16. Media-dependent layer specification for CSN

16.1 Overview

Accurate synchronized time is distributed throughout a gPTP domain through time measurements between adjacent PTP Relay Instances or PTP End Instrances in a packet network. Time is communicated from the root of the clock spanning tree (i.e., the Grandmaster PTP Instance) toward the leaves of the tree (i.e., from leaf-facing "master" ports to root-facing "slave" ports) through measurements made across the links connecting the PTP Instances. While the semantics of time transfer are consistent across the time-aware packet network, the method for communicating synchronized time from a master port to its immediate downstream link partner varies depending on the type of link interconnecting the two PTP Instances.

This clause specifies the protocol that provides accurate synchronized time across links of a *coordinated shared network* (CSN) as part of a packet network.

16.2 Coordinated Shared Network characteristics

A CSN is a contention-free, time-division, multiplexed-access network of devices sharing a common medium and supporting reserved bandwidth based on priority or flow (QoS). One of the nodes of the CSN acts as the network coordinator, granting transmission opportunities to the otherCSN nodes of the network. A CSN physically is a shared medium, in that a CSN node has a single physical port connected to the half-duplex medium, but is logically a fully connected one-hop mesh network, in that everyCSN node can transmit frames to every other CSN node over the shared medium.

A CSN supports two types of transmission: unicast transmission for point-to-point (CSN node-to-node) transmission and multicast/broadcast transmission for point-to-multipoint (CSN node-to-other/all-nodes) transmission. Figure 16-1 illustrates a CSN acting as a backbone for PTP Instances.

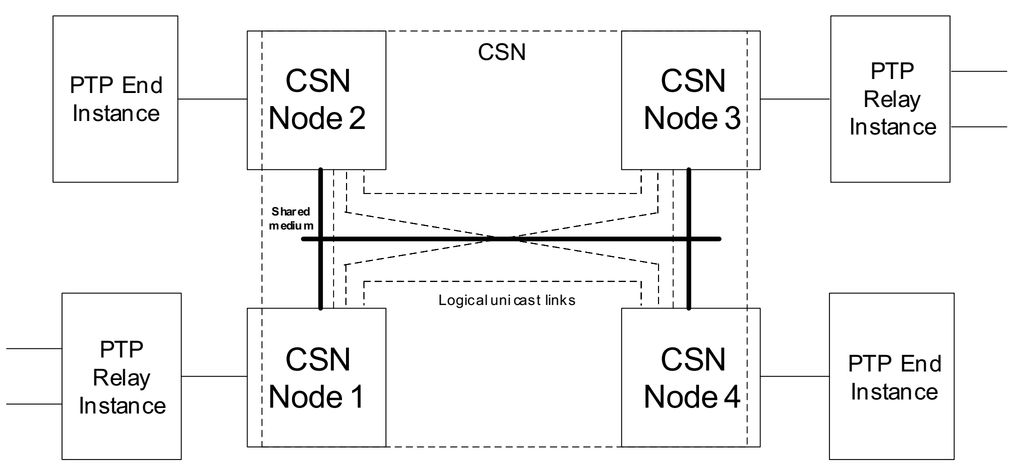

Figure 16-1—Example of CSN backbone in a TSN LAN

NOTE—In this clause, the term *node* is used to refer to a CSN node (i.e., it does not refer to a PTP Relay Instance or PTP End Instance). A CSN node is a 2-port PTP Relay Instance that forwards data packets between a segment external to the CSN (which can connect to an upstream or downstream PTP Instance) and the CSN, all at the data link layer. Nonetheless, to avoid confusion the term *node* is usually preceded by *CSN*, except when it is obvious that CSN nodes are being referenced.

16.3 Layering for CSN links

One PortSync entity and one MD entity are together associated with each CSN logical port (CSN node-to-node link) as illustrated in Figure 16-2. The PortSync entities is described in 10.1.2. The MD entity translates media-independent primitives to MD primitives as necessary for communicating synchronized time over the CSN links. The CSN MD entity shall implement the MDSyncSendSM and MDSyncReceiveSM states machines of 11.2.14 and 11.2.15.

The CSN MD entity either implements the MDPdelayReq and MDPdelayResp state machines of 11.2.19 and 11.2.20 to measure the propagation delay on a CSN link, or measures it through a CSN-native method and populates the variables described in 16.4.3.3.

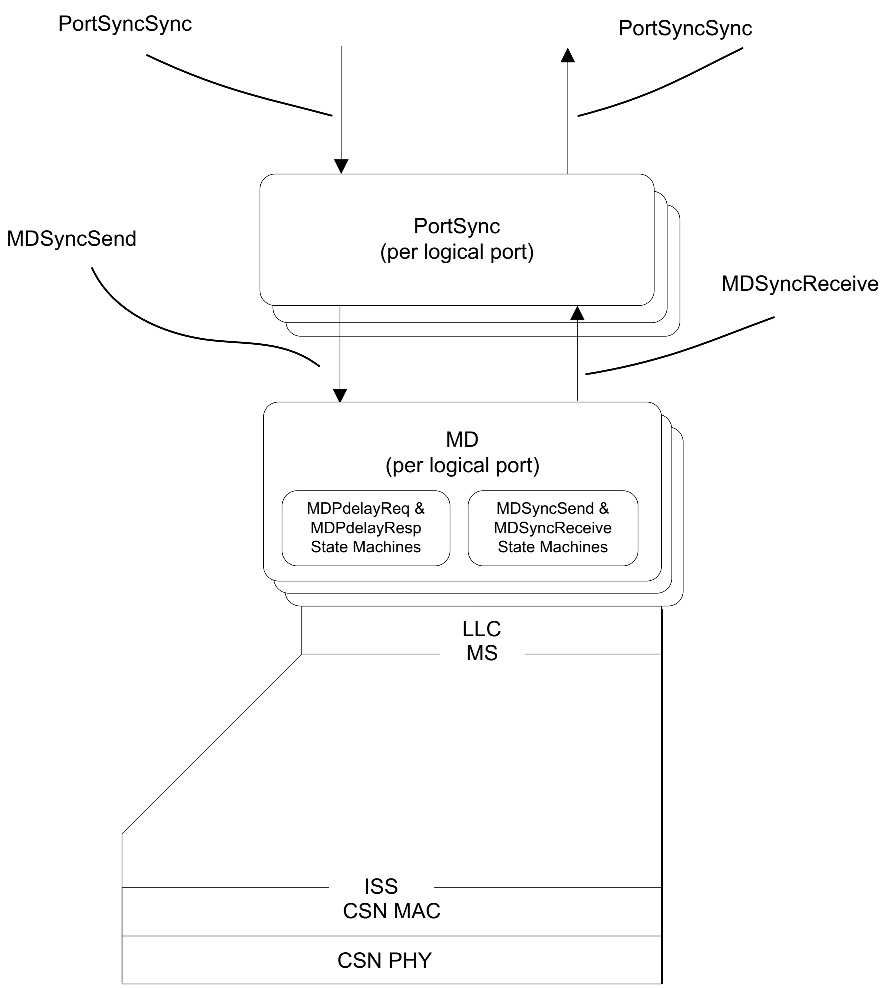

Figure 16-2—Media-dependent and lower entities in CSN nodes

16.4 Path delay measurement over a CSN backbone

16.4.1 General

The Path Delay over a CSN backbone is calculated for the following path types:

a) Between the upstream PTP Relay Instance and the ingress CSN node
b) Between the ingress and egress CSN nodes
c) Between the egress CSN node and the downstream PTP Instance (PTP Relay Instance or PTP End Instance)

To maintain the synchronization, residence time on each PTP Instance and the propagation delay between PTP Instances is measured, requiring precise timestamping on both CSN node ingress and egress ports as illustrated in Figure 16-4 (the numbered paths in Figure 16-4 refer to the numbered paths in Figure 16-3). In Figure 16-4, ti_1 is the syncEventEgressTimestamp for the Sync message at the upstream PTP Relay Instance, ti_2 is the syncEventIngressTimestamp for the Sync message at the ingress CSN time-aware node, te_1 is the syncEventEgressTimestamp for the Sync message at the egress CSN time-aware node, and te_2 is the syncEventIngressTimestamp for the Sync message at the downstream PTP Relay Instance or PTP End Instance.

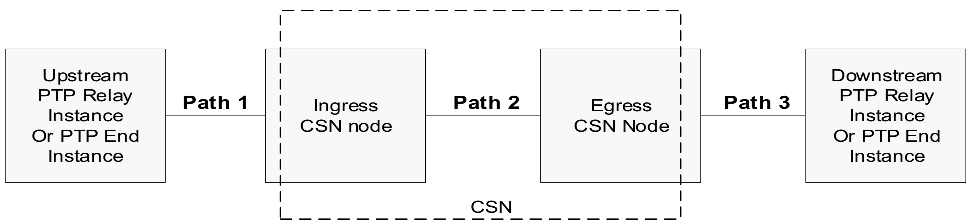

Figure 16-3—Path types over CSN as IEEE 802.1AS backbone

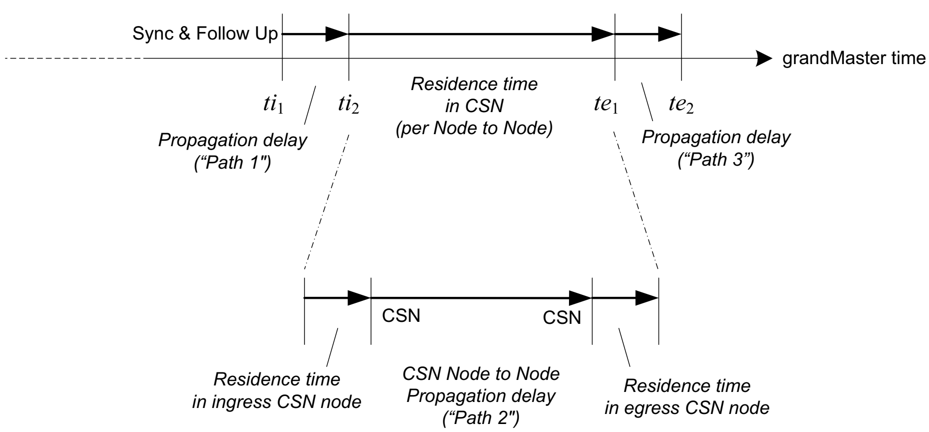

Figure 16-4—Propagation delay and residence time over a CSN backbone

16.4.2 Path delay measurement between CSN node and neighbor PTP Instance

The path delay measurement between a CSN node and a neighbor PTP Instance is made as specified for the respective medium. This path delay measurement is made for the link between the CSN node and the neighbor PTP Instance.

16.4.3 Path delay measurement between CSN nodes

16.4.3.1 General

The path delay between the two nodes of a CSN is the propagation delay for the logical link that connects those two nodes. The method of measuring the path delay between two CSN nodes has two variations, which are described in 16.4.3.2 and 16.4.3.3. The specific method to be used for a specific link technology is specified in 16.6.

16.4.3.2 Path delay measurement without network clock reference

Each CSN node has a free-running local clock. The path delay measurement uses the peer-to-peer delay mechanism protocol, messages, and state machines described in Clause 11 for full-duplex point-to-point links, as illustrated by Figure 16-5. The criteria of 11.2.17 for determining whether the peer-to-peer delay mechanism is instance specific or is provided by CMLDS apply here.

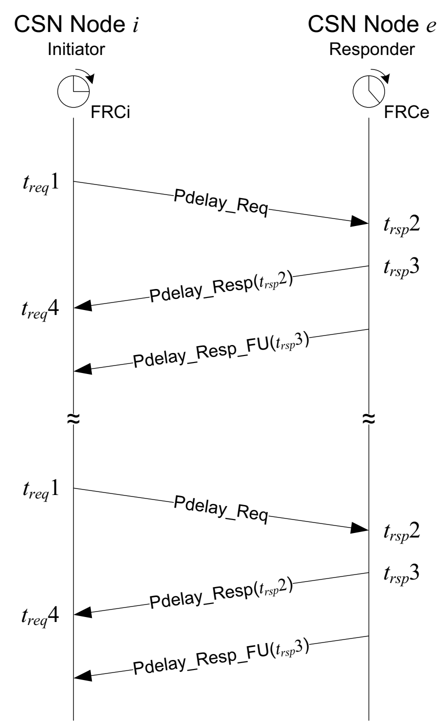

Figure 16-5—CSN node-to-node path delay measurement

The computation of the neighborRateRatio and meanLinkDelay between two CSN nodes is done using the timestamps at the initiator and information conveyed in the successive Pdelay_Resp and Pdelay_Resp_Follow_Up messages. Any scheme that uses this information is acceptable, as long as the performance requirements of B.2.4 are met. As one example, the neighborRateRatio is computed as the ratio between a time interval measured by the local clock of the responder and its associated time interval measured by the local clock of the initiator, using a set of received Pdelay_Resp and Pdelay_Resp_Follow_Up messages and a second set of received Pdelay_Resp and Pdelay_Resp_Follow_Up messages some number of Pdelay_Req message transmission intervals later, i.e., as show in Equation (16-1).

$$\frac{(t_{rsp}3)_N - (t_{rsp}3)_0}{(t_{req}4)_N - (t_{req}4)_0} \qquad (16\text{-}1)$$

where

$(t_{rsp}3)_k$ is the time relative to the local clock of the responder that the k^{th} Pdelay_Resp message is sent
$(t_{req}4)_k$ is the time relative to the local clock of the initiator that the k^{th} Pdelay_Resp message is received
N is the number of Pdelay_Req message transmission intervals separating the first set of received Pdelay_Resp and Pdelay_Resp_Follow_Up messages and the second set

The successive sets of received Pdelay_Resp and Pdelay_Resp_Follow_Up messages are indexed from 0 to N with the first set indexed 0. The meanLinkDelay between the PTP Instance and the CSN node is computed as shown in Equation (16-2).

$$\frac{(t_{req}4 - t_{req}1)r - (t_{rsp}3 - t_{rsp}2)}{2} \qquad (16\text{-}2)$$

where

r is equal to neighborRateRatio
$t_{req}1$ is the time relative to the local clock of the initiator that the Pdelay_Req message for this message exchange is sent
$t_{rsp}2$ is the time relative to the local clock of the responder that the Pdelay_Req message for this message exchange is received
$t_{rsp}3$ is the time relative to the local clock of the responder that the Pdelay_Resp message for this message exchange is sent
$t_{req}4$ is the time relative to the local clock of the initiator that the Pdelay_Resp message for this message exchange is received

NOTE—The difference between mean propagation delay relative to the Grandmaster Clock time base and relative to the time base of the CSN node at the other end of the attached link (i.e., the responder CSN node) is usually negligible. To see this, note that the former can be obtained from the latter by multiplying the latter by the ratio of the Grandmaster Clock frequency to the frequency of the LocalClock entity of the CSN node at the other end of the link. This ratio differs from 1 by 200 ppm or less. For example, for a worst-case frequency offset of the LocalClock entity of the CSN node at the other end of the link, relative to the Grandmaster Clock, of 200 ppm, and a measured propagation time of 100 ns, the difference in mean propagation delay relative to the two time bases is 20 ps.

Although the propagation delay between two CSN nodes is constant, a Pdelay_Req message is still sent periodically by each CSN node to each other active CSN node to measure the neighborRateRatio between the node and each other node. Each CSN node shall implement the state machines described in 11.2.19 and 11.2.20.

16.4.3.3 Native CSN path delay measurement

Some CSN technologies feature a native mechanism that provides a path delay measurement with accuracy similar to the accuracy the peer delay protocol provides. For these CSNs, the path delay can be provided using the native measurement method rather than using the Pdelay protocol defined in 11.2.19 and 11.2.20. Such a situation is described in more detail as follows. The CSN MD entity populates the following per-PTP Port and MD-entity global variables (described respectively in 10.2.5 and 11.2.13) as indicated:

— asCapable (10.2.5.1) is set to TRUE.
— neighborRateRatio (10.2.5.7) is set to the value provided by the native CSN measurement.
— meanLinkDelay (10.2.5.8) is set to the value provided by the native CSN measurement.
— computeNeighborRateRatio (10.2.5.10) is set to FALSE.

— computeMeanLinkDelay (10.2.5.11) is set to FALSE.
— isMeasuringDelay (11.2.13.6) is set to TRUE to indicate that the CSN MD entity is measuring path delay (in this case, using its internal mechanism).
— domainNumber (8.1) is set to the domain number of this gPTP domain.

16.4.3.4 Intrinsic CSN path delay measurement

If the CSN features a native mechanism that causes each CSN node's local clock to be fully synchronized to the local clocks of other nodes of the CSN such that the synchronized CSN time complies with the requirements specified in B.1, the CSN nodes need not implement the path delay mechanism but rather can treat the path delay as part of the residence time of the distributed system. The propagation of the Sync messages in this case is described in 16.5.3.

16.5 Synchronization messages

16.5.1 General

The CSN shall propagate synchronized time over the CSN to CSN end stations and to downstream non-CSN links, using Sync (and, if the message is two-step, the associated Follow_Up) messages, as illustrated in Figure 16-6.

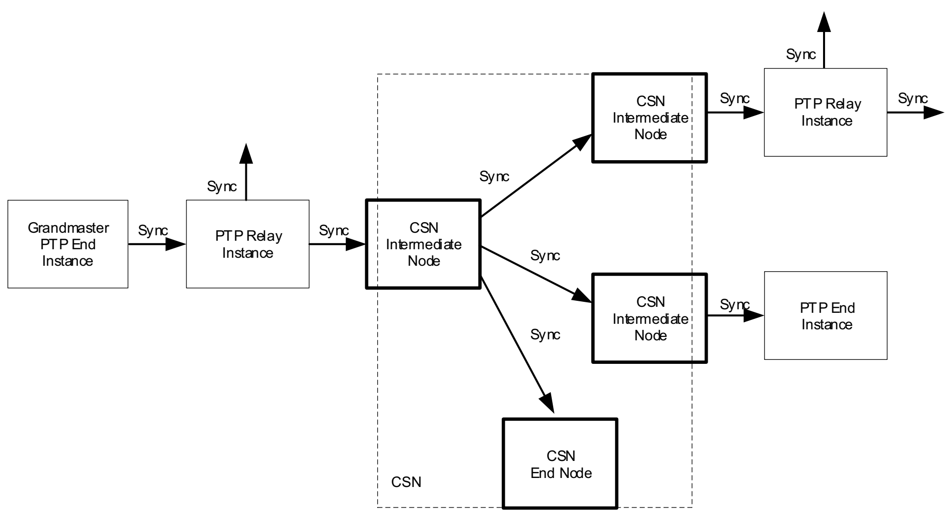

Figure 16-6—IEEE 802.1AS Sync message propagation over the CSN backbone

Once the path delays have been measured (a) between the upstream PTP Relay Instance or PTP End Instance and the ingress CSN node, (b) between the CSN nodes, and (c) between the egress CSN node and the downstream PTP Relay Instance or PTP End Instance, the CSN backbone can propagate the synchronization information received at its boundary nodes.

As with path delay measurements, various CSN technologies choose various methods for propagating time. These methods are described in 16.5.2 and 16.5.3.

16.5.2 Synchronization message propagation on CSN without network reference clock

If the CSN does not feature a native mechanism that synchronizes the CSN node local clocks to each other or to a reference (i.e., to synchronize the CSN time in compliance with the requirements specified in B.1), the CSN local clocks at CSN ingress and CSN egress nodes are considered independent, free-running clocks.

In this case, synchronization over the CSN links uses the Sync and Follow_Up protocol (or only Sync if optional one-step processing is used), messages, and state machines specified for full-duplex point-to-point links in 10.2.8, 10.2.12, 11.2.14, and 11.2.15. Individual CSN link technologies may specify media-specific encapsulation of gPTP event messages. See Table 16-2 for selection of options per link technology.

One PortSync and one MD entity is instantiated per logical port (i.e., per CSN link). A CSN node behaves equivalently to a PTP Instance. Sync and, in the two-step case, Follow_Up messages are either transmitted using unicast on each link or broadcasted. However, if Sync and Follow_Up messages are broadcasted, the following apply:

- The Sync and Follow_Up messages are broadcast with the same port number used to broadcast Announce messages.
- All PortSync/MD entity pairs except one set their logSyncInterval attribute (see 10.7.2.3) to 127 so that they do not generate any Sync messages.
- A dynamic selection of the MD entity that broadcasts the Sync message is needed (a CSN node can dynamically leave the CSN). The dynamic selection algorithm is implementation specific and out of the scope of this standard.

16.5.3 Synchronization message propagation on a CSN with network reference clock

16.5.3.1 General

If the CSN features a native mechanism that allows the CSN node's local clocks to be fully synchronized to each other in a way that complies with the requirements specified in B.1, it is possible to simplify the path delay mechanism, as described below. This method is an alternative to 16.5.2. Individual CSN link technologies may specify media-specific encapsulation of gPTP event messages. See Table 16-2 (in 16.6.1) for selection of options per link technology.

Sync messages are timestamped when they are:

- Received at the ingress CSN node's PTP Port (syncEventIngressTimestamp) and
- Transmitted at the egress CSN node's PTP Port (syncEventEgressTimestamp).

The elapsed time between the egress and ingress timestamps is computed as the CSN residence time. In this scheme, the Sync message handling is split between the MDSyncSendSM state machine in the CSN ingress node and the MDSyncReceiveSM state machine in the CSN egress node as described in 16.5.3.2 and 16.5.3.3.

The reference plane for a CSN port and the path delay measurement method are specific to the type of CSN technology, and are defined in Table 16-2.

16.5.3.2 CSN ingress node

16.5.3.2.1 General

The CSN ingress node timestamps Sync messages received from the upstream PTP Instance and compute the upstreamTxTime as described in item f) of 11.2.14.2.1.

In addition, the setFollowUp function of the MDSyncSendSM state machine [see item a) in 11.2.15.2.3] is modified as follows:

a) The quantity *rateRatio* × *(syncEventEgressTimestamp – upstreamTxTime)* is not added to the followUpCorrectionField of the Follow_Up message (or the Sync message in the one-step case) to be transmitted by the ingress to the egress CSN node
b) The CSN TLV (see 16.5.3.2.2) is appended to the Follow_Up message (or to the Sync message in the one-step case) transmitted by the ingress to the egress CSN node.

16.5.3.2.2 CSN TLV

16.5.3.2.2.1 General

The fields of the CSN TLV are specified in Table 16-1 and 16.5.3.2.2.2 through 16.5.3.2.2.10. This TLV is a standard organization extension TLV for the Follow_Up message (or the Sync message in the one-step case), as specified in 14.3 of IEEE Std 1588-2019. This TLV is not allowed to occur before the Follow_Up information TLV (see 11.4.4.3).

Table 16-1—CSN TLV

Bits (7 6 5 4 3 2 1 0)	Octets	Offset from start of TLV
tlvType	2	0
lengthField	2	2
organizationId	3	4
organizationSubType	3	7
rxTime	12	10
neighborRateRatio	4	14
meanLinkDelay	12	26
delayAsymmetry	12	38
domainNumber	1	50

16.5.3.2.2.2 tlvType (Enumeration16)

The value of the tlvType field is 0x3.

NOTE—This value indicates the TLV is a vendor and standard organization extension TLV, as specified in 14.3.2.1 and Table 50 of IEEE Std 1588-2019. The tlvType is specified in that standard as ORGANIZATION_EXTENSION with a value of 0x3.

16.5.3.2.2.3 lengthField (UInteger16)

The value of the length is 46.

16.5.3.2.2.4 organizationId (Octet3)

The value of organizationId is 00-80-C2.

16.5.3.2.2.5 organizationSubType (Enumeration24)

The value of organizationSubType is 3.

16.5.3.2.2.6 upstreamTxTime (UScaledNs)

The computed upstreamTxTime value is described in item f) of 11.2.14.2.1.

16.5.3.2.2.7 neighborRateRatio (Integer32)

The neighborRateRatio value is described in 10.2.5.7.

16.5.3.2.2.8 meanLinkDelay (UScaledNs)

The meanLinkDelay value is described in 10.2.5.8.

16.5.3.2.2.9 delayAsymmetry (ScaledNs)

The delayAsymmetry value is described in 10.2.5.9.

16.5.3.2.2.10 domainNumber (UInteger8)

This parameter is the domain number of this gPTP domain.

16.5.3.3 CSN egress node

The CSN egress port sets neighborRateRatio to 1 and meanLinkDelay to 0 for its CSN port.

The CSN egress port modifies the function setMDSyncReceive of the MDSyncReceiveSM state machine [item f) in 11.2.14.2.1] for the port attached to the CSN link entity to extract upstreamTxTime, meanLinkDelay, and neighborRateRatio from the respective fields of the CSN TLV in the Follow_Up message (or Sync message in the one-step case) received from the CSN ingress node.

The CSN egress port also modifies the ClockSlaveSync state machine (see 10.2.13) to get the upstreamTxTime, meanLinkDelay, neighborRateRatio, and delayAsymmetry values from the respective fields of the CSN TLV in the Follow_Up message (or Sync message in the one-step case) received from the CSN ingress node.

The CSN egress node removes the CSN TLV from the Follow_Up message (or Sync message in the one-step case) received from the CSN ingress node and transmits the message to the downstream PTP Instance.

16.6 Specific CSN requirements

16.6.1 General

The reference plane for a CSN port is specific to the type of CSN technology and is defined in Table 16-2.

Table 16-2—Definitions and option selections per link technology

CSN link technology	Reference plane	Path Delay measurement	gPTP event message encapsulation
Multimedia over Coax Alliance (MoCA) v2.0	The first bit of an Event message crossing to and from the MoCA CTC domain.	MoCA Ranging Protocol (method of either 16.4.3.3 or 16.4.3.4)	Encapsulated in control frames as described in the MoCA MAC/PHY Specification v2.0.
ITU-T G.hn (SG15)	The first bit of an Event message crossing the A-interface (see 16.6.3).	peer-to-peer mechanism as defined in 16.4.3.2.	None

16.6.2 MoCA-specific behavior

The MoCA network is a CSN. The non-MoCA port of a CSN time-aware node behaves as a PTP Port, which might or might not use the MoCA channel time clock (CTC) for timestamping event messages. If the non-MoCA port of the CSN time-aware node uses a different clock than the MoCA CTC, then the CSN time-aware node reconciles the non-CTC timestamp with the CTC time.

Sync messages shall be timestamped using the CTC when they cross:

— The MoCA ingress node's timestamp reference plane (syncEventIngressTimestamp) and
— The egress CSN node's reference plane (syncEventEgressTimestamp).

The elapsed time between the egress and ingress timestamps, syncEventIngressTimestamp − syncEventIngressTimestamp, is computed as the MoCA residence time.

The MoCA port whose PTP Port state is MasterPort propagates the Sync and Follow_Up messages (or only the Sync message in the one-step case) as described in 16.5.3. The CSN TLV values of the Follow_Up message sent over the MoCA network are computed using the LocalClock, i.e., the MoCA CTC.

IEEE 802.1AS frames shall be transmitted over the MoCA network as MoCA control frames as described in the MoCA MAC/PHY Specification v2.0.

NOTE—The CTC is specified in the MoCA MAC/PHY Specification v2.0.

16.6.3 ITU-T G.hn-specific behavior

A port of a PTP Instance that includes one or more ITU-T G.hn ports shall behave as defined in 16.3, 16.4, and 16.5; however, for aspects where more than one behavior or option is described, the system behaves as defined in Table 16-2.

ITU-T G.hn defines a 32-bit timestamp (which is placed in the TSMP field of a G.hn encapsulation header). This timestamp, as described in Table 16-2, is captured each time an Event message is transmitted or received by an ITU-T G.hn port and is used for all gPTP event messages, including SYNC and PDELAY messages.

16.7 Grandmaster PTP Instance capability

Each CSN Node may be grandmaster capable to allow a CSN node to act as the Grandmaster PTP Instance either for a homogeneous CSN or for a heterogeneous network.

The Announce messages are either sent via unicast on each link or broadcasted. However, if Announce messages are broadcasted, the Announce message shall use the same port number as used by the Sync and Follow_Up messages (or only the Sync message in the one-step case) by a single PortSync/MD entity pair on the PTP Port. This is accomplished by setting the logAnnounceInterval attribute (see 10.7.2.2) to 127 for all but one PortSync/MD entity pair so that they do not generate any Announce messages.

16.8 CSN clock and node performance requirements

The CSN clock performance complies with the requirements specified in B.1. The CSN node performance complies with the requirements specified in B.2.4 and should follow the recommendations of B.2.2 and B.2.3.