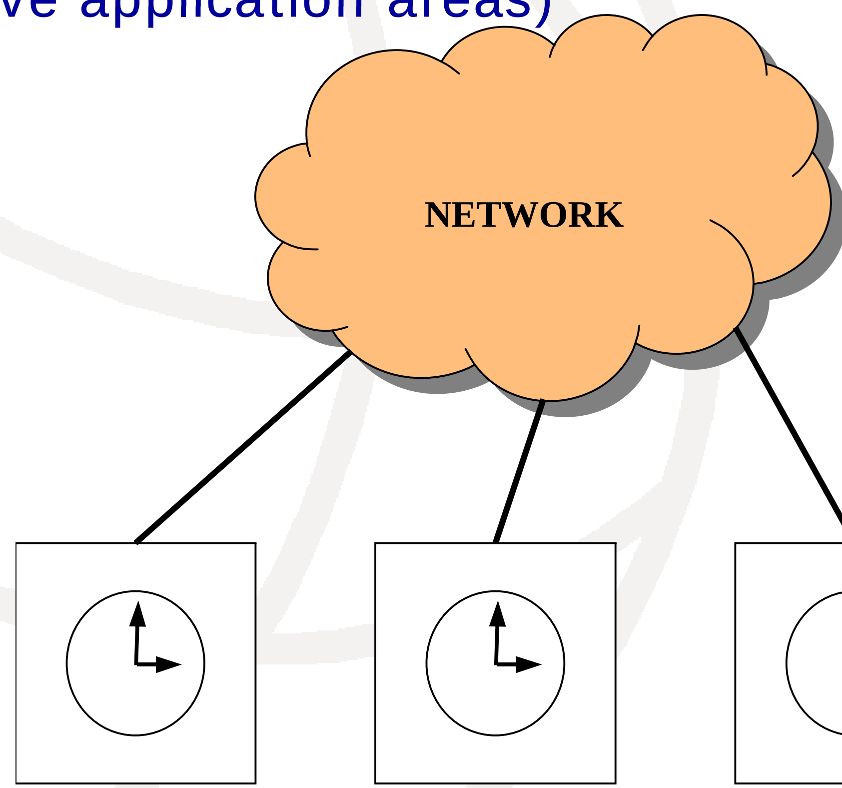
- Many of the slides in this presentation were taken or adapted from references [1] – [3]
- The author would like to acknowledge and thank John Eidson for having provided the base material from which many of the slides of reference [1] were taken or adapted

Outline

- Purpose of IEEE 1588
- IEEE 1588 version 2 features
- IEEE 1588 synchronization using peer delay mechanism
- Purpose of IEEE 802.1AS
- PTP profile included in IEEE 802.1AS
- IEEE 802.1AS synchronization
- IEEE 802.1AS best master selection

Purpose of IEEE 1588

- IEEE 1588 Precision Time Protocol (PTP) is a protocol designed to synchronize real-time clocks in the nodes of a distributed system that communicate using a network
  - It does not say how to use these clocks (this is specified by the respective application areas)



1588 V2 New Features – 1

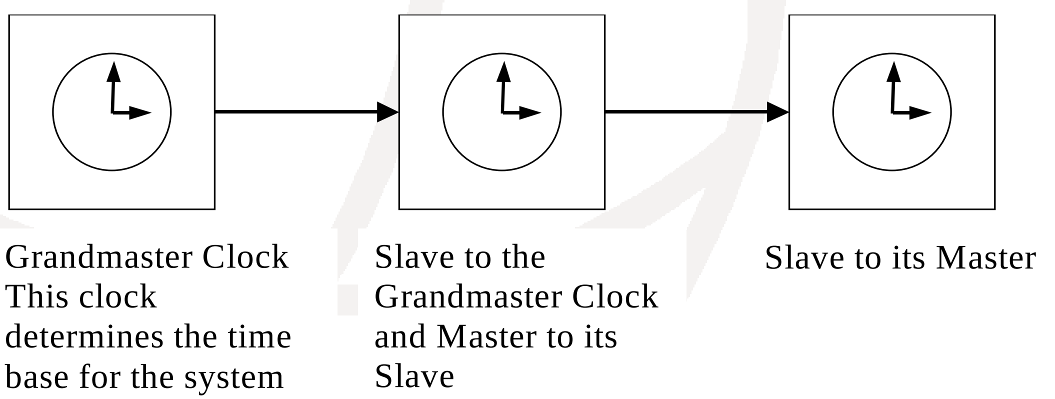
- IEEE 1588™ – 2008 (IEEE 1588 V2) [4] was published July 24, 2008. New features include:
  - Mappings to UDP/IPv4&6, Ethernet (direct mapping), DeviceNet™, PROFINET, ControlNet™
  - Formal mechanisms for message extensions (using TLV)
  - Transparent clocks
  - Synchronization accuracies better than 1 ns
  - Options for redundancy and fault tolerance
  - New management capabilities and options
  - Higher sampling rates compared to V1; asymmetry corrections
  - Optional unicast messaging (in addition to multicast)
  - PTP profiles

IEEE 1588 V2 New Features – 2

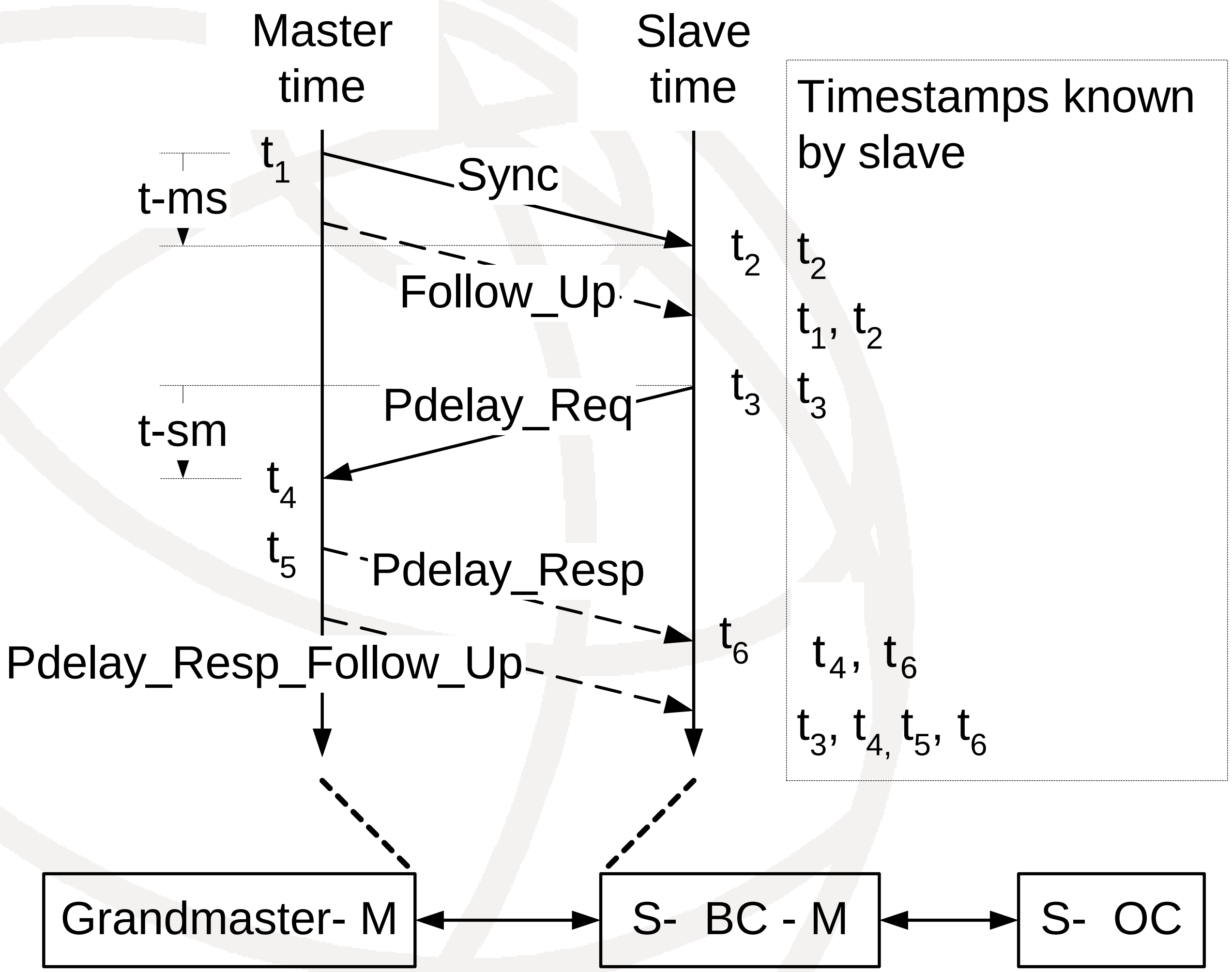
- IEEE 1588 V2 new features (cont.):
  - Conformance specifications
  - Configuration options
  - Security (experimental specification only
  - Means to accumulate cumulative frequency scale factor offset relative to grandmaster (experimental specification only)
- IEEE 1588 V2 contains a large number of features, not all of which are required
  - Each application may use only a subset of those features that are optional
  - The specification of the attribute values and optional features used is part of the PTP profile (The PTP profile included in IEEE 802.1AS is described in more detail later)

Synchronization using Peer Delay Mechanism – 1

- Focus on two-step ordinary and boundary clocks using peer delay, because these are used in 802.1AS
- Each slave synchronizes to its master using Sync, Follow_Up, Pdelay_Req, Pdelay_Resp, and Pdelay_Resp_Follow_Up messages exchanged between master and its slave



Synchronization using Peer Delay Mechanism – 2



Synchronization using Peer Delay Mechanism – 3

- Under the assumption that the link is symmetric (i.e., propagation time from master to slave = propagation time from slave to master)

  Offset = $t_2 - t_1$ – (propagation time) = (t-ms) – (propagation time)

  (propagation time) = $[(t_4 - t_3) + (t_6 - t_5)]/2$

- If the link is not symmetric
  - The propagation time computed as above is the mean of the master-to-slave and slave-to- master propagation times
  - The offset is in error by the difference between the actual master-to-slave and mean propagation times
    - The protocol includes the means to correct for the error if it is measured separately

Synchronization using Peer Delay Mechanism – 4

- The peer delay mechanism is limited to point- to-point links between two clocks
  - This is because the protocol does not provide for the clock that receives Pdelay_Req to keep track of which clock it receives the message from, and respond separately to each clock
  - This limitation is consistent with 802.1AS
    - Links between 802.1AS time-aware systems are logically point-to-point (need not be physically point-to-point)
- The mechanism operates separately and independently in both directions on a link

Overview of IEEE 802.1AS

- IEEE 802.1AS is the standard for transport of precise timing and synchronization in Audio/Video Bridging (AVB) networks
  - 802.1AS nodes are referred to as Time-Aware Systems
- IEEE 802.1AS is currently in sponsor ballot
  - Latest draft is P802.1AS/D7.0 [5]
  - As of the preparation of this presentation, the initial sponsor ballot has closed
  - Comment resolution is in progress, and will continue during the May 24 – 27, 2010 IEEE 802.1 AVB TG meeting
  - A recirculation is expected
  - Final approval expected later in 2010

Overview of IEEE 802.1AS

- IEEE 802.1AS is based on IEEE 1588 V2, and includes a PTP profile
  - Time-aware bridge acts as a boundary clock (but with peer-to-peer transparent clock formulation of synchronization)
  - Bridge participates in best master selection; this is driven by 3 reasons:
    - Fast reconfiguration to control phase transients when GM changes
    - Scalability (without best master selection at each bridge, larger timeout values needed for larger networks)
    - Data spanning tree determined by RSTP not necessarily optimal for synch
  - Time-aware end station acts as ordinary clock

PTP Profile Included in IEEE 802.1AS – 1

Profile Item	Specification
Best master clock algorithm (BMCA) option	Alternate BMCA (similar, but not identical, to 1588 clause 9)
Management mechanism	SNMP MIB
Path delay mechanism	Peer delay mechanism
802.1AS specifies default values; 802.1BA may specify additional ranges for each AVB profile	Sync interval: 1/8 s Announce interval: 1 s Pdelay interval: 1 s Announce receipt timeout: 2 announce intervals Sync receipt timeout: 3 sync intervals
Node types	Boundary clock (synchronization specified in manner similar to peer-to-peer transparent clock; BC and peer-to-peer TC synchronization can be shown to be mathematically equivalent, see [6]) Ordinary clock

PTP Profile Included in IEEE 802.1AS – 2

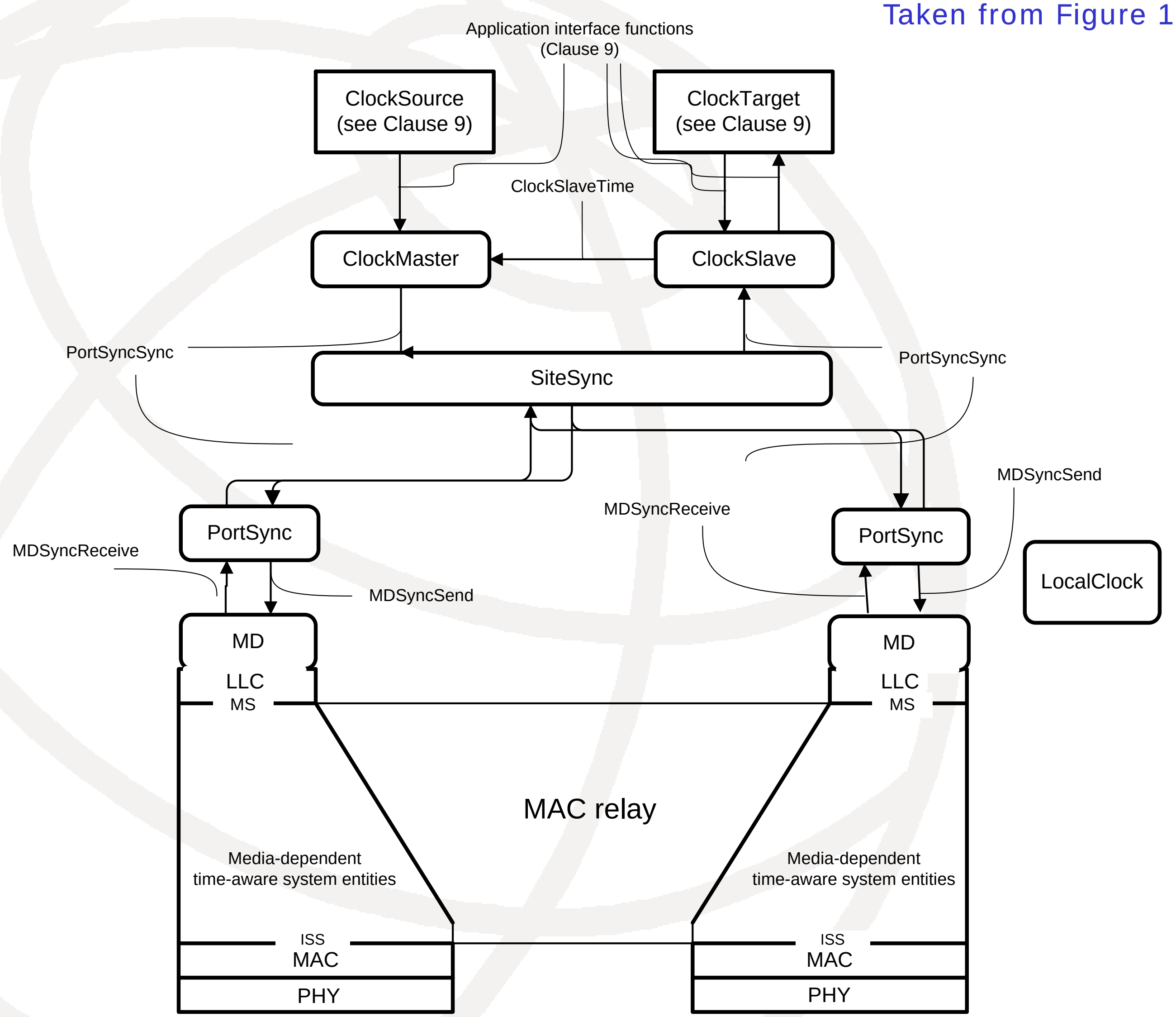
Profile Item	Specification
Transport mechanism	Full-duplex IEEE 802.3 Coordinated shared network (CSN, e.g., Multimedia over Coax Alliance (MoCA) specification, ITU-T G.hn) IEEE 802.3 Ethernet passive optical network (EPON); uses facilities of IEEE 802.3 multipoint control protocol (MPCP) (not part of PTP profile) 802.11 wireless; uses facilities of IEEE 802.11v [7] (not part of PTP profile)
Optional features	Bridges/end-station required to measure frequency offset to nearest neighbor (but not required to adjust frequency) Nearest-neighbor frequency offset is accumulated and used to correct propagation time and compute synchronized time Standard organization TLV is defined to carry cumulative frequency offset and additional information

PTP Profile Included in IEEE 802.1AS – 3

Profile Item	Specification
Optional features (cont.)	Standard organization TLV is defined for use in Signaling message, to allow a node to request its neighbor to adjust message rate if it is going in or out of low power mode (to be used to support power management/Energy Efficient Ethernet (EEE)) Path Trace feature, with associated TLV, is used and is mandatory Acceptable master table is used for IEEE 802.3 EPON links to ensure that optical line terminal (OLT) is master and optical network units (ONUs) are slaves; other optional features of IEEE1588 clauses 16 and 17 are not used Annex K security protocol is not used Annex L cumulative frequency scale factor is not used (but cumulative frequency offset is accumulated)

802.1AS Architecture and Entities

Taken from Figure 10-1 of [5]



Synchronization in IEEE 802.1AS – 1

- Every IEEE 802.3 port of a time-aware system runs peer delay mechanism
  - Measure propagation delay as specified in 11.4 of IEEE 1588
    - Responder provides requestReceiptTimestamp and responseOriginTimestamp separately
  - Requester uses successive Pdelay_Resp and Pdelay_Resp_Follow_Up messages to measure frequency offset of responder relative to requester
  - Frequency offset is used to correct propagation delay measurement (frequency offset multiplied by turnaround time)

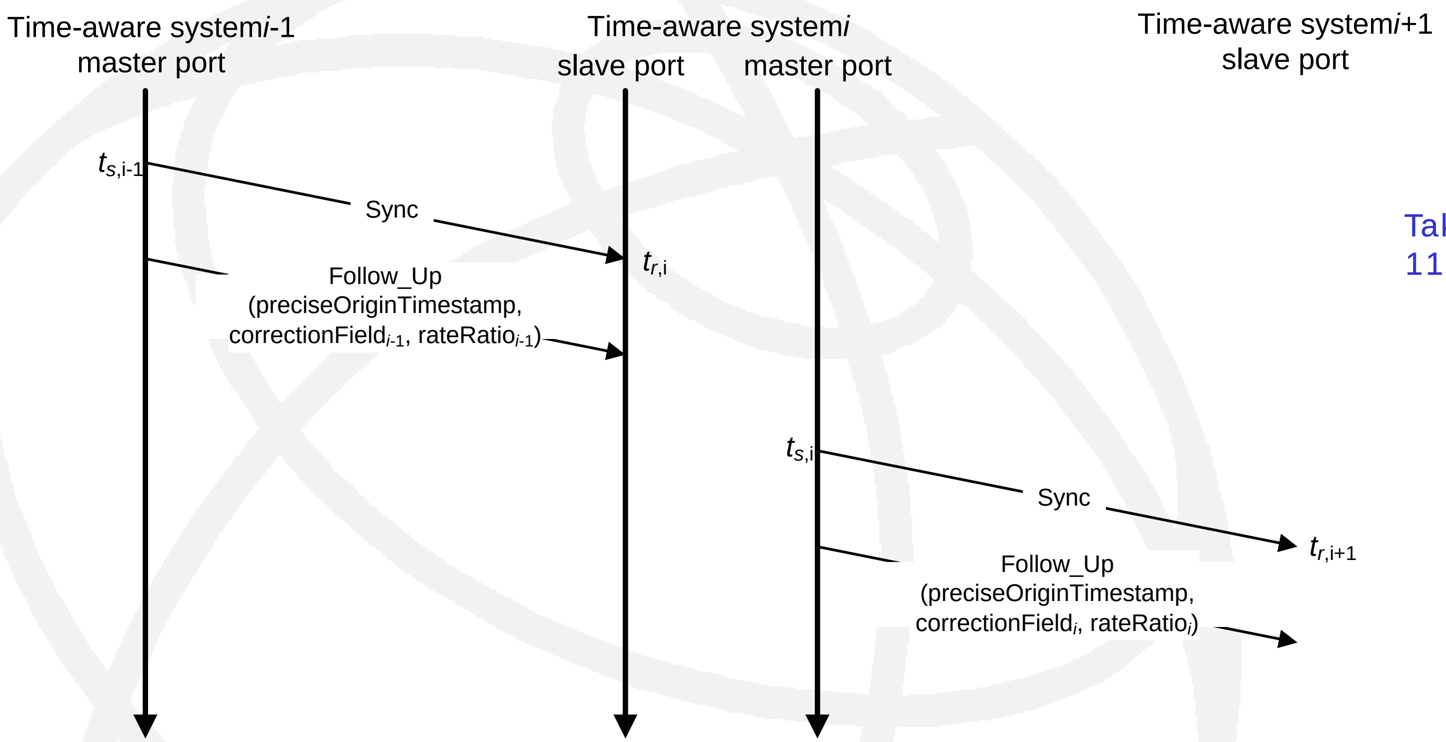
Synchronization in IEEE 802.1AS – 2

- Frequency offset is accumulated in standard organization TLV (1588 clause 14)
  - TLV is attached to Follow_Up
  - Frequency offset is initialized to zero at grandmaster
  - Accumulation allows each time-aware system to know its frequency offset relative to grandmaster
- The advantage of accumulating the frequency offset relative to the grandmaster, rather than measuring it directly using Sync and Follow_Up, is that it can be determined on receipt of first Follow_Up after a change of grandmaster

Synchronization in IEEE 802.1AS – 3

- Each time-aware system sends Sync and Follow_Up on its master ports
- Normally, send Sync and Follow_Up as soon as possible after receiving Sync and Follow_Up on slave port
  - However, don't send until at least one-half sync interval has elapsed since last sync was sent, to prevent bunching of successive messages
  - Also, send Sync and Follow_Up after a sync interval has elapsed since sending of last Sync, even if Sync and Follow_Up have not been received

Synchronization in IEEE 802.1AS – 4

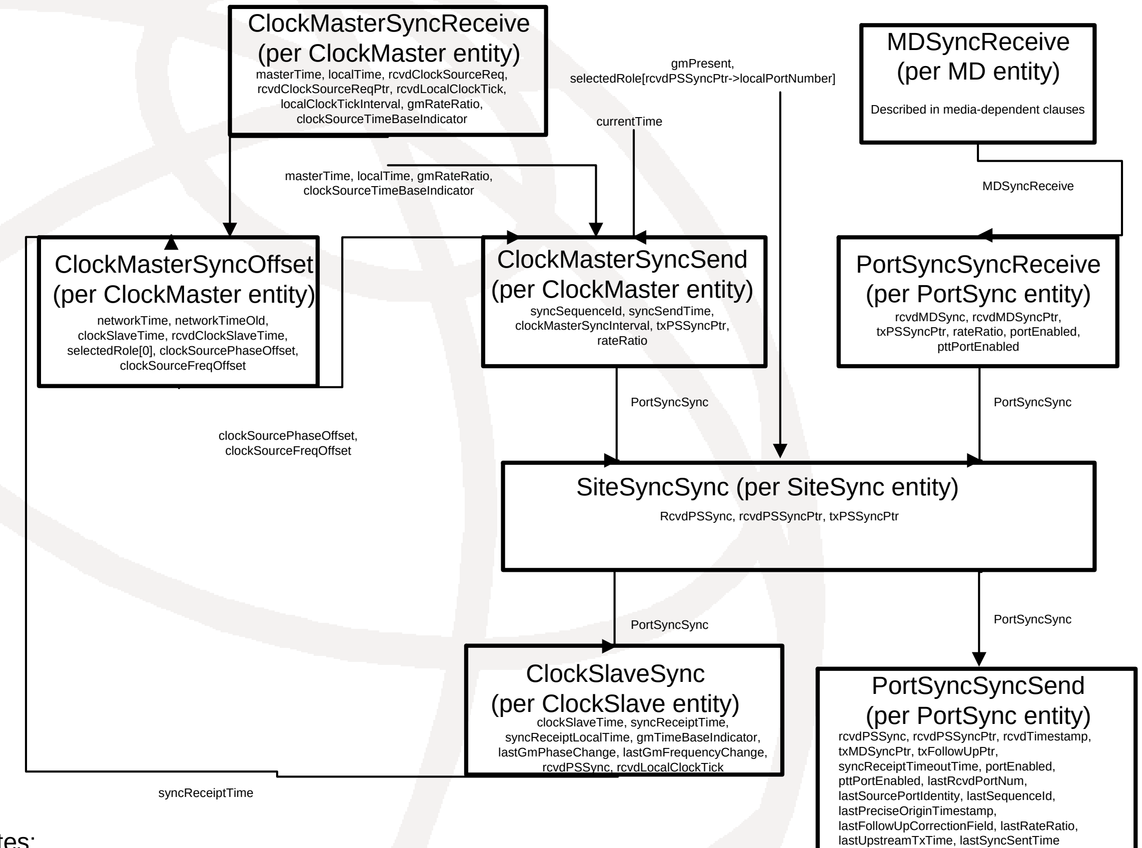


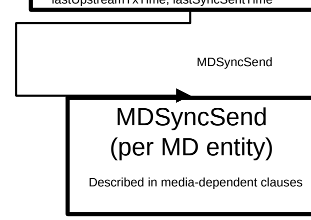
Taken from Figure 11-2 of [5]

- $\text{correctionField}_i = \text{correctionField}_{i-1} + \text{propDelay}_{i-1,i} + (t_{s,i} - t_{r,i})(1+y_{GM})$
  - y_{GM} = cumulative frequency offset of GM relative to time-aware system i

Synchronization State Machines

Taken from Figure 10-2 of [5]





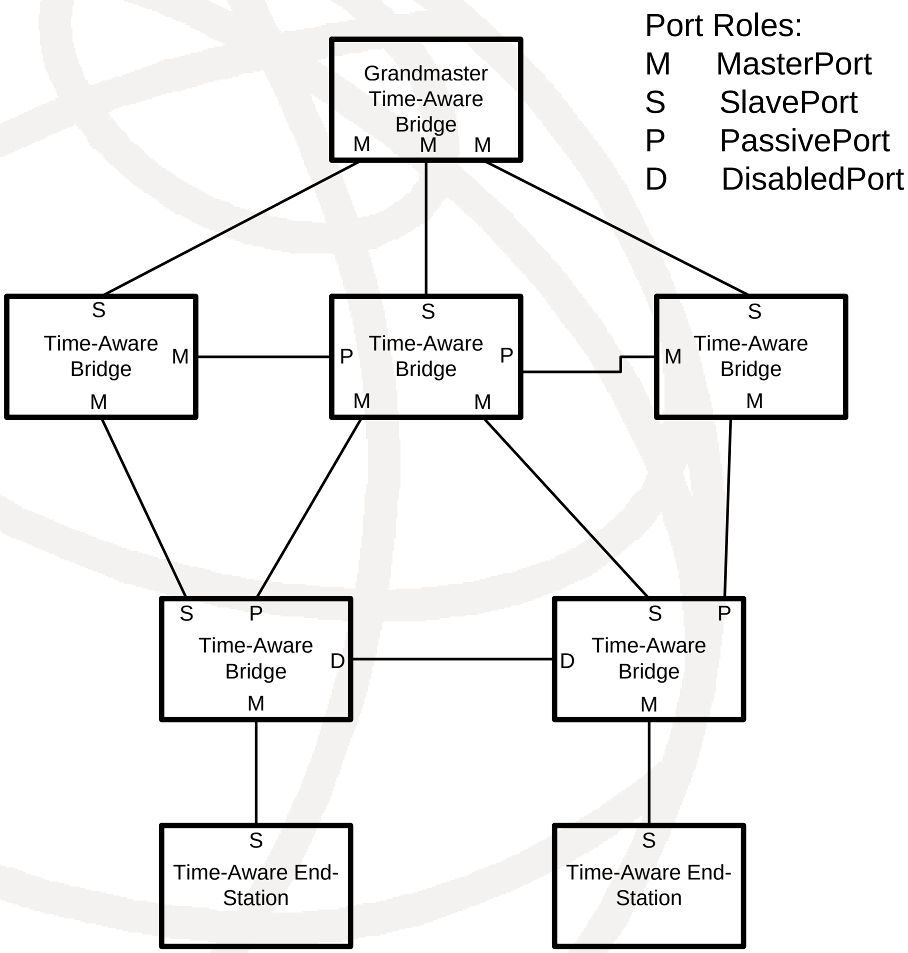
Notes:
a) selectedRole for each port and gmPresent are set by Port Role Selection state machine (see 10.3.12)
b) currentTime is a global variable that is always equal to the current time relative to the local oscillator
c) application interfaces to higher layers are not shown
d) the ClockMasterSyncReceive, ClockMasterSyncSend, and ClockMasterSyncOffset state machines are optional for time-aware systems that are not grandmaster-capable.

Best Master Selection in IEEE 802.1AS – 1

- IEEE 802.1AS uses a mechanism that is very similar to the default mechanism; there are 3 main differences
  - No qualification of Announce messages, and therefore no consideration of foreign masters
    - BMCA runs on receipt of an Announce message on any port attached to another time-aware system
    - This was done to speed up reconfiguration when the grandmaster changes
  - The pre-master state is eliminated; a port that is determined to be a master port immediately goes to the master state
  - The uncalibrated state is eliminated, because PLL filtering is not done in bridges

Best Master Selection in IEEE 802.1AS – 2

Taken from Figure 10-10 of [5]



Best Master Selection in IEEE 802.1AS – 3

- The BMCA is expressed using a subset of the Rapid Spanning Tree (RSTP) protocol formalism of IEEE 802.1D [8] and IEEE 802.1Q [9]
- This formulation is mathematically equivalent to the dataset comparison and state decision algorithms of IEEE 1588
  - Aspects of RSTP pertaining to updating the forwarding data base of a bridge are not needed for BMCA
- BMCA creates a spanning tree, with the GM at the root (unless no time-aware system is GM-capable (see below))
  - May or may not be the same as the data spanning tree created by RSTP

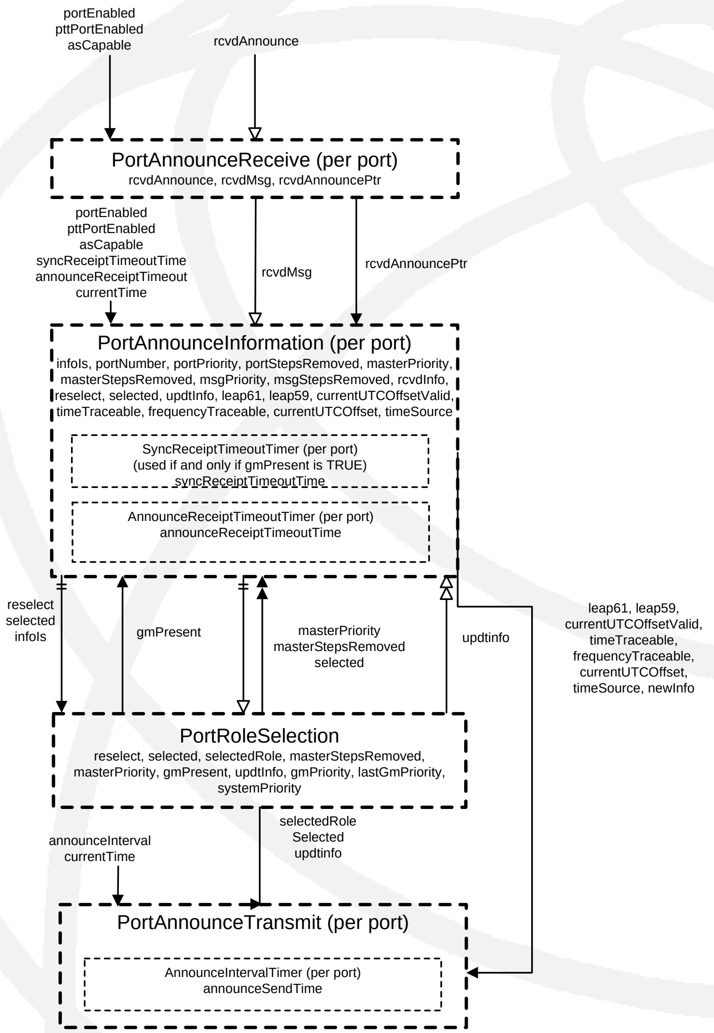
Best Master Selection in IEEE 802.1AS – 4

- The attributes priority1, clockClass, clockAccuracy, offsetScaledLogVariance, priority2, and clockIdentity are concatenated as unsigned integers into an overall attribute systemIdentity
- Part 1 of the dataset comparison algorithm is expressed as a comparison of systemIdentity attributes (smaller is better)
- The value 255 for priority1 is used to indicate that a time-aware system is not GM-capable
  - If no system is GM-capable, Sync is not sent by any system

Best Master Selection in IEEE 802.1AS – 5

- A spanning tree priority vector is defined, using the root systemIdentity, rootPathCost (number of hops from the root, i.e., 1588 stepsRemoved), sourcePortIdentity, and portNumber of receiving port
- Following IEEE 802.1D, 6 different, but related, priority vectors are defined
- These priority vectors are set and compared in 4 interacting state machines
  - The machines also set the ports to Master, Slave, or Passive
  - The operation of these state machines is equivalent to the dataset comparison and state decision algorithms (see [10] and [11])

Best Master Selection State Machines



Notation:
Variables are shown both within the machine where they are principally used and between machines where they are used to communicate information. In the latter case a variety of arrow styles, running from one machine to another, show how each is typically used:

- Not changed by the target machine. Where the mcahines are both per Port, this variable communicates between instances for the same port
- Set (or cleared) by the originating machine, cleared (or set) by the target machine. Where the machines are both per Port, this communicates between instances for the same port.
- As above, except that the originating per port machine instance communicates with multiple port machine instances (by setting or clearing variables owned by those ports).
- As above, except that multiple per Port instances communicate with (an)other instance(s) (by setting or clearing variables owned by the originating ports).

Taken from Figure 10-11 of [5]

Summary

- IEEE 802.1AS is compatible with IEEE Std 1588™ – 2008, in that it includes a PTP profile
  - The specific profile requirements were chosen to achieve low cost and still meet application requirements
- Support is added for IEEE 802.11, IEEE 802.3 EPON, and coordinated shared network (e.g., MoCA, ITU-T G.hn)

References – 1

1. Geoffrey M. Garner, *IEEE 1588 Version 2*, Tutorial presented at ISPCS '08, Ann Arbor, MI, USA, September 24, 2008.
2. Geoffrey M. Garner, Aaron Gelter, and Michael D. Johas Teener, *New Simulation and Test Results for IEEE 802.1AS Timing Performance*, ISPCS '09, Brescia, Italy, October 14 – 16, 2009.
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7. IEEE Std P802.11v™/D10.0, *Draft Standard for Information technology -Telecommunications and information exchange between systems - Local and metropolitan area networks-Specific requirements - Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications, Amendment 8: IEEE 802.11 Wireless Network Management, March, 2010.*
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