

## Informative Appendix to the IEEE 802.1as/D4.0 Specifications

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### Media-dependent layer specification for CSN Network

#### 1 Overview

Accurate time is distributed throughout an 802.1AS domain through time measurements between adjacent time-aware bridges or stations in a bridged local area network. Time is communicated from the root of the clock spanning tree (i.e. the grand master, assuming the root is grandmaster-capable) toward the leaves of the tree (i.e. through a leaf-facing 'master' port to some number of root-facing 'slave' ports) and across links between master and slave link partners through measurements. While the semantics of time transfer are consistent across the time-aware bridged LAN, the method for communicating time from a master station to its immediate downstream link partner varies depending on the type of link interconnecting the two time-aware systems.

This appendix specifies the protocol that provides accurate clock synchronization across the links of a Coordinated Shared Network (CSN) that are part of a bridged LAN.

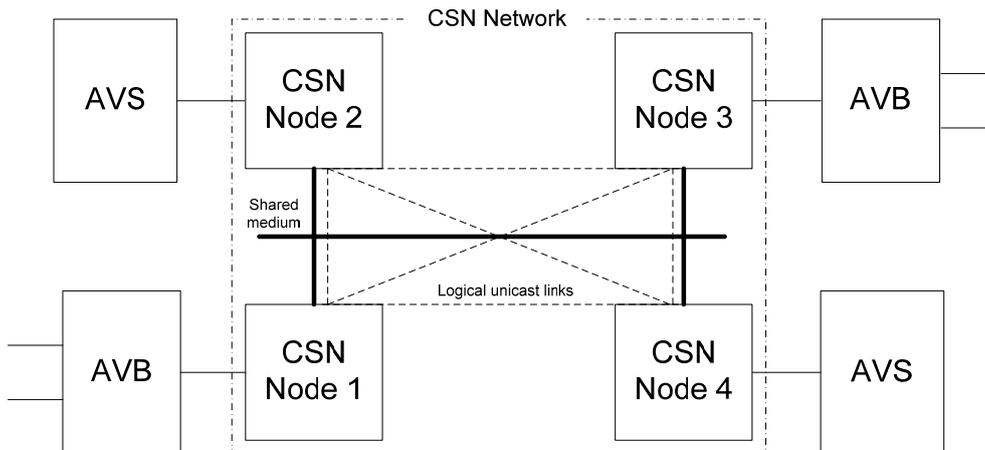
#### 2 Coordinated Shared Network Characteristics

A Coordinated Shared Network (CSN) is a contention-free, QoS-able, time-division multiplexed-access, network. One of the nodes of the network acts as the network coordinator node, granting transmission opportunities to the other nodes of the network.

CSNs support two types of transmission: unicast transmission for point-to-point (node-to-node) transmission and broadcast transmission for point-to-multipoint (node-to-all-other-nodes) transmission. Each node-to-node link has its own bandwidth characteristics, which could change over time as a result of the periodic ranging of the link. The broadcast transmission characteristics are the lowest common characteristics of all the links of the network.

A CSN network is physically a shared network, in that a CSN node has a single physical port connected to the half-duplex medium, but is also a logically fully-connected mesh network, in that every node could transmit to every other node using its own profile over the shared medium.

Figure 1 illustrates a CSN network acting as a backbone for 802.3 time-aware systems.

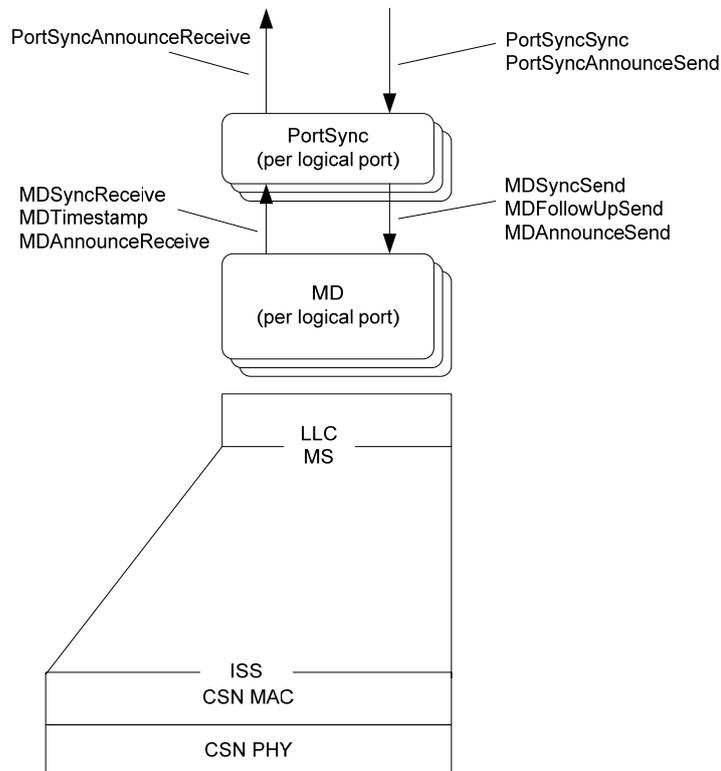


**Figure 1: Example of CSN Backbone in an AVB LAN**

### 3 Layering for CSN links

A PortSync entity and an MD entity are associated with each CSN logical port (node-to-node link) as illustrated in

Figure 2. The MD entity is the same MD entity described in Clause 11. It translates media-independent primitives to media-dependent primitives as necessary for communicating time over the CSN links.



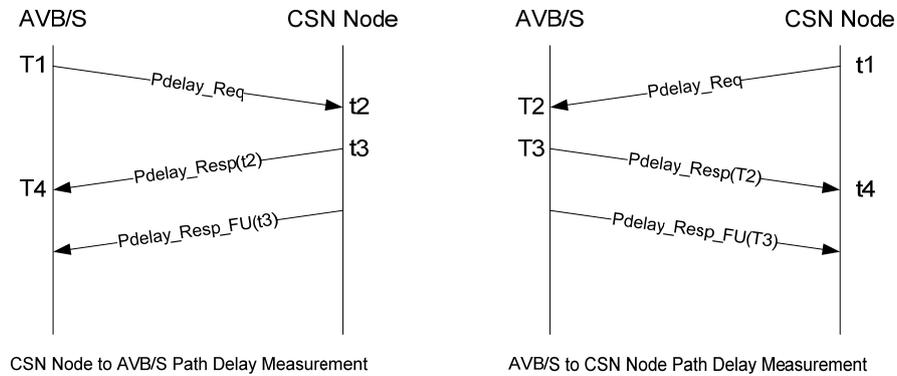
**Figure 2: MAC dependent and lower entities in CSN nodes**

## 4 Path Delay Calculation over a CSN Backbone

### 4.1 Path Delay Calculation at the CSN Boundaries

At the boundaries of the CSN, a CSN node contains a full-duplex 802.3 port. Therefore the path delay calculation between a time-aware bridge or end-station and a CSN node uses the protocol, messages, and state machine described in 11.2.11 and 11.2.12 for full-duplex 802.3 point-to-point links.

The CSN node both terminates Pdelay requests sent by the time-aware bridge or end-station and generates Pdelay requests to the time-aware bridge or end-station to measure the path delays between the time-aware bridge or end-station and the CSN node, as illustrated in Figure 3.



**Figure 3: Path Delay Measurements at the CSN Boundaries**

The computation of the neighborRateRatio and the mean propagation delay between the time-aware bridge or end-station and the CSN node are described in 11.2.11.2.3 and 11.2.11.2.4, respectively:

For the time-aware bridge or end-station, the neighborRateRatio is computed as the ratio of

$$(t3 - previous\_t3) / (T4 - previous\_T4)$$

and the mean-propagation delay from the AVB/S to the CSN node is computed as

$$((T4 - T1) - (t3 - t2) * neighborRateRatio) / 2$$

Similarly for the CSN node, the neighborRateRatio is computed as the ratio of

$$(T3 - previous\_T3) / (t4 - previous\_t4)$$

and the mean-propagation delay from the CSN node to the AVB/S is computed as

$$((t4 - t1) - (T3 - T2) * neighborRateRatio) / 2$$

### 4.2 Path Delay Calculation between CSN Nodes

The path delay between the nodes of the CSN is the propagation delay for each node to node logical link.

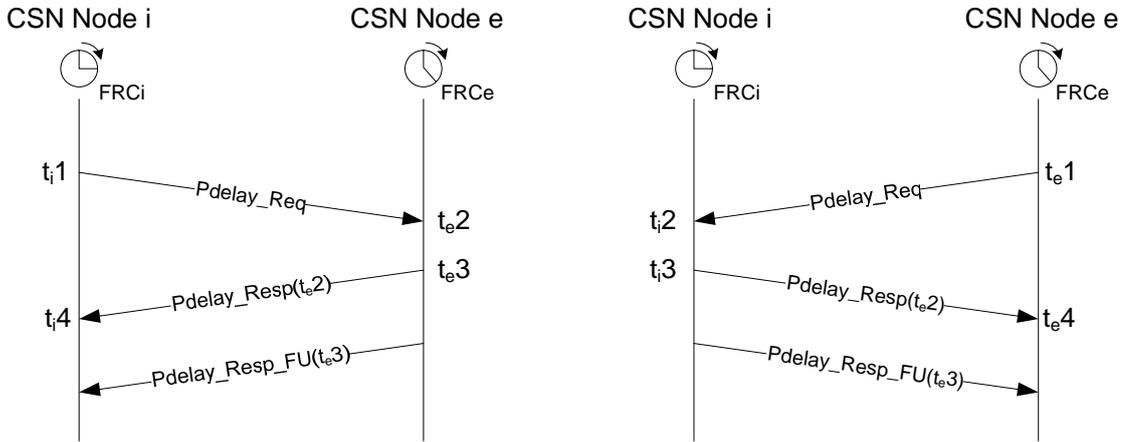
A Pdelay\_Req message should be first generated when a new node joins the CSN network and should be sent to each other nodes of the network.

Although the propagation delay between two CSN nodes is a constant, a Pdelay\_Req message should be periodically sent by each node to each other active node of the network to compute the neighborRateRatio between these nodes.

The computation of the path delay between two nodes of the CSN network could be performed in two schemes depending of the hardware characteristics of the CSN nodes and the network.

#### 4.2.1 Path Delay Measurement without Network Clock reference

In the first scheme, each CSN node features a free running local clock. The path delay measurement uses the protocol, messages and state machines described in Clause 11 for 802.3 full-duplex, point-to-point links, as illustrated by Figure 4.



**Figure 4: CSN Node to Node Path Delay Measurement without Network Clock reference**

The neighborRateRatio is always computed as the ratio of the rate of the upstream neighbor local clock to the rate of the local clock of the current node that receives the Pdelay\_Resp and Pdelay\_Resp\_Follow\_Up messages.

The ingress CSN node (Node<sub>i</sub>) computes its neighborRateRatio as the ratio of

$$(t_{e3} - \text{previous\_}t_{e3}) / (t_{i4} - \text{previous\_}t_{i4})$$

and the mean-propagation delay from the ingress to egress CSN node is computed as

$$((t_{i4} - t_{i1}) - (t_{e3} - t_{e2}) * \text{neighborRateRatio}) / 2$$

Similarly the egress CSN node (Node<sub>e</sub>) computes its neighborRateRatio is as the ratio of

$$(t_{i3} - \text{previous\_}t_{i3}) / (t_{e4} - \text{previous\_}t_{e4})$$

and the mean-propagation delay from the ingress to egress CSN node is computed as

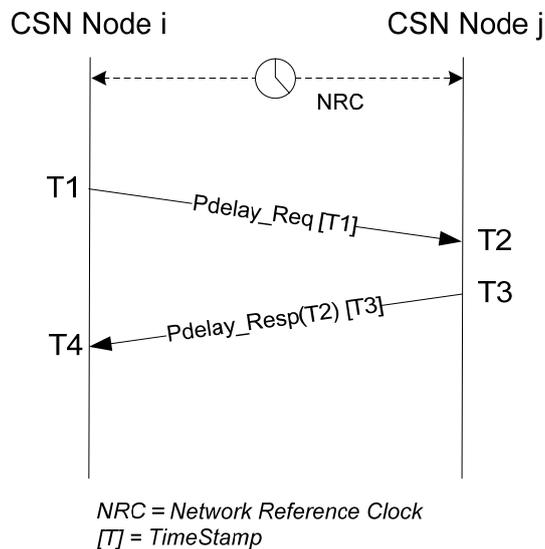
$$((t_{e4} - t_{e1}) - (t_{i3} - t_{i2}) * \text{neighborRateRatio}) / 2$$

#### 4.2.2 Path Delay Measurement with Network Clock reference

In CSN networks,

- nodes are synchronized to the same CSN Network Reference Clock propagated to each node
- frames are transmitted at pre-deterministic Network clock time and natively include their transmission timestamp in network clock time units
- received frames are time stamped relative to the network clock time.

If the media dependant characteristics of the CSN Network Reference Clock match the required path delay measurement requirements, the path measurement could be simplified to a two-way exchange only as described in Figure 5.



**Figure 5: CSN Node to Node Path Delay Measurement with Network Clock reference**

1. The Pdelay\_Req message is transmitted @ T1. This CSN network time transmission timestamp information is natively included in the CSN message (i.e., is included in CSN layer overhead).
2. The downstream node timestamps the Pdelay\_Req message reception and includes this timing (T2) information within the Pdelay\_Resp transmitted @ T3. This transmission timestamp information is natively included in the CSN message.
3. The upstream node timestamps the Pd\_Resp message reception @ T4.

Since the two nodes are using the same clock reference the neighborRateRatio is equal to 1.

The egress CSN computes the mean-propagation delay from the ingress to egress CSN node is computed as

$$(T4 - T1) - (T3 - T2) / 2$$

## 5 Synchronization Messages

Once all the path delays have been measured between 1) the upstream time-aware bridge or end-station and the ingress CSN node, 2) between the CSN nodes, 3) between the egress CSN node and the downstream time-aware bridge or end-station, the CSN backbone could propagate the synchronization messages received on its boundaries nodes.

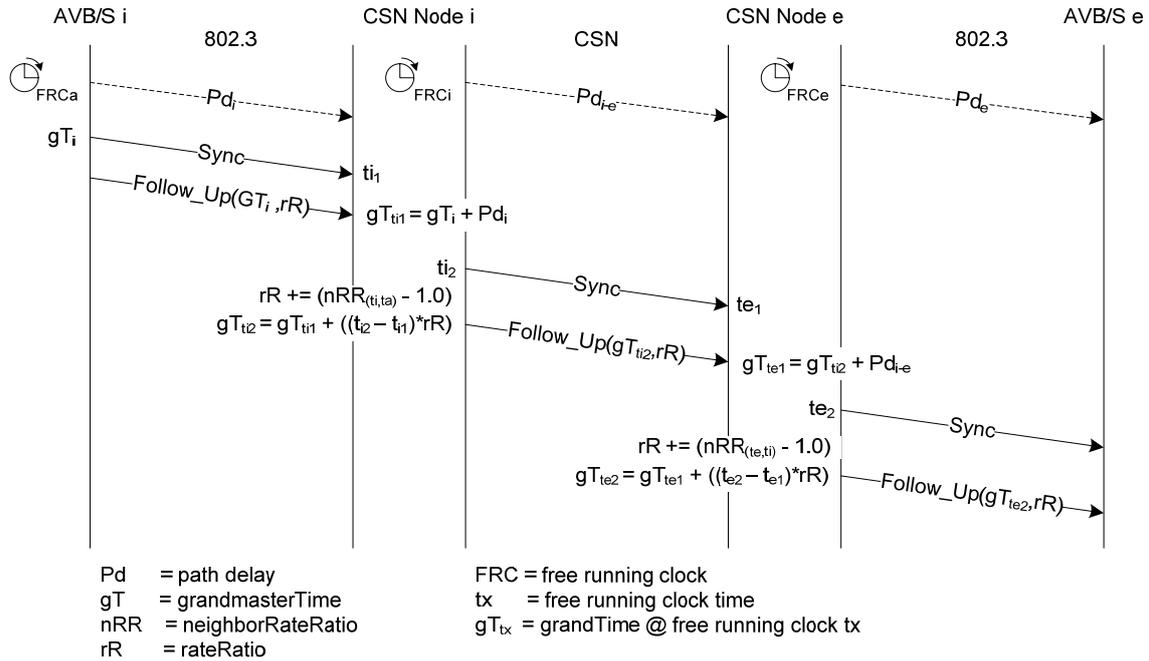
As for the path measurement the synchronization over the CSN backbone could use the Sync and Follow\_Up protocol, messages and state machines specified for 802.3 full duplex point to point links in Clause 10.2.

Sync messages received on a CSN ingress node from an upstream time-aware bridge or (talker) end-device are propagated to each node of the CSN. The Egress CSN nodes will in turn generate Sync and Follow\_Up messages to the downstream time-aware bridge or (listener) end-device.

AS for the path delay measurement, two schemes could be applied to propagate the Sync messages over the CSN network: without or with reference to the CSN Network Clock.

### 5.1 Synchronization Message Propagation without CSN Network Clock reference

In this first scheme, each CSN node features a free running local clock. The scheme is totally independent of the CSN reference clock, and therefore the accuracy is not dependent on the media dependant characteristics of the CSN Network Clock. The propagation sequence is described in Figure 6.



**Figure 6: Sync Messages Propagation without CSN Network Clock**

1. The ingress CSN node (Node<sub>i</sub>) receives a Sync message from the upstream AVB/S<sub>i</sub> time stamped by its own free running clock @  $t_{i1}$  relative to the local clock of the ingress CSN node.

2. The Follow\_Up message indicates that the Sync message received @  $t_{i1}$  was sent by the upstream AVB/S at grandmasterTime  $gT_i$  and provides the accumulated rateRatio relative to the grandmasterTime.

3. Node<sub>i</sub> calculates the grandmasterTime @  $t_{i1}$  by adding to the grandmasterTime the path delay from the upstream AVB/S to its own node ( $Pd_i$ ):

$$gT_{i1} = gT_i + Pd_i$$

4. Node<sub>i</sub> sends a Sync message per logical port to each of the other nodes of the CSN network @  $t_{i2}$  relative to the local clock of the ingress CSN node.

*Note: Although the CSN would be able to broadcast a single Sync message to all the nodes, one separate Sync message is sent per logical port to each of the other CSN nodes (at different times). This scheme allows the PortSync and MD entities of clauses 10 and 11 to be replicated per logical port.*

5. Node<sub>i</sub> computes the new accumulated rateRatio:

$$rR += (\text{neighborRateRatio} - 1.0)$$

and calculates the grandmasterTime @  $t_{i2}$  by adding to the grandmasterTime received @  $t_{i1}$  the node residence time (the interval of time between the reception of the Sync message and its transmission over the CSN) normalized by the rateRatio:

$$gT_{i2} = gT_{i1} + ((t_{i2} - t_{i1}) * rR)$$

6. Node<sub>i</sub> sends a Follow\_Up messages to the other nodes of the CSN network with the  $gT_{i2}$  timing information and the new accumulated rate ratio  $rR$

7. The egress CSN Nodes (Node<sub>e</sub>) receive the Sync message @  $t_{e1}$  relative to the local clock of the egress CSN node.

8. The Follow\_Up message indicates that the Sync message received @  $t_{e1}$  was sent by the ingress node at grandmasterTime  $gT_{i2}$  and provides the accumulated rateRatio

9. Each Node<sub>e</sub> calculates the grandmasterTime @  $t_{e1}$  by adding to the grandmasterTime the path delay from the ingress node to its own node ( $Pd_{i-e}$ ):

$$gT_{e1} = gT_{i2} + Pd_{i-e}$$

10. Each egress Node<sub>e</sub> sends a Sync message to their downstream AVB/S @  $t_{e2}$  relative to the local clock of the egress CSN node.

11. Each egress Node<sub>e</sub> computes the new accumulated rateRatio:

$$rR += (\text{neighborRateRatio} - 1.0)$$

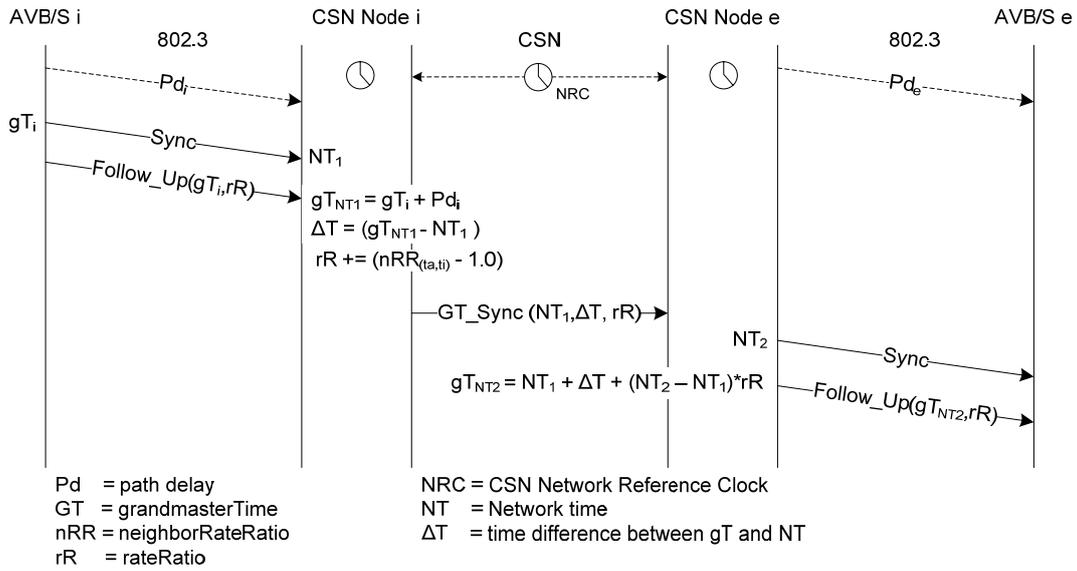
and calculates the grandmasterTime @  $t_{e2}$  by adding to the grandmasterTime received @  $t_{e1}$  the node residence time (the interval of time between the reception of the Sync message and its transmission to the AVB/S) normalized by the rateRatio:

$$gT_{e2} = gT_{e1} + ((t_{e2} - t_{e1}) * rR)$$

12. Each egress Node<sub>e</sub> sends a Follow\_Up message to their downstream AVB/S with the  $gT_{ie2}$  timing information and the new accumulated rate ratio rR.

## 5.2 Synchronization Message Propagation with CSN Network Clock reference

If the media dependant characteristics of the CSN Network Reference Clock match the required synchronization requirements, the sync message propagation over the CSN network could be simplified to a single message propagation as described in Figure 7.



**Figure 7: Sync Messages Propagation with CSN Network Reference Clock**

1. The ingress CSN node (node<sub>i</sub>) receives a Sync message from the upstream AVB/S<sub>i</sub> time stamped @ NT<sub>1</sub> relative to the CSN Network time.
2. The Follow\_Up message indicates that the Sync message received @ NT<sub>1</sub> was sent by the upstream AVB/S @ grandmasterTime gT<sub>i</sub> and provides the accumulated rateRatio relative to the grandmasterTime.
3. The Node<sub>i</sub>
  - 1) calculates the grandmasterTime @ NT<sub>1</sub> by adding to the grandmasterTime the path delay from the upstream AVB/S to its own node (Pd<sub>i</sub>):
 
$$gT_{NT1} = gT_i + Pd_i$$
  - 2) calculates the time difference between the grandmasterTime and the CSN Network time:
 
$$\Delta T = GT_{NT1} - NT_1$$
  - 3) and computes the new accumulated rateRatio:

$$rR += (\text{neighborRateRatio} - 1.0)$$

4. The Node<sub>i</sub> broadcasts a synchronization message to the other nodes of the CSN network to indicate NT<sub>1</sub>, ΔT and the accumulated rateRatio to the egress nodes.
5. Each egress Node<sub>e</sub> sends a Sync message to their downstream AVB/S @ NT<sub>2</sub> relative to the CSN Network time.
- 6.

Each egress Node<sub>e</sub> calculates the grandmasterTime @ NT<sub>2</sub> by adding to the grandmasterTime received @ NT<sub>1</sub> the CSN residence time (the interval of time between the reception of the Sync message by the egress node and its transmission to the downstream AVB/S) normalized by the rateRatio:

$$gT_{NT2} = NT_1 + \Delta T + (NT_2 - NT_1) * rR$$

7. Each egress Node<sub>e</sub> sends a Follow\_Up message to their downstream AVB/S with the  $gT_{NT2}$  timing information and the new accumulated rate ratio rR