Data-Over-Cable Service Interface Specifications
Mobile Applications

Synchronization Techniques for DOCSIS® Technology Specification

CM-SP-SYNC-I02-210407

ISSUED

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Document Status Sheet

Document Control Number:	CM-SP-SYNC-I02-210407			
Document Title:	Synchronization Techniques for DOCSIS® Technology Specification			
Revision History:	D01 - 07/30/18 D02 - 04/19/19 D03 - 01/07/20 D04 - 04/07/20 I01 - 04/20/20 I02 - 04/07/21			
Date:	April 7, 2021			
Status:	~~Work in Progress~~	~~Draft~~	**Issued**	~~Closed~~
Distribution Restrictions:	~~Author Only~~	~~CL/Member~~	~~CL/ Member/ Vendor~~	**Public**

Key to Document Status Codes

Work in Progress An incomplete document, designed to guide discussion and generate feedback that may include several alternative requirements for consideration.

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Closed A static document, reviewed, tested, validated, and closed to further engineering change requests to the specification through CableLabs.

Trademarks

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1 SCOPE

1.1 Introduction and Purpose

This document specifies the requirements on cable equipment for providing synchronization and timing as a service over the DOCSIS® network. New opportunities for DOCSIS technology include applications such as mobile backhaul and financial trading markets. These applications require time and frequency synchronization. Although the DOCSIS timing technology described in this document can be applicable to various applications, the present release focuses on the mobile backhaul application.

A mobile backhaul (MBH) is the network that connects the mobile switching core (i.e., evolved packet core, EPC, for LTE or the 5G core) and the radio access network (RAN) node. This document focuses on using DOCSIS technology to carry precision frequency and phase synchronization signals, with the hybrid fiber-coax (HFC) plant as a segment of an operator's overall timing distribution chain. Other aspects of mobile backhaul such as latency will be addressed in separate documents.

As mobile backhaul networks across worldwide operators can have different deployments and architectural scenarios, this specification outlines several synchronization approaches and defines their respective requirements on the DOCSIS equipment. It is assumed that the DOCSIS equipment is designed to meet the DOCSIS 3.1 suite of specifications.

The architecture and requirements defined in this specification enable cable operators to take advantage of their rich infrastructural assets to provide economical and capable backhaul services comparable to fiber for their own mobile traffic or to provide timing as a service to other mobile operators.

This specification is organized as follows:

- Section 5 provides an overview on mobile backhaul architecture, describes DOCSIS network connectivity use cases, and introduces four approaches to providing timing based on network capabilities.
- Section 6 describes the main DOCSIS technology for providing synchronization and timing services over the HFC network. The technology in this section is meant to be application-agnostic.
- Section 7 details the methods and requirements to provide physical layer timing support for frequency synchronization.
- Section 8 details the methods and requirements to provide phase synchronization over full timing support networks.
- Annex A describes timestamp conversion between DOCSIS and PTP timestamps.
- Annex B describes test environments and methodologies.
- Annex C outlines requirements on Distributed Access Architecture.
- Annex D details a list of DOCSIS TLV encodings to support synchronization.
- Appendix I is a placeholder for the methods and requirements to provide partial timing support for phase synchronization, to be finalized and included in a later version of this document.
- Appendix II is a placeholder for the methods and requirements to provide partial timing support for frequency synchronization, to be included in a later version of this document.
- Appendix III provides detailed background on mobile synchronization requirements.
- Appendix IV discusses several approaches to transporting Precision Time Protocol and Synchronous Ethernet control plan messages.
- Appendix V provides lists of timing recommendations for synchronizations developed by ITU-T.
- Appendix VI provides the text of a proposed new MIB, DOCS-CM-SYNC-MIB.
- Appendix VII provides a list of Acknowledgements.

- Appendix VIII provides a list of Engineering Changes incorporated into each new version of this specification.

NOTE: Appendices are for background information and are informative.

1.2 Requirements

Throughout this document, the words that are used to define the significance of particular requirements are capitalized. These words are:

"MUST"	This word means that the item is an absolute requirement of this specification.
"MUST NOT"	This phrase means that the item is an absolute prohibition of this specification.
"SHOULD"	This word means that there may exist valid reasons in particular circumstances to ignore this item, but the full implications should be understood, and the case carefully weighed before choosing a different course.
"SHOULD NOT"	This phrase means that there may exist valid reasons in particular circumstances when the listed behavior is acceptable or even useful, but the full implications should be understood, and the case carefully weighed before implementing any behavior described with this label.
"MAY"	This word means that this item is truly optional. One vendor may choose to include the item because a particular marketplace requires it or because it enhances the product, for example; another vendor may omit the same item.

2 REFERENCES

2.1 Normative References

In order to claim compliance with this specification, it is necessary to conform to the following standards and other works as indicated, in addition to the other requirements of this specification. Notwithstanding, intellectual property rights may be required to use or implement such normative references.

All references are subject to revision, and parties to agreement based on this specification are encouraged to investigate the possibility of applying the most recent editions of the documents listed below.

[MULPIv3.1] MAC and Upper Layer Protocols Interface Specification, CM-SP-MULPIv3.1-I21-201020, October 20, 2020, Cable Television Laboratories, Inc.

[R-DTI] Remote DOCSIS Timing Interface Specification, CM-SP-R-DTI-I08-200323, March 23, 2020, Cable Television Laboratories, Inc.

[R-PHY] Remote PHY Specification, CM-SP-R-PHY-I15-201207, December 7, 2020, Cable Television Laboratories, Inc.

[R-OSSI] Remote PHY OSS Interface Specification, CM-SP-R-OSSI-I15-210311, March 11, 2021, Cable Television Laboratories, Inc.

2.2 Informative References

This specification uses the following informative references.

[IEEE 1588-2008] IEEE 1588, IEEE Standard for a Precision Clock Synchronization Protocol for Networked Measurement and Control Systems, July 2008.

[SCTE 2011] John T. Chapman, Rakesh Chopra, Laurent Montini, "The DOCSIS Timing Protocol (DTP), Generating precision timing services from a DOCSIS system," *INTX/SCTE Spring Technical Forum*, 2011.

[SCTE 2017] Jennifer Andreoli-Fang and John T. Chapman, "Synchronization for Mobile Backhaul over DOCSIS," Proceedings of SCTE Fall Technical Forum, October, 2017, https://www.nctatechnicalpapers.com/Paper/2017/2017-mobile-backhaul-synchronization-architecture.

[SCTE 2020] Elias Chavarria Reyes, John T. Chapman, "How the DOCSIS Time Protocol makes the SYNC Specification Tick," *SCTE Cable-Tec Expo Fall Technical Forum*, Denver, October 14, 2020.

[BWR WP] John T. Chapman and Jennifer Andreoli-Fang, “Mobile Backhaul over DOCSIS,” Proceedings of SCTE Fall Technical Forum, October, 2017, https://www.nctatechnicalpapers.com/Paper/2017/2017-mobile-backhaul-over-docsis.

[SCF] “Small Cells And Dense Cellular Networks”, The Small Cell Forum, https://scf.io/en/documents/500_Small_Cells_And_Dense_Cellular_Networks.php

[G.703] ITU-T Recommendation G.703, Physical/electrical characteristics of hierarchical digital interfaces, April 2016.

[G.803] ITU-T Recommendation G.803, Architecture of transport networks based on the synchronous digital hierarchy (SDH), June 2005.

[G.8260] ITU-T Recommendation G.8260, Definitions and terminology for synchronization in packet networks, August 2015.

[G.8261] ITU-T Recommendation G.8261, Timing and synchronization aspects in packet networks, August 2019.

[G.8261.1] ITU-T Recommendation G.8261.1, Packet delay variation network limits applicable to packet-based methods (Frequency synchronization), February 2012.

[G.8262] ITU-T Recommendation G.8262, Timing characteristics of synchronous Ethernet equipment slave clock, November 2018.

[G.8264] ITU-T Recommendation G.8264, Distribution of timing information through packet networks, August 2017.

[G.8265.1] ITU-T Recommendation G.8265.1, Precision time protocol telecom profile for frequency synchronization, July 2014.

[G.8271] ITU-T Recommendation G.8271, Time and phase synchronization aspects of telecommunication networks, August 2017.

[G.8271-A1] ITU-T Recommendation G.8271, Amendment 1, Time and phase synchronization aspects of telecommunication networks, March 2018.

[G.8271.1] ITU-T Recommendation G.8271.1, Network limits for time synchronization in packet networks, October 2017.

[G.8271.2] ITU-T Recommendation G.8271.2, Network limits for time synchronization in packet networks with partial timing support from the network, August 2017.

[G.8272] ITU-T Recommendation G.8272, Timing characteristics of primary reference time clocks, November 2018.

[G.8272.1] ITU-T Recommendation G.8272.1, Timing characteristics of enhanced primary reference time clocks, November 2016.

[G.8273] ITU-T Recommendation G.8273, Framework of phase and time clocks, March 2018.

[G.8273.2] ITU-T Recommendation G.8273.2, Timing characteristics of telecom boundary clocks and telecom time slave clocks, August 2019.

[G.8273.4] ITU-T Recommendation G.8273.4, Timing characteristics of partial timing support telecom boundary clocks and telecom time slave clocks, February 2020.

[G.8275] ITU-T Recommendation G.8275, Architecture and requirements for packet-based time and phase distribution, August 2017.

[G.8275.1] ITU-T Recommendation G.8275.1, Precision time protocol telecom profile for phase/time synchronization with full timing support from the network, June 2016.

[G.8275.1-A1] ITU-T Recommendation G.8275.1, Amendment 1, Precision time protocol telecom profile for phase/time synchronization with full timing support from the network, August 2017.

[G.8275.2] ITU-T Recommendation G.8275.2, Precision time protocol telecom profile for phase/time synchronization with partial timing support from the network, June 2016.

[G.8275.2-A1] ITU-T Recommendation G.8275.2, Amendment 1, Precision time protocol telecom profile for phase/time synchronization with partial timing support from the network, August 2017.

[R-DEPI] Remote Downstream External PHY Interface Specification, CM-SP-R-DEPI-I15-201207, December 7, 2020, Cable Television Laboratories, Inc.

[R-UEPI] Remote Upstream External PHY Interface Specification, CM-SP-R-UEPI-I13-201207, December 7, 2020, Cable Television Laboratories, Inc.

[TS 36.104] 3GPP Technical Specification 36.104, Evolved Universal Terrestrial Radio Access (E-UTRA); Base Station (BS) radio transmission and reception, October 2019.

[TS 36.133] 3GPP Technical Specification 36.133, Evolved Universal Terrestrial Radio Access (E-UTRA); Requirements for support of radio resource management, October 2019.

[TS 36.922] 3GPP Technical Specification 36.922, Evolved Universal Terrestrial Radio Access (E-UTRA); TDD Home eNode B (HeNB) Radio Frequency (RF) requirements analysis, July 2018.

[TS 38.104] 3GPP Technical Specification 38.104, NR; Base Station (BS) radio transmission and reception, October 2019.

2.3 Reference Acquisition

- Cable Television Laboratories, Inc., 858 Coal Creek Circle, Louisville, CO 80027;
  Phone: +1-303-661-9100; Fax: +1-303-661-9199; http://www.cablelabs.com
- Common Public Radio Interface (CPRI), www.CPRI.info
- ETSI / 3GPP, http://www.3gpp.org
- IEEE: Institute of Electrical and Electronics Engineers, http://www.ieee.org
- INTX/NCTA, https://www.nctatechnicalpapers.com/
- ITU-T: Telecommunication Standardization Sector (ITU-T) of the International Telecommunication Union, https://www.itu.int/itu-t/recommendations/index.aspx?ser=G
- SCTE: Society of Cable Telecommunications Engineers, Inc., 140 Philips Road, Exton, PA 19341;
  Phone: +1-610-363-6888 / 800-542-5040; Fax: +1-610-363-5898; http://www.scte.org/
- Small Cell Forum, https://www.smallcellforum.org/

3 TERMS AND DEFINITIONS

This specification uses the following terms.

backhaul	In a cellular network, the portion of network that runs between the eNB and the mobile core.
eNodeB (eNB)	4G LTE base station
fronthaul	The network link between the remote radio heads at the cell sites and the centralized baseband controller.
full timing support networks	Networks that are composed exclusively of network elements that support [IEEE 1588-2008] protocol operation (such as Ordinary Clock or Boundary Clock).
macrocell	A cell in cellular networks that provides radio coverage served by a powered cellular base station.
partial timing support networks	Networks that include network elements that are not IEEE 1588 aware.
small cell	A low-powered cellular radio access node that operates in licensed or unlicensed spectrum that has a range of 10 meters to a few hundred meters.

4 ABBREVIATIONS

This specification uses the following abbreviations.

3GPP	3rd generation partnership project
ABS	almost blank subframe
APTS	assisted partial time support
B2B	business-to-business
B2C	business-to-customer
BC	boundary clock
BMCA	best master clock algorithm
BTS	base transceiver station
CCAP	converged cable access platform
CIN	converged interconnect network
CM	cable modem
CMCI	CM to CPE interface
CMTS	cable modem termination system
CoMP	coordinated multipoint
CPE	customer premises equipment
CS	coordinated scheduling
CSI	channel state information
CSR	cell site router
cTE	constant time error
DAA	distributed access architecture
DL	downlink
dTE	dynamic time error
dTE_H	dTE high-pass filtered noise generation
dTE_L	dTE low-pass filtered noise generation
DTP	DOCSIS time protocol
DWDM	dense wavelength division multiplexing
EEC	Ethernet equipment clock
E1	European basic multiplex rate 2.048 Mbps
eICIC	enhanced inter-cell interference coordination
eMBMS	evolved multimedia broadcast multicast services
eNB	evolved node B
EPC	evolved packet core
ePRTC	enhanced primary reference time clock
ESMC	Ethernet synchronization messaging channel
FDD	frequency-division duplex
FO	fiber optic
FTS	full timing support
GCP	generic control plane
GM	grandmaster
GNSS	global navigation satellite system
GSM	global system for mobile communications
GPS	global positioning system
HetNet	heterogeneous network
HFC	hybrid fiber-coax
HSS	home subscriber server

I-CMTS	integrated CMTS
ICIC	inter-cell interference coordination
IP	Internet protocol
ITU	international telecommunication union
ITU-T	international telecommunication union–telecommunication
IWF	interworking function
KPI	key performance indicator
LE	line extender
L2	layer 2
L2TPv3	layer 2 tunneling protocol version 3
L3	layer 3
LTE	long-term evolution
LTE-A	LTE advanced
MAC	media access control
MAP	bandwidth allocation map
MBH	mobile backhaul
MBSFN	MBMS single frequency network
MIMO	multiple-input and multiple output
MME	mobility management entity
MMM	MAC management message
MNO	mobile network operator
MPLS	multiprotocol label switching
MSO	multiple systems operator
MTIE	maximum time interval error
NGC	next-generation core
NSI	network-side interface
OFDM	orthogonal frequency division multiplexing
OFDMA	orthogonal frequency division multiple access
OSSP	organization specific slow protocol
OTT	over-the-top
P2P	point-to-point
PDCCH	PHY downlink control channel
PDSCH	PHY downlink shared channel
PEC-M	packet-based equipment clock - master
PGW	packet data network gateway
PHY	physical
PLC	powerline communication
PN	primary node
POC	point of concentration
PON	passive optical network
ppb	parts per billion
PPS	pulse-per-second
PRC	primary reference clock
PRTC	primary reference time clock
PSP	Packet streaming protocol
PTP	precision time protocol
PTS	partial timing support
PW	pseudowire
QL	quality level

RAN	radio access network
RC	resource coordinator
RF	radio frequency
RMD	remote MACPHY device
RPD	remote PHY device
RxD	either RMD or RPD
SC	small cell
SC-QAM	single-carrier quadrature amplitude modulation
SGW	serving gateway
SINR	signal-to-interference-plus-noise ratio
SLA	service level agreement
SSM	synchronization status message
SyncE	synchronous Ethernet
T1	basic multiplex rate 1.544 Mbps
T-BC	telecom boundary clock
T-GM	telecom grandmaster (master clock only)
T-TSC	telecom time slave clock
T-BC-A	telecom boundary clock-assisted
T-BC-P	telecom boundary clock–partial
T-TSC-A	telecom time slave clock–assisted
T-TSC-P	telecom time slave clock–partial
TDD	time-division duplex
TDEV	time deviation
TDM	time-division multiplexing
TE	time error
TRO	true ranging offset
TU	transmission unit
UDP	user datagram protocol
UE	user equipment
UL	uplink
UTC	coordinated universal time
VPLS	virtual private LAN service
VPN	virtual private network
WCDMA	wide band code division multiple access
WEA	wireless end application

5 OVERVIEW

The growth in mobile data consumption has been putting pressure on mobile network operators (MNOs) to build out small-cell networks. All this traffic needs to be backhauled from the base stations to the mobile core. Traditional choices for backhaul focus on fiber and microwave, but hybrid fiber-coax (HFC) networks have been making advancements. HFC is now being considered a backhaul contender by MNOs because of its capacity growth, cost efficiency, and speed of deployment.

There are at least three fundamental requirements for DOCSIS architecture to provide mobile backhaul or fronthaul services: timing and synchronization, bandwidth, and latency. This specification defines requirements on the DOCSIS equipment that enables it to meet the synchronization (sync) performance targets needed by the mobile network.

5.1 Mobile Backhaul Architecture

A mobile backhaul (MBH) is the network that connects the mobile switching core (i.e., evolved packet core, EPC, for LTE or next-generation core, NGC, for 5G) and the radio access network (RAN) node.

Mobile backhaul networks across worldwide operators can have different deployment and architecture-specific aspects, but these backhaul networks have common characteristics. From the network point of view, the backhaul might be built upon two scenarios:

- Self-built deployment (end-to-end network managed by a multiple systems operator, MSO):
  Full backhaul path is under operator control. This scenario is particularly interesting with respect to the operation of sync trail, covered in Section 8.
- Ethernet-managed services (part of the transmission network is leased from a third party):
  This case will be included in a later version of this specification.

This specification is applicable to a scenario in which an MSO owns the fixed access network.

Figure 1 depicts an example deployment scenario of the current mobile backhaul.

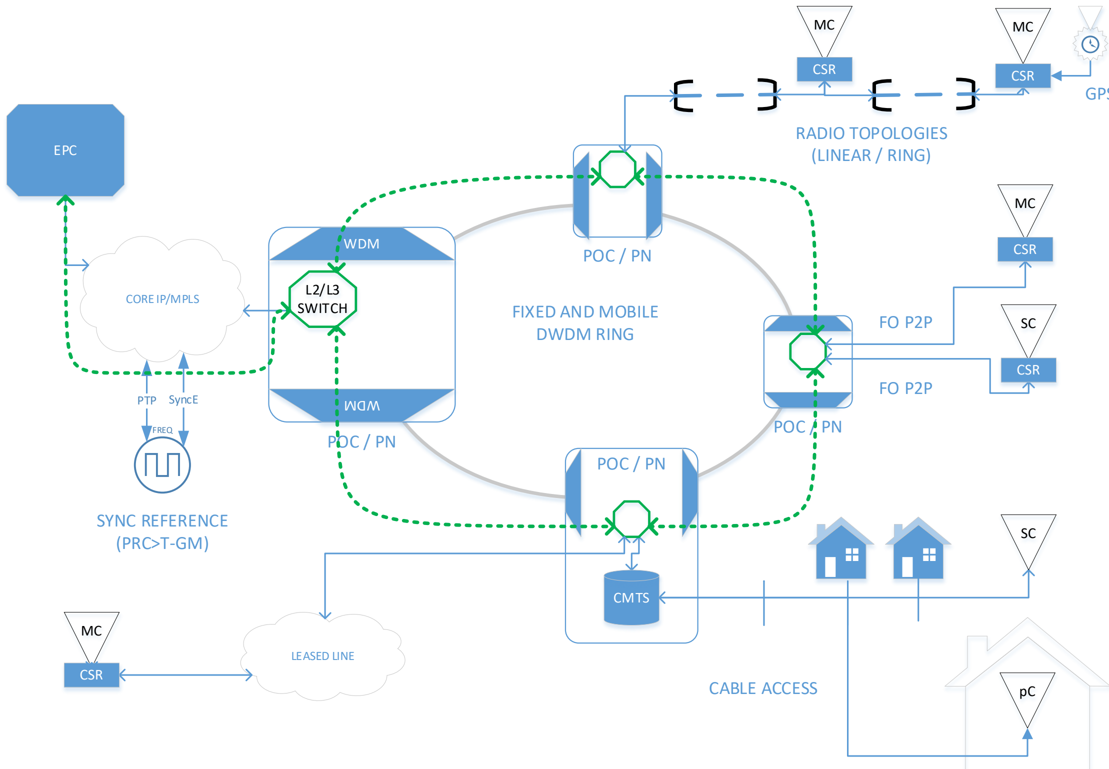

Figure 1 - Current Mobile Backhaul Deployment Example

Generally speaking, the EPC is connected to a country-wide packet core (typically IP/MPLS) that connects the regional and metro transport networks. Dense wavelength division multiplexing (DWDM) technology has been widely employed to build fixed and mobile packet aggregation networks at both core and regional/metro networks.

This backhaul might be based on L2 (VPLS) and/or L3 (VPN), and it carries the traffic and signaling from the RAN sites to the switching, management, and sync nodes sitting in the core network.

This architecture has managed connectivity for 3G and 4G nodes. Even for 2G nodes, in which traditional backhaul was based on TDM E1/T1 services, circuit emulation over the packet backhaul is widely used.

RAN sites linked to the aggregation network are mainly based on two kinds of links.

- Point-to-point (P2P) microwave radio links: ease and speed of deployment, Ethernet-based, native Synchronous Ethernet (SyncE) support, and symmetrical capacity.
- P2P fiber-optic (FO) links: high speed, ease of maintenance, native Ethernet and SyncE support, and symmetrical capacity.

Both technologies offer premium performance but at a high cost of ownership. They also provide support for frequency sync (SyncE or PTP-based). This kind of backhaul commits a Service Level Agreement (SLA), and protection topologies are typically built.

Mobile backhaul using fixed access networks (i.e., DOCSIS/HFC) promises cheaper connectivity to the aggregation backhaul and enough performance to meet the bandwidth and latency requirements, particularly for small cells.

Mobile cell sites are broadly classified into macrocells and small cells.

- Macrocell (MC): Cells defined as macrocells have large coverage radii and provide the main coverage throughout the country. They are the basic pillars of coverage for MNOs. Macro RAN sites use varying technologies (2G, WCDMA, 3G, 4G) and are deployed in technical rooms with proper aerial masts attached. They are placed at high buildings that have line of sight over the entire cell surface. MNOs have traditionally used P2P microwave links to backhaul the macro RAN site and are now steadily using P2P optical fiber links.

- Small cell (SC): The Small Cell Forum defines small cells as “an umbrella term for operator-controlled, low-powered radio access nodes, including those that operate in licensed spectrum and unlicensed carrier-grade Wi-Fi. Small cells typically have a range from 10 meters to several hundred meters.” [SCF].

Within the small cell category, there are multiple variants, which are summarized in Table 1.

Table 1 - Small Cell Variants

Type	Description
Femtocells	A low-power, short range, self-contained small cell. Initially used to describe consumer small cell units intended for residential homes, the term has expanded to encompass higher capacity units for enterprise, rural and metropolitan areas.
Picocells	Typically used to describe low power compact base stations used in enterprise or public indoor areas, the term is sometimes used to encompass outdoor small cells as well.
Microcells	Typically used to describe an outdoor short-range base station aimed at enhancing coverage for both indoor and outdoor users where macro coverage is insufficient. Occasionally installed indoors to provide coverage and capacity in areas above the scope of a picocell.
Metrocells	A recent term used to describe small cell technologies designed for high capacity metropolitan areas. Such devices are typically installed on building walls or street furniture (e.g., lampposts). This category can include technologies such as femtocells, picocells and microcells where they meet these deployment criteria.

The above labels for small cells have been used across the literature with different interpretations; as such, this specification will only use the umbrella term ‘small cell’.

5.2 Mobile Air Interface Synchronization Requirements

Although many wireless networks previously required only frequency synchronization, many of today’s deployments also require time and phase synchronization. Figure 2 shows the difference between the three kinds of synchronization. In the figure, the x axis denotes the progression in time, T denotes time, and f denotes frequency.

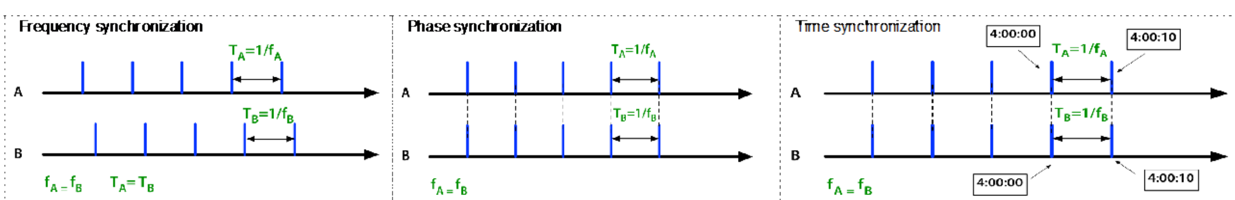

Figure 2 - Frequency, Phase, and Time Synchronization

Long-Term Evolution (LTE) Time-Division Duplex (TDD) requires additional phase synchronization between neighboring cells. Additionally, heterogenous networks and dense deployments introduce high interference for cell-edge users. To reduce the negative effect on user throughput, mobile operators utilize advanced LTE interference coordination techniques that are part of the LTE Advanced (LTE-A) standards. Ultimately, though these techniques improve the small-cell system capacity, they pose stringent requirements on synchronization. Table 2 summarizes synchronization requirements for 4G LTE Frequency-Division Duplex (FDD), 4G LTE TDD, and 5G TDD. See Appendix III for additional information to enable LTE-A features such as coordinated multipoint (CoMP), enhanced inter-cell interference coordination (eICIC), and evolved multimedia broadcast multicast services (eMBMS), as well as a technical overview of these techniques.

Table 2 - 4G/LTE and 5G Air Interface Synchronization Requirements

	Frequency	Phase	Notes
4G LTE FDD	± 50 ppb	None	3GPP TS 36.104 §6.5.1
4G LTE TDD	±50 ppb (wide area) ±100 ppb (local area) ±250 ppb (home)	10 µs (wide: cell radius >3 km) 3 µs (local: cell radius <3 km) 1.33 µs + propagation time (home eNB radius >500 m) 3 µs (home eNB radius <500 m)	Phase: 3GPP TS 36.133 §7.4.2 Frequency: 3GPP TS 36.922 §6.4.1.2
5G TDD	±50 ppb (wide area) ±100 ppb (local area)	≤ 3 µs	3GPP TS 38.104 Table 6.5.1.2.1

5.3 Deployment Best Practices for Synchronization

Whenever coordination is required, either macro-to-macro or macro-to-small cell, sync (frequency, phase, time) will also be needed. The requirement for sync at the radio access derives from the slotted access nature of legacy GSM networks. Traditional mobile base stations need to be frequency synchronized to establish proper frequency alignment to guarantee certain network key performance indicators (KPIs), such as successful call establishment and handover.

In addition to frequency synchronization, LTE TDD and the latest generations of mobile technologies such as LTE-A, which include CoMP and eICIC, all require stringent time and phase synchronization. See Appendix III for a technical overview on these features. Supporting these features places additional requirements on the mobile backhaul network.

Key recommendations for building out the end-to-end timing distribution network are summarized in this section, with a few rationales for the benefit of the reader. Cross references to document sections that describe requirements in detail are also provided here.

1. The recommended clock reference is Coordinated Universal Time (UTC), traceable through an available Global Navigation Satellite System (GNSS).
2. The time protocol transport is [IEEE 1588-2008] PTP Time with holdover assisted by SyncE frequency reference hop by hop (as recommended in ITU-T [G.8275.1]). This is to ensure compatibility among vendors and technologies where possible at the network. Requirements are captured in Section 8.
3. The deployment of synchronization starts with identifying the end points that require timing. After identifying which base station requires phase synchronization, the next step is to identify the shortest paths from that base station to the closest common aggregation points that will support [IEEE 1588-2008] for hop-by-hop time distribution. The path can include any fixed access network, such as a cable segment.
4. Grandmaster clocks can be installed at various locations, such as at an aggregation site.
5. SyncE, or a physical clock, can be used as a frequency holdover source.
6. Native IP/Ethernet-based technologies are recommended for implementing the boundary clock; native non-Ethernet-based technologies such as DOCSIS technology are recommended for implementing the distributed boundary clock. For information on distributed boundary clocks, see Section 8.5. It is recommended that all time sync implementations for transmission equipment be compliant with the relevant ITU-T G.827x suite of standards. See Section 8.6 for performance requirements.
7. It is recommended that the boundary clock be able to transmit PTP sync messages as either one-step or two-step messages.
8. The telecom time slave clock (T-TSC) is used for time recovery at the end application which is the base station.

Because the DOCSIS network is part of the timing distribution chain, it needs to be able to carry precision timing from the cable modem termination system (CMTS) to the cable modem (CM). See Section 5.6 for a network architecture that includes support of PTP over the DOCSIS network. In the DOCSIS 3.1 specifications, the DOCSIS Time Protocol (DTP) was designed to carry [IEEE 1588-2008] timing. The DOCSIS link needs to work with other elements of the operator network to meet the overall timing requirement needed by the base station slave clock. See Section 8.4 for end-to-end performance budgeting.

5.4 Connectivity Use Cases

5.4.1 Wireless End Application (WEA) and DOCSIS Connectivity Use Cases

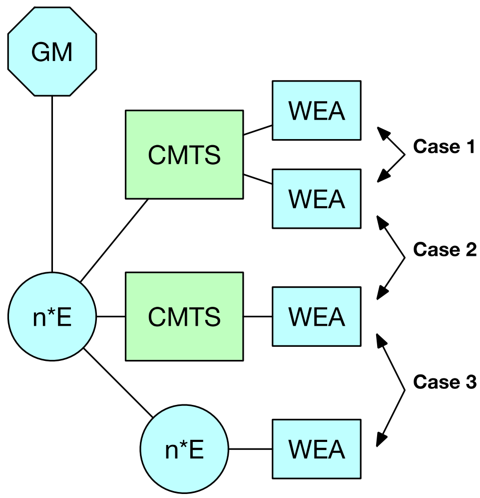

Figure 3 - WEA to DOCSIS Network Connectivity Use Cases

There are three cases of how wireless end applications (WEAs) are related through the DOCSIS network. They are shown in Figure 3. The "E" in Figure 3 represents an Ethernet switch, which can be a participant node (a boundary clock, BC) or a non-participant node.

- Case 1: Two WEAs, typically two small cells, connected to the same DOCSIS network. Time error is contained within a single DOCSIS network.
- Case 2: Two WEAs, typically two small cells, connected to different DOCSIS networks. Time error is distributed across two DOCSIS networks and an IP network segment.
- Case 3: A WEA connected to a DOCSIS network that is communicating with a macrocell WEA on a separate IP network segment. Time error is distributed across a DOCSIS network and an IP network segment.

There is another use case in which multiple WEAs can be on the same LAN segment behind a CM and can communicate directly with each other rather than having to send traffic over the DOCSIS network.

The WEAs in case 1 and case 2 could be located inside the residential home or outside on the HFC plant.

5.4.2 GNSS Connectivity to the DOCSIS and HFC Plant

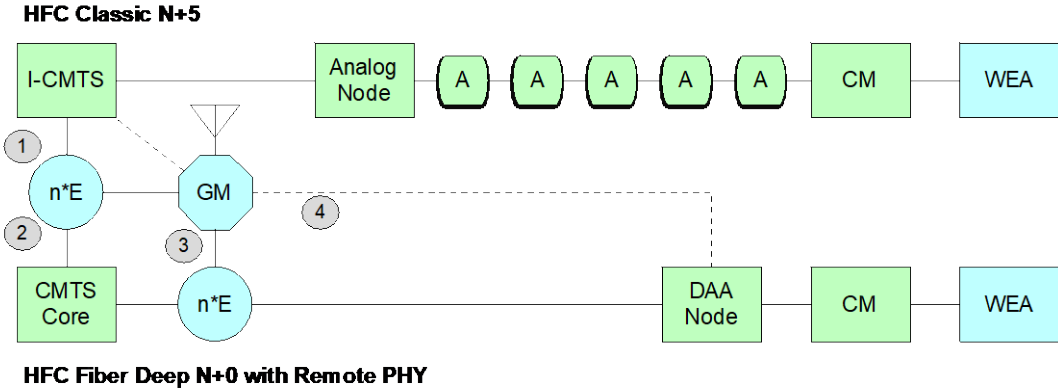

Figure 4 - GNSS Connectivity to the DOCSIS and HFC Plant

There are several options as to how the GNSS clock source connects to the DOCSIS network and the HFC plant, and thus ultimately to the WEA. They provide different levels of time error. Figure 4 shows two specific examples that illustrate four distinct deployment cases. Note that both an integrated CMTS (I-CMTS) and a Distributed Access Architecture (DAA) system could have a variable number of HFC amplifiers. A DAA node can contain either a Remote PHY Device (RPD) or a Remote MACPHY Device (RMD).

- Case 1: GNSS is brought through a packet network to an I-CMTS that is feeding a classic HFC plant, consisting of analog fiber running to an optical node. The node is followed by some number of amplifier and line extender cascades, which then connect to a CM and then the WEA.
- Case 2: GNSS is brought through a packet network to a CMTS Core, which then drives a DAA system. There are zero or more packet switch/router hops between the CMTS Core and the DAA node, and there are zero or more amplifiers between the DAA Node and the CM. This case is discouraged.
- Case 3: GNSS is brought though a packet network to the DAA node. The CMTS Core is not involved in the clocking path. This scenario is typical for both physical and cloud CMTS Cores. There are some number of IP switch/router hops between the GNSS source and the DAA node, and there are zero or more amplifiers between the DAA node and the CM.
- Case 4: GNSS is brought directly into the I-CMTS or the DAA node. There are no packet switch/router hops involved in the timing path. There are zero or more amplifiers between the DAA node and the CM.

In a DAA system, this specification is focused on the CMTS Core, which is a subset of CCAP Core as described in [R-PHY].

5.4.3 GNSS and DOCSIS Reference System

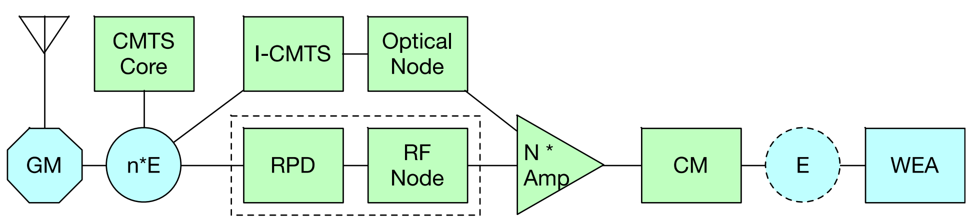

Figure 5 - GNSS and DOCSIS Reference System

Figure 5 shows the reference system for the DOCSIS network and the HFC plant and its connectivity to GNSS. This system contains the connectivity scenarios covered in Figure 4. The maximum time error, max|TE|, includes all the time error sources. The target in this specification for deployment is 1,500 ns. The time error (TE) budget for each component is defined in Section 8.4. Time error budgets comprise multiple components:

- constant time error (cTE)—error that does not change in steady state;
- dynamic time error (dTE)—error that does change in steady state (typically, fast changes are >0.1 Hz, slow changes are <0.1 Hz);
- rearrangement—abrupt changes caused by network reconfiguration; and
- holdover—long-term stability in case of reference source failure.

The cable operator is free to mix and match different classes of equipment, different numbers of Ethernet switch hops, and different DOCSIS network architectures to arrive at its own network design.

This specification presumes that the WEA is directly connected to an Ethernet port on the CM. The use of other types of connectivity such as MoCA or Wi-Fi are for future study. A switch could be inserted between the CM and the WEA, but that would come out of the backbone Ethernet switch hop budget.

This specification recognizes three distinct network segments, listed below, and allocates a time error budget to each network segment.

- Ethernet network, from the primary reference time clock (PRTC) to the CMTS network-side interface (NSI) port, denoted as n*E in Figure 5
- DOCSIS network, from the CMTS to the CM
- WEA network, from the CM to CPE interface (CMCI) port to the WEA air interface

5.5 Review of Synchronization Technologies

5.5.1 IEEE 1588-2008

See [R-DTI], section on IEEE 1588 Operation.

5.5.1.1 ITU-T Telecom Profiles

See [R-DTI], section on ITU-T Telecom Profiles.

For a list of ITU-T recommendations, see Appendix V.

5.5.2 Synchronous Ethernet (SyncE)

See [R-DTI], section on Synchronous Ethernet.

5.5.3 One Pulse-per-Second (1 PPS) Interface

Time and phase synchronization interfaces (see [G.8271]) are recommended for the following purposes:

1. Measurement interface:

   In order to allow network operators to measure the quality of the time/phase synchronization distributed along a synchronization chain, each element (such as a PRTC, T-GM, T-BC, and T-TSC) can have a dedicated external phase/time output interface implemented.

   A one pulse-per-second (1 PPS) interface is an adequate measurement interface, implemented according to one of the interfaces specified in ITU-T [G.8271], Annex A. Additional measurement interfaces are for further study.

2. Distribution interface:

   Time and phase synchronization interfaces are sometimes needed to connect systems belonging to a time/phase synchronization distribution chain.

A typical application is the case of a T-TSC connected to an end application, such as a base station, that is equipped with an existing input 1 PPS interface. The details of the distribution interfaces are for further study.

Figure 6 shows examples of both types of time and phase synchronization interfaces, where 1 denotes measurement interfaces and 2 denotes distribution interfaces. Different requirements can apply to these points.

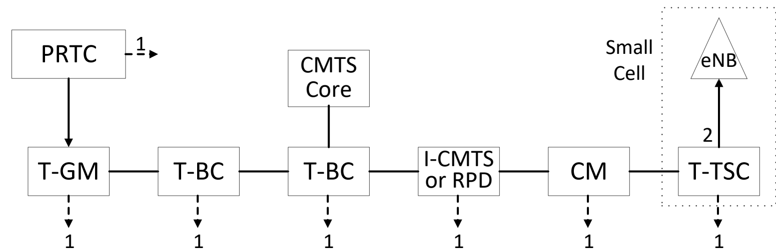

Figure 6 - Possible Locations of External Time and Phase Interfaces in a Chain of Elements

An output of a 1 PPS signal is an electrical signal at a 1 Hz rate is used to either deliver time or test time of a piece of precision timing equipment such as a GNSS timing receiver, atomic clock, or PTP clock. This output of 1 PPS signal can be measured by test equipment either in the lab or in the field. As typically implemented, its signal characteristics vary from a narrow pulse to a 50% duty cycle, with the pulse amplitude ranging from 0 volts at its minimum to several volts at its maximum. Figure 7 shows 1 PPS signal characteristics.

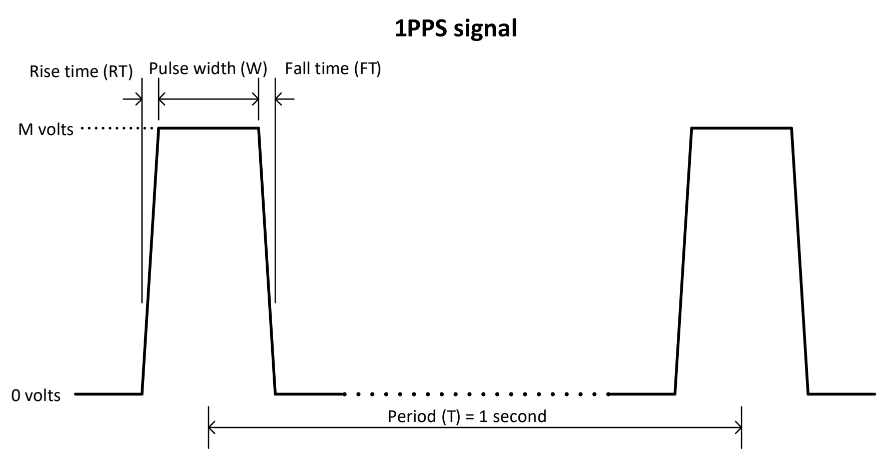

Figure 7 - 1 PPS Signal Characteristics

The 1 PPS signal characteristics as defined in ITU-T [G.703] are an unbalanced 50 Ω signal with the pulse width between 100 ns and 500 ms, a minimum voltage between -0.3 V and 0.3 V (denoted as "0" volts in Figure 7), and a maximum voltage between 1.2 V and 5.5 V (denoted as "M" volts in Figure 7). The rise time is specified to be less than 5 ns. This signal indicates the significant event occurring on the midpoint of the leading edge of the signal. The system generates a positive pulse on the 1 PPS signal such that the midpoint of the leading edge of the signal at the externally accessible connector occurs at the 1 second roll-over of the system. The 1 PPS significant event aligns to the start of the applicable timecode second; in the case of an [IEEE 1588-2008] element such as a grandmaster or boundary clock, this 1 PPS significant event aligns the instant that the fractional second part of the PTP time-of-day of the equipment is zero.

The 1 PPS 50 Ω measurement interface is useful in a number of scenarios. For example, a GNSS receiver can be tested against UTC at a national lab or against an atomic clock. As another example, a PTP slave or boundary clock can be tested against the PTP grandmaster supplying its time. In a similar fashion, if a DOCSIS element were to provide a 1 PPS signal, it could be measured against its source of time or against a source traceable to UTC, such as a GNSS receiver.

Figure 8 illustrates a measurement setup for using 1 PPS signals to characterize a PTP slave against a PTP grandmaster.

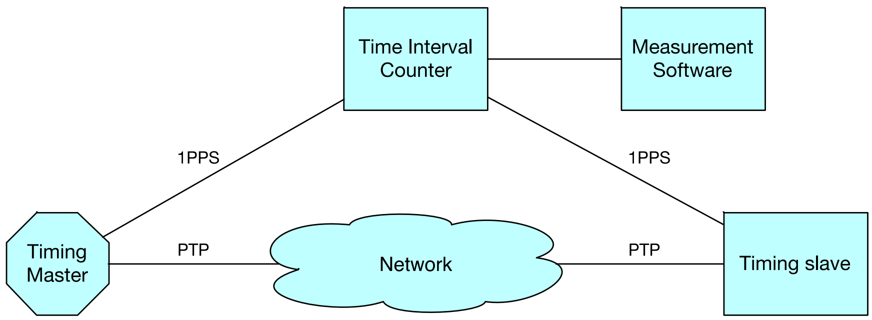

Figure 8 - Measurement Setup for Characterizing a PTP Slave using 1 PPS Signals

In this setup, the PTP packets traverse a network between timing master and slave, with 1 PPS signals from both devices connected to separate channels of a time interval counter. A computer with the appropriate software can be used to collect measurement data from the counter over a given period of time.

5.6 Synchronization Approaches

This document covers four synchronization approaches for mobile backhaul. This section briefly introduces them, and additional details can be found in later sections.

- Physical Layer Timing Support for Frequency Synchronization (Section 7)
- Full Timing Support for Phase Synchronization (Section 8)
- Partial Timing Support for Phase Synchronization (Appendix I)
- Partial Timing Support for Frequency Synchronization (Appendix II)

Full Timing Support networks are composed exclusively of network elements that support [IEEE 1588-2008] protocol operation (such as Ordinary Clock or Boundary Clock). Partial Timing Support networks can include network elements that are not IEEE 1588 aware.

Annex C adds specific requirements for the DAA/R-PHY case for each of the four synchronization approaches.

5.6.1 Physical Layer Timing Support for Frequency Synchronization

Details for physical layer timing support for frequency synchronization are covered in Section 7.

Figure 9 shows an end-to-end view of the synchronization flow for mobile backhaul with physical layer timing support providing frequency synchronization service to an end application mobile base station. Figure 9 addresses a SyncE-only system, and therefore does not apply to the R-PHY scenario. In this network, the SyncE chain is fully terminated at the SyncE-to-DOCSIS interworking function (IWF). In an I-CMTS system, the SyncE-to-DOCSIS IWF resides at the I-CMTS; in a DAA system, the SyncE-to-DOCSIS IWF resides at the RPD/RMD. From the SyncE-to-DOCSIS IWF, the synchronization information is transferred between DOCSIS equipment by using only a physical layer clock. Finally, at the DOCSIS-to-SyncE IWF, the synchronization information is regenerated in a suitable format for use by the end application mobile base station. In both I-CMTS and DAA systems, the DOCSIS-to-SyncE IWF resides at the CM.

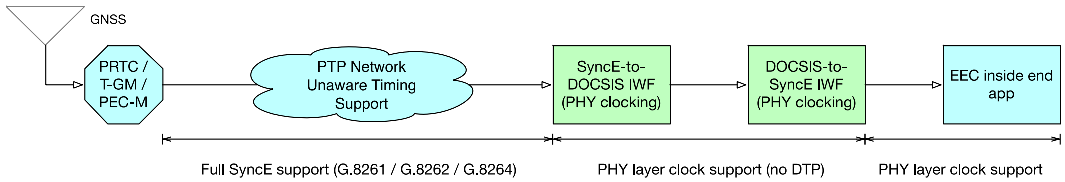

Figure 9 - End-to-End View of Physical Layer Timing Support for Frequency Sync

While this scenario does not apply to R-PHY, a similar deployment approach can be achieved using R-PHY as described in Section C.4.

5.6.2 Full Timing Support for Phase Synchronization

Details for full timing support for phase synchronization are covered in Section 8. Figure 10 shows an end-to-end view of the synchronization flow for mobile backhaul with full timing support providing phase synchronization service to an end application mobile base station. In this network, the PTP and SyncE chain are fully terminated at the PTP-to-DOCSIS IWF. In a I-CMTS system, the PTP-to-DOCSIS IWF resides at the I-CMTS; in a DAA system, the PTP-to-DOCSIS IWF resides at the RPD/RMD. From the PTP-to-DOCSIS IWF, the synchronization information is transferred between DOCSIS equipment by mimicking the [G.8275.1] PTP profile, and the DOCSIS equipment performance is based on [G.8273.2]. Finally, at the DOCSIS-to-PTP IWF, the synchronization information is regenerated in a suitable format for use by the end application mobile base station. In both I-CMTS and DAA systems, the DOCSIS-to-PTP IWF resides at the CM.

In an I-CMTS system, the DTP protocol (see Section 6) is run at the I-CMTS and the CM. In an RPHY system, the DTP protocol is run at the CMTS Core (on behalf of its RPDs) and CM. In an FMA system, the DTP protocol is run where the DOCSIS MAC resides and the CM.

This scenario also supports frequency synchronization service to the end application mobile base station.

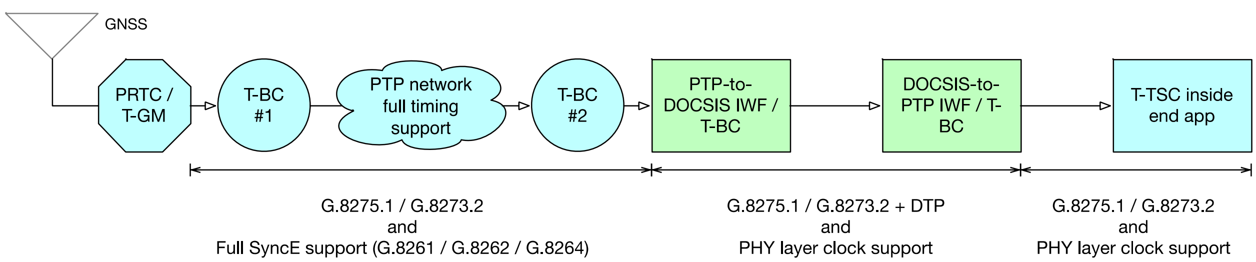

Figure 10 - End-to-End View of Full Timing Support for Phase Sync

For requirements specific to DAA/R-PHY, refer to Section C.2 in this document.

In this document the full timing support deployment is written with the inclusion of physical layer (SyncE) support. It is recommended that the source of SyncE within a network is generated from same source as the PTP domain (e.g., GPS or PRTC). The inclusion of SyncE follows the work carried out by the ITU-T and published in recommendations [G.8271.1], [G.8275.1], and [G.8273.2] among others. This use case, however, may be divided into three sub-cases:

- SyncE is available throughout the network
- SyncE is available only in the core of the network, up to the PTP-to-DOCSIS IWF (and therefore is not present from the DOCSIS-to-PTP IWF output downstream towards the end application)
- SyncE is not available anywhere in the network

When considering to not support SyncE throughout the network, of most interest would be the lack of support of SyncE from the DOCSIS-to-PTP IWF downstream towards the end application. The use of SyncE in that portion of the network may be beneficial, with a few examples provided below.

- If the DOCSIS-to-PTP IWF is followed by a full on-path support network designed to operate with physical layer support (e.g. a mixture of T-BC and T-TSC following [G.8271.1], [G.8275.1], and [G.8273.2], etc.)
- If the end application requires an input physical layer clock for proper operation (e.g. a T-TSC that follows [G.8273.2] recommendation, or a T-TSC designed without a strong embedded oscillator)
- To extend the holdover duration before the end application is “out of holdover” specification, when PTP messages are lost, as the input physical layer clock is a more stable frequency source than the oscillator embedded inside the end application (and is not subject to frequency movements due to temperature changes)
- If the end application is capable of using the physical layer clock to achieve faster frequency or phase synchronization convergence to permit the radio service to be enabled sooner after power-up or reset

When not having SyncE available throughout the network, the use of SyncE in the core/upper part of the network would generally depend on the operator’s desire to follow strictly the design architectures outlined by the ITU-T for full on-path deployments as covered in [G.8275], [G.8271.1], etc.. Following those recommendations closely removes some burden from the operator in the study of how to successfully architect synchronization in their network (e.g., budget of time error for each equipment, failure/recovery scenarios, equipment specifications and associated test cases, etc.).

Note that the CM is able to generate a physical layer clock (SyncE) to send to the end application based on the PTP information it receives over the DOCSIS network.

5.6.3 Partial Timing Support for Phase Synchronization

Initial details for partial timing support for phase synchronization are covered in Annex D. Further details will be covered in a future release of this specification. Figure 11 shows an end-to-end view of the synchronization flow for mobile backhaul with partial timing support providing phase synchronization service to an end application mobile base station. In this network, the PTP chain is fully terminated at the PTP-to-DOCSIS IWF. From the PTP-to-DOCSIS IWF, the synchronization information is transferred between DOCSIS equipment by mimicking the [G.8275.2] PTP profile, and the DOCSIS equipment performance is based on [G.8273.4]. Finally, at the DOCSIS-to-PTP IWF, the synchronization information is regenerated in a suitable format for use by the end application mobile base station.

In an I-CMTS system, the DTP protocol (see Section 6) is run at the I-CMTS and the CM. In an RPHY system, the DTP protocol is run at the CMTS Core (on behalf of its RPDs) and CM. In an FMA system, the DTP protocol is run where the DOCSIS MAC resides and the CM.

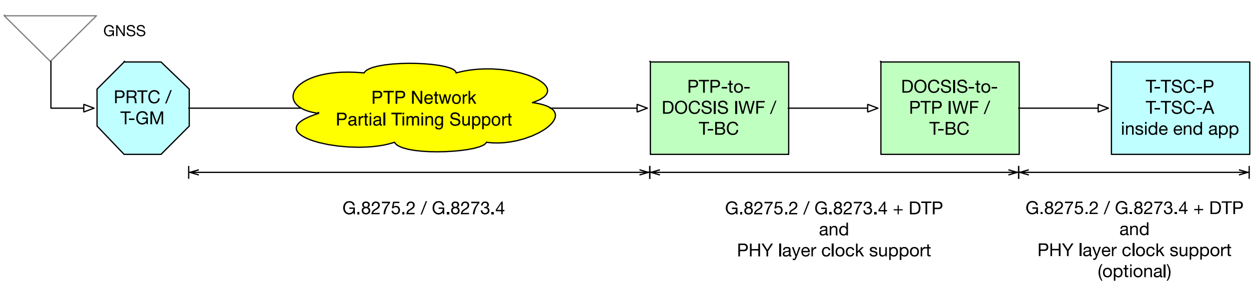

Figure 11 - End-to-End View of Partial Timing Support for Phase Sync

Figure 12 shows an end-to-end view of the synchronization flow for mobile backhaul with partial timing support providing phase synchronization service to an end application mobile base station. In this network, the PTP information is transferred transparently over-the-top (OTT) of the DOCSIS equipment (i.e., the DOCSIS equipment does not terminate or regenerate the PTP flow). This scenario is not further explored in this document because of the challenge of the asymmetry introduced by the DOCSIS network, which is larger than permitted in precision timing service applications.

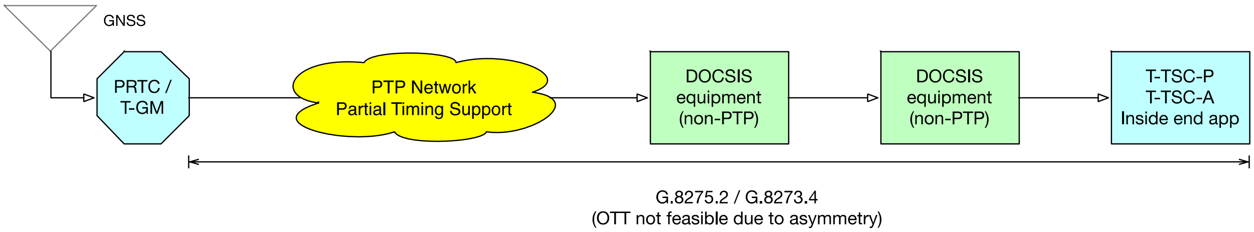

Figure 12 - End-to-End View of Partial Timing Support for Phase Sync (Over-the-Top)

5.6.4 Partial Timing Support for Frequency Synchronization

Initial details for partial timing support for frequency synchronization are covered in Appendix II. Further details will be covered in a future release of the specification. Figure 13 shows an end-to-end view of the synchronization flow for mobile backhaul with partial timing support providing frequency synchronization service to an end application mobile base station. In this network, the PTP chain is fully terminated at the PTP-to-DOCSIS IWF. From the PTP-to-DOCSIS IWF, the synchronization information is transferred between DOCSIS equipment by using only a physical layer clock. Finally, at the CM, the synchronization information is regenerated in a suitable format for use by the end application mobile base station.

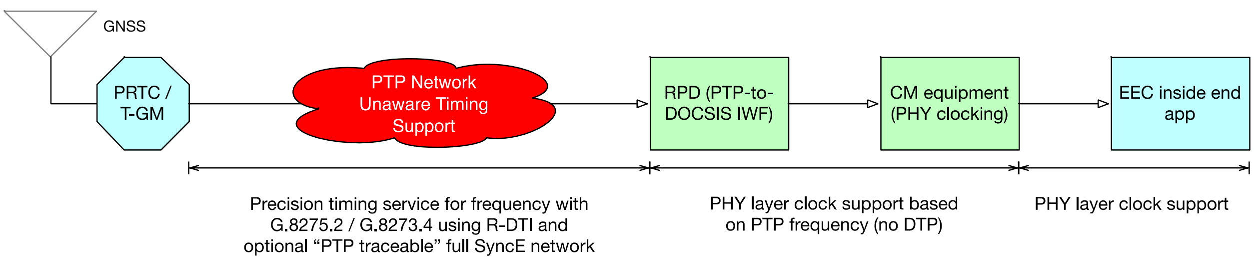

Figure 13 - End-to-End View of Partial Timing Support for Frequency Sync

6 DOCSIS TIME PROTOCOL

The DOCSIS Time Protocol (DTP) was introduced in the DOCSIS 3.1 specifications and allows for the passing of the IEEE 1588 protocol operation over the DOCSIS network with no jitter from network buffering. DTP provides two basic services:

1. a hardware path for a timestamp, and
2. a signaling path that determines the downstream timing offset, which is used as a correction factor for PTP.

6.1 DTP in a Nutshell

This section provides a review of why DTP was created and how DTP works. Rather than starting off with math equations, an intuitive and simplified approach is provided. All the math can be derived from an interpretation of the simplified description provided below.

6.1.1 DTP in Perspective

In a compliant Ethernet PTP system, the Ethernet ports have specific PTP hardware that can insert and recover timestamps from the PTP messages in a highly accurate manner and without any queuing delays. One design option would have been to add similar hardware to the DOCSIS ports of the CMTS and CM. However, that would have required hardware changes to existing application specific integrated circuits (ASICs). Instead, an alternate method was devised that reused parts of existing DOCSIS. That method became DTP.

DOCSIS is already a synchronous system. DTP uses the DOCSIS 3.1 timestamp and then measures the results of the ranging procedure to determine the one-way path delay. This path delay is then added to the initial CM timestamp to align it with the CMTS timestamp. DTP also provides a signaling mechanism to exchange timing information between the CMTS and CM.

6.1.2 DTP in Practice

The timing paths of a DOCSIS system is presented in more detail in this subsection. For reference, the original DTP timing diagram from [MULPIv3.1] is repeated in Figure 14. A simplified version of DTP timing is shown in Figure 15. The simplified diagram only shows the delays in the DOCSIS loop. The offset (-o) and PHY(-p) delays are combined. It also shows the internal CM ranging value that was implied but not shown in the [MULPIv3.1] analysis. In Figure 15, DS-T is the downstream delay internal to the CMTS; DS-H is the downstream HFC delay; DS-C is the downstream delay internal to the CM; US-T is the upstream delay internal to the CMTS; US-H is the upstream HFC delay; and US-C is the upstream delay internal to the CM.

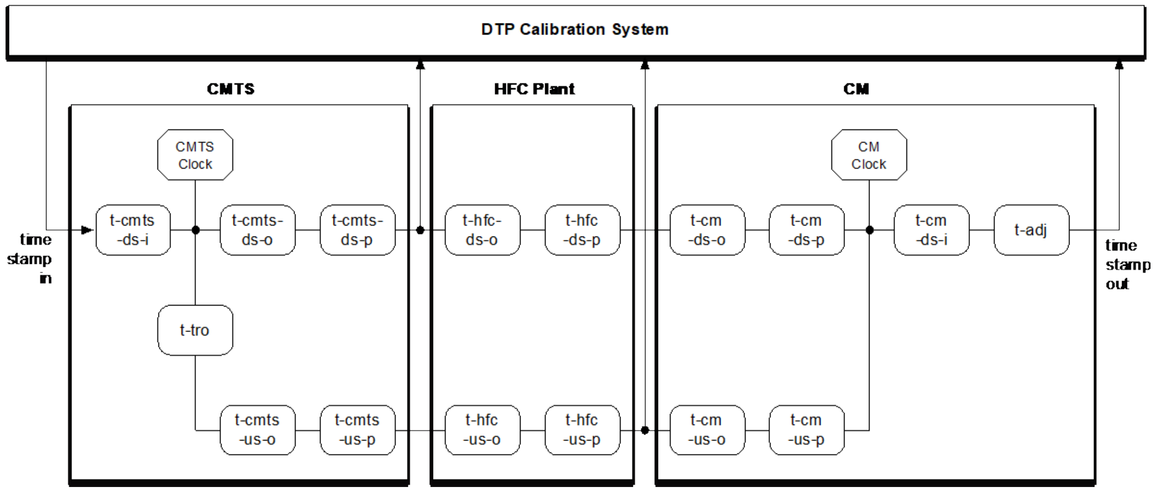

Figure 14 - DTP Path Modeling

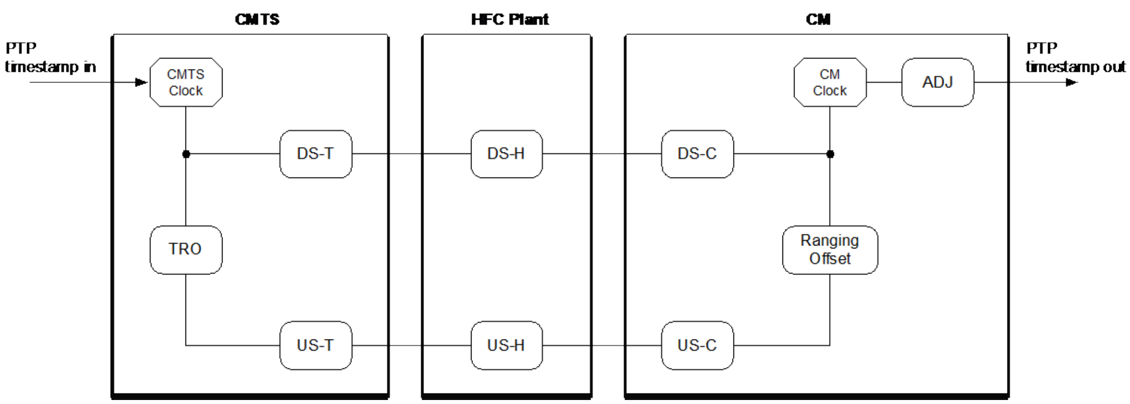

Figure 15 - DTP Timing Simplified

The CMTS is first synchronized to the 1588 timestamp. The 1588 timestamp is reformatted into the DOCSIS 3.1 timestamp and sent to the CM through the downstream path which consists of the CMTS, the HFC, and the CM. This means that the CM timestamp, prior to any adjustment (ADJ) for 1588 time alignment, is a delayed copy of the CMTS timestamp. The delayed copy of CMTS timestamp at the CM is also known as the "unadjusted" CM timestamp. If the latency of the full CMTS clock to CM clock downstream path is known, that value becomes the *ADJ* value which is then added to the CM clock to recreate the CMTS clock.

For example, assume the CMTS clock has a value of 2000 and that timestamp is passed through a DS delay of 1800. Then the timestamp of 2000 arrives at the CM, the CMTS clock will have advanced to 3800. So, if the received timestamp of 2000 at the CM has the downstream delay of 1800 added to it, it will also become 3800 and match the CMTS. It's that simple. Some detective work needs to be done to find out what that downstream delay is.

Each CM has an internal ranging offset that it changes during ranging. Because this value depends on implementation and is different for different manufacturers, the internal ranging offset cannot be directly used by DTP. This internal ranging offset is adjusted so that all CMs will transmit at whatever time they need to so that their packet will arrive at the CMTS according to the time indicated in the DOCSIS MAP message.

This is where the True Ranging Offset (TRO) comes in. By definition, the TRO is the sum of all the round-trip delays in the DS and US paths, including any delays the CM adds during ranging. This is shown in Figure 15. *Conceptually, the TRO is also the difference between the unadjusted CM timestamp when an upstream packet is sent, and the time as indicated in the MAP when the upstream packet is expected to arrive at the CMTS.*

The CM can determine the TRO value by subtracting these two CM and CMTS timestamps, and the result will be the same for all CMs at that location in the HFC network. This was the pivotal observation that made the DTP algorithm possible. A longer explanation on how TRO works with an example is included in [MULPIv3.1].

Once the TRO and the internal delays of the CMTS and CM are known, the sum of internal delays of the CMTS and CM can be subtracted from the TRO to get the round-trip HFC plant delay. The *ADJ* is then half of the round-trip HFC plant delay plus the DS delays of the CMTS and the CM.

6.1.3 DTP Calibration and Considerations

To make all this work in deployments, there are some practical considerations.

The DS and US delays internal to the CMTS and CM need to be known. These could be measured with a piece of test equipment that understands the DOCSIS protocol and measures the delays of the CMTS and CM individually. This test equipment would need to be designed. In the downstream, a reference point such as the start of the DOCSIS 3.1 timestamp, adjusted for half of the interleaver delay, could be used. In the upstream, there is no timestamp, so some other common reference point between the CMTS and CM, like the start of a burst, can be used.

Alternatively, the CMTS and CM can be measured as pairs. This is simple and works, but will not scale over time when there are lots of pairs and different hardware and software revisions.

The time delays of the CMTS and CM are also impacted by the configuration of the modulation and interleavers. The calibration and calculation process will have to take this into account. Calibration can be done with a zero-length reference HFC plant. Even with a zero-length plant, the CM will have a TRO which is dependent on a ranging value. Thus, the calculation of the round-trip delay on a deployed plant is dependent on the difference between the TRO on zero length plant and the TRO on a deployed plant.

The HFC plant may have some asymmetry if the optical forward and reverse paths are different, for example, an optical forward and a digital reverse. There could be phase delay difference at the DS and US frequencies. For DAA systems, the symmetry should be quite good. In general, there should be enough TE budget to just divide the plant delay in half to get the one-way HFC delay.

Additional background on DTP can be found in [SCTE 2011], [SCTE 2017], and [SCTE 2020].

6.2 DTP Timestamp Data Path

The CMTS receives the PTP timestamp on a PTP slave port and synchronizes its internal clock to this PTP timestamp. The CMTS then synchronizes all DOCSIS timestamps to its internal clock. This process makes the DOCSIS timestamp traceable to a PTP timestamp.

DOCSIS 3.1 specifications have the timestamp format shown in Figure 16. The format was chosen to provide bit-level backwards compatibility with the DOCSIS 3.0 32-bit timestamp.

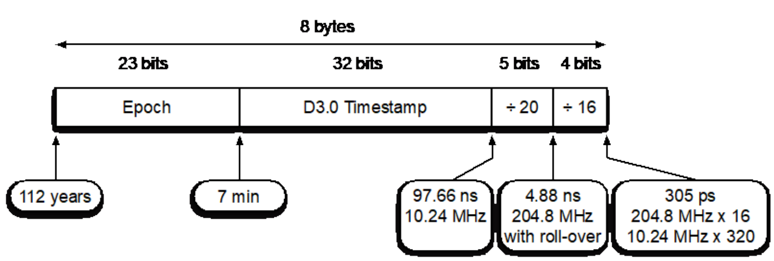

Figure 16 - DOCSIS 3.1 Timestamp

6.3 DTP Path Modeling

To derive a downstream offset, DTP uses a model of the DOCSIS system that includes the HFC plant, as shown in Figure 14. The CMTS and CM are responsible for reporting their DTP parameter values within the constant time error (specified later in this document). The "p" parameters are for a physical path delay; the "o" parameters are for an offset delay that might change as the result of configuration, such as an interleaver; the "i" parameters are for an interface delay.

The essence of the DTP algorithm is the true ranging offset (TRO). The DOCSIS MAC protocol uses a ranging procedure so that each CM can compensate for the distance between the CMTS and the CM, which allows packets sent from different CMs at different lengths from the CMTS appear at the CMTS upstream as back-to-back. The value of the ranging offset in each CM is vendor dependent and cannot be directly used.

The TRO effectively measures the result of that ranging process. The offset is the difference between the time that a packet arrives at the CMTS, as defined by the minislot number in the DOCSIS MAP scheduling message (which corresponds to a DOCSIS timestamp value), and the timestamp value at the CM when the packet is actually launched onto the upstream. This difference works out to be the round-trip delay of the DOCSIS system.

6.4 DTP Calibration and Operation

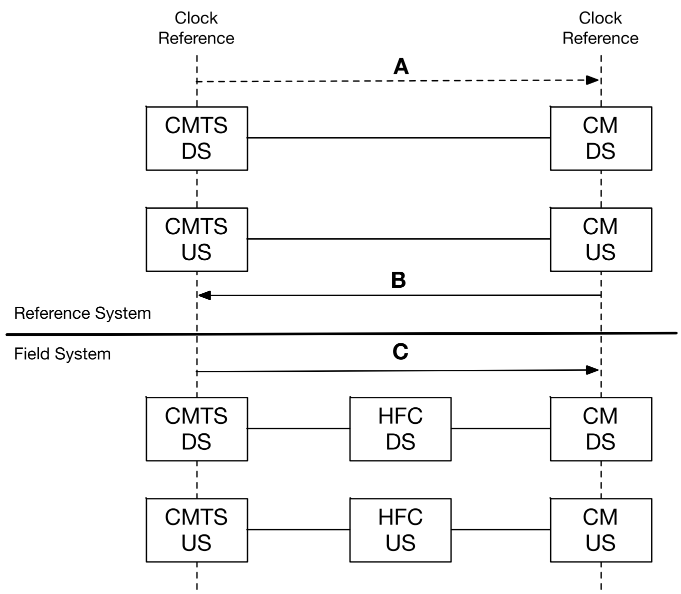

Figure 17 - DTP Calibration and Operation

In the DTP algorithm, the CMTS is effectively reporting its delay from its Ethernet port to its DOCSIS port. The CM does the opposite, i.e., from its DOCSIS port to its Ethernet port. For this kind of reporting to work with high accuracy, there has to be a way to define the reference point on the DOCSIS RF interface that both the CMTS and CM can measure against. That point is not directly observable because of the interleaving and scrambling of the DOCSIS signal. The preferred and most likely approach to solve this issue is to develop a test procedure and test equipment with which both the CMTS and CM can calibrate.

In the absence of such an interface definition, the alternative approach to calculating the DTP algorithm would be for the DTP algorithm to use measured results instead of vendor provided results, as shown in Figure 17. On a zero-length plant, test equipment could measure the one-way delay of the downstream path from the CMTS NSI port to the CM CMCI port. The system could also report the TRO for the zero-length plant.

The differences between a zero-length plant and a real plant that have the same CMTS and CM are the HFC plant and the TRO value. As such, a cable operator could choose to use lab measurements in lieu of parameters provided by the CMTS and CM. It remains to be seen if this approach provides more accurate or less accurate results. Details on how to perform these measurements are provided in the next section.

6.4.1 Obtaining Lab Measurements for DTP Algorithm

The measurements are all performed under the same configuration elements, such as interleaving. As such, the measurement results are only applicable on live DOCSIS systems that are operating under the same configuration elements used during the measurements. To support live DOCSIS systems with configuration elements that can be changed by the operator, it is necessary to collect measurements under all the configuration elements under which the operator wants to run DTP.

The first step is to characterize the combined timing parameters of a CMTS-CM pair. The second step is to characterize the timing parameters of each HFC fixed delay element, e.g., optical node. Finally, the third step is to compute the DTP time adjustment in a live DOCSIS system composed of the same CMTS-CM pair and HFC fixed element(s).

For reference, we have from [MULPIv3.1] that:

(1) *t-tro = t-cmts-ds-o + t-cmts-ds-p + t-hfc-ds-o + t-hfc-ds-p + t-cm-ds-o + t-cm-ds-p + t-cm-us-o + t-cm-us-p + t-hfc-us-o + t-hfc-us-p + t-cmts-us-o + t-cmts-us-p*

(2) *t-cm-adj = t-cmts-ds-i + t-cmts-ds-o + t-cmts-ds-p + t-hfc-ds-o + t-hfc-ds-p + t-cm-ds-o + t-cm-ds-p + t-cm-ds-i*

6.4.1.1 Measuring the CMTS-CM combined timing parameters

Configure a reference-length plant, i.e., the HFC path is just a coax connection of reference length from the CMTS to the CM. Record the following values (where *R* denotes as the recorded value):

(1) *t-tro-R*: True ranging offset as reported by the CM.
(2) *t-cm-adj-R*: Value of the DTP time adjustment that brings the average PTP 2-Way Time Error (cTE) to zero.
(3) *t-hfc-ds-p-R:* Downstream path delay introduced by the coax cable going from the CMTS to the CM. This is computed based on the length of the coax cable and the speed of propagation in the coax cable.
(4) *t-hfc-us-p-R:* Upstream path delay introduced by the coax cable going from the CMTS to the CM. This is computed based on the length of the coax cable and the speed of propagation in the coax cable.

Note: the values *t-hfc-ds-p-R* and *t-hfc-us-p-R* are the same.

Note: Since the HFC path is just a coax connection, it follows that *t-hfc-ds-o = 0* and *t-hfc-us-o = 0*.

With the above values recorded, the following is obtained from (1) and (2):

(3) *t-tro-R – t-hfc-ds-p-R – t-hfc-us-p-R = t-cmts-ds-o + t-cmts-ds-p + t-cm-ds-o + t-cm-ds-p + t-cm-us-o + t-cm-us-p + t-cmts-us-o + t-cmts-us-p*

(4) *t-cm-adj-R – t-hfc-ds-p-R = t-cmts-ds-i + t-cmts-ds-o + t-cmts-ds-p + t-cm-ds-o + t-cm-ds-p + t-cm-ds-i*

In both equations, the left-hand side is composed of measured values, and the right-hand side is composed of CMTS and CM timing parameters, which was the goal of this step.

From (1), (2), (3), (4*)*, the following general expression is obtained:

(5) *t-tro = t-hfc-ds-o + t-hfc-ds-p + t-hfc-us-o + t-hfc-us-p + (t-tro-R – t-hfc-ds-p-R – t-hfc-us-p-R)*

(6) *t-cm-adj = t-hfc-ds-o + t-hfc-ds-p + (t-cm-adj-R – t-hfc-ds-p-R)*

6.4.1.2 Measuring the HFC timing parameters

Add a single HFC element (e.g., optical node) between the CMTS and the CM. Record the following values (where "*-1", as in -one,* does not indicate any significance other than to indicate this specific measurement case):

(7) *t-tro-1:* True ranging offset as reported by the CM.

(8) *t-cm-adj-1*: Value of the DTP time adjustment that brings the average PTP 2-Way Time Error (cTE) to zero.

(9) *t-hfc-ds-p-1:* Downstream path delay introduced by the fiber and coax cables going from the CMTS to the CM. This is computed based on the length of the fiber and coax cables and the speed of propagation in each.

(10) *t-hfc-us-p-1:* Upstream path delay introduced by the fiber and coax cables going from the CMTS to the CM. This is computed based on the length of the fiber and coax cables and the speed of propagation in each.

With the above values recorded, the following is obtained from (5), (6):

(11) *t-hfc-ds-o + t-hfc-us-o = t-tro-1 – t-hfc-ds-p-1 – t-hfc-us-p-1 – (t-tro-R – t-hfc-ds-p-R – t-hfc-us-p-R)*

(12) *t-hfc-ds-o = t-cm-adj-1 – t-hfc-ds-p-1 – (t-cm-adj-R – t-hfc-ds-p-R)*

Equation (12) provides the HFC downstream offset timing parameter. Combining (11) and (12), we obtain:

(13) *t-hfc-us-o = (t-tro-1 – t-hfc-us-p-1) – (t-tro-R – t-hfc-us-p-R) – (t-cm-adj-1 – t-cm-adj-R)*

Equation (13) provides the HFC upstream offset timing parameter.

Note: The values obtained for the HFC timing parameters can later be used with any other CMTS-CM pair different from the ones used for the zero-length plant.

6.4.1.3 Computing the DTP Time Adjustment in a live DOCSIS system

Note: The variables *t-hfc-ds-o* and *t-hfc-us-o* are chosen to model both fixed delays and any path asymmetry between the upstream and downstream HFC transmission paths. This allows the assumption to be made that the remaining path delay from the hfc downstream path and the hfc upstream paths are equal. Hence, t-hfc-us-p = t-hfc-ds-p.

Updating (5), we get:

(14) *t-tro = t-hfc-ds-o +2*t-hfc-ds-p + t-hfc-us-o + (t-tro-R – t-hfc-ds-p-R – t-hfc-us-p-R)*

(15) *t-hfc-ds-p = [t-tro – t-hfc-ds-o – t-hfc-us-o – (t-tro-R – t-hfc-ds-p-R – t-hfc-us-p-R)]/2*

Substituting (15) into (6), we get:

(16) *t-cm-adj = t-hfc-ds-o + [t-tro – t-hfc-ds-o – t-hfc-us-o – (t-tro-R – t-hfc-ds-p-R – t-hfc-us-p-R)]/2 + (t-cm-adj-R – t-hfc-ds-p-R)*

(17) *t-cm-adj = t-cm-adj-R + [t-tro + t-hfc-ds-o – t-hfc-us-o – (t-tro-R + t-hfc-ds-p-R – t-hfc-us-p-R)]/2*

On the calibration setup (see Section 6.4.1.1), if the HFC downstream and upstream path delays are equal, i.e., *t-hfc-ds-p-R = t-hfc-us-p-R*, we get:

(18) *t-cm-adj = t-cm-adj-R + [t-tro + t-hfc-ds-o – t-hfc-us-o – t-tro-R]/2*

Equation (18) can now be used to compute the DTP time adjustment based on the t-tro reported by the CM in a live DOCSIS system, and the parameters previously measured (*t-cm-adj-R* and *t-tro-R*) and computed (*t-hfc-ds-o* and *t-hfc-us-o*).

Note: If there are multiple HFC elements, then the values of *t-hfc-ds-o* and *t-hfc-us-o* should reflect the addition of the timing parameters of each HFC element.

6.4.2 DTP Profile

As a result of the DTP lab measurement process defined in Section 6.4.1, the following DTP parameters are measured and stored internally in the CMTS / CMTS core or in a remote data base for each CMTS-CM or RPD-CM pair for a specific configuration:

- *t-tro-R*
- *t-cm-adj-R*

For a live DOCSIS system which might contain multiple CMTS-CM pairs, the DTP master will need to be aware of the correct CMTS-CM timing parameters to be used for computing the time adjust for a specific CM.

A DTP profile is a set of DTP measured parameters to be used for calculating a time adjust for a CM.

In a live DOCSIS system the DTP master can be configured with a set of DTP profiles depending on the versatility of CMTS-CM pairs. The list of the DTP profiles can be locally configured or use a common aggregated data base remotely.

The DTP profile to be used for calculating a Time adjust for a specific CM, will be determined by matching all or part of the following CMTS and CM system description information:

- Hardware version
- Software version
- Model Number
- Vendor OUI / ID
- Boot ROM Version

The DTP Master can retrieve the CM's system description information listed above from DTP capabilities during registration. The list of TLVs is specified in Annex D of this specification.

The DTP Master can retrieve the system description information of the RPD by reading RPD Identification TLVs (TLV 50) via GCP as specified in [R-PHY].

A CMTS acting as a DTP master MUST retrieve CM system description by registration TLVs, as specified in Annex D.

A CMTS Core acting as a DTP master MUST retrieve RPD's system description information via GCP.

A DTP capable CM MUST advertise its system information during registration.

The details on the specifics of how to retrieve the set of DTP profiles from a remote aggregated database is for future study.

6.5 DTP Signaling Control Path

Either the CMTS or the CM can be the DTP Master. Figure 18 shows the case in which the CMTS is the clock master. In this case, the CMTS initiates a DTP transaction. It can include its own DTP parameters, but that is informational. It can also override the CM DTP parameters, thus allowing centralized updating and fine-tuning of CMs that are already deployed. The CM returns the parameters that it knows about and the TRO measurement. The CMTS would run the algorithm and provide the downstream offset, which would be used to correct the PTP timestamp.

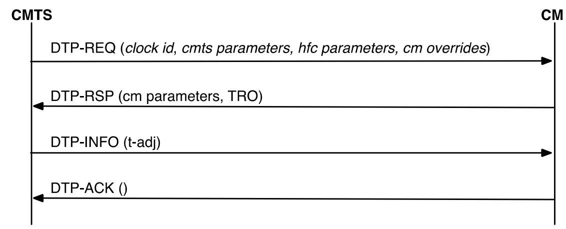

Figure 18 - DTP Signaling with CMTS as DTP Master

6.6 Location of the DTP Algorithm

The DOCSIS DTP design allows the CM to act as a DTP Master and run the DTP algorithm. The advantage of this approach is that the CM could adjust the PTP offset anytime there is a change in the TRO due to a change in ranging. This should provide the quickest tracking of PTP to DOCSIS ranging. It is also more scalable if there are a large number of CMs per CMTS, it is consistent for how ranging calculations are done, and it places the DTP algorithm in the same software stack that the PTP Master is located which can provide implementation convenience.

The DOCSIS DTP design also allows the CMTS to act as a DTP Master and run the DTP algorithm. The advantage of this approach is a centralized location for the DTP software that can allow the vendor or operator to have greater control over the algorithm.

A variation of the CMTS as DTP Master is to have the CMTS collect all the DTP parameters by acting as a DTP master but then pass the parameters to a separate platform such as a cloud platform that performs the DTP algorithm. The advantage of this approach is that it results in greater control over the DTP algorithm.

The CM MUST support DTP Master mode and calculation of the DTP algorithm. The CM MUST support DTP Slave mode. The CMTS MUST support DTP Master mode. The CMTS MUST support DTP Slave mode.

6.7 PTP and SyncE Control Plane over DOCSIS

The goal is to take the DOCSIS path between the CMTS and the CM and make it emulate a regular Ethernet path between two boundary clocks, which means emulating the support of multicast Ethernet or IP unicast.

6.7.1 PTP Control Plane over DOCSIS

In an I-CMTS system, the PTP-to-DOCSIS IWF resides at the I-CMTS. In a DAA system, the PTP-to-DOCSIS IWF resides at the RPD/RMD. In both I-CMTS and DAA systems, the DOCSIS-to-PTP IWF resides at the CM.

In this spec, the PTP Control Plane refers to PTP Announce and signaling messages. In the case of both PTP [G.8275.1] and [G.8275.2] profiles, the PTP-to-DOCSIS IWF needs to send PTP Announce messages to the DOCSIS-to-PTP IWF so that the latter can establish the PTP synchronization hierarchy. In the case of PTP [G.8275.1] profile, there are no signaling messages. In the case of [G.8275.2] profile, the PTP signaling messages are exchanged for generic communication between the IWFs (for details, see [IEEE 1588-2008]); for example, signaling messages can be used for negotiation of the rate of PTP Announce messages going from the PTP-to-DOCSIS IWF to the DOCSIS-to-PTP IWF. The transport mechanism used to carry the PTP Announce and signaling messages depends on the PTP profile being used by the PTP-to-DOCSIS IWF, as later discussed in Section 6.7.3.

In the case of both PTP [G.8275.1] and [G.8275.2], the DOCSIS-to-PTP IWF generates the content of the PTP Announce message that it sends to the PTP-to-DOCSIS IWFs based on its own clock, which is based on to what it is locked.

In the case of PTP [G.8275.1] profile, the rate at which the PTP-to-DOCSIS IWF sends PTP Announce messages to the DOCSIS-to-PTP IWFs is fixed to be 8 pkt/s, as this is the only valid rate defined in [G.8275.1]. A rate of 8 pkt/s allows a detection of network rearrangements within 125 ms. In the case of PTP [G.8275.2] profile, the rate at which the PTP-to-DOCSIS IWF sends PTP Announce messages to the DOCSIS-to-PTP IWFs is negotiated between the IWFs, as defined in [G.8275.2].

The PTP-to-DOCSIS IWF will appear as one PTP hop. The DOCSIS-to-PTP IWF will appear as a second PTP hop. As a result, the DOCSIS network will increment the PTP hop count by two, once for the PTP-to-DOCSIS IWF and once for the DOCSIS-to-PTP IWF. Since the hop count is a field of the PTP Announce message, both the PTP-to-DOCSIS and DOCSIS-to-PTP IWFs will each increase the steps-removed value by one.

NOTES:

- The PTP profile on the Ethernet ports of the DOCSIS-to-PTP IWF is provided through the DOCSIS configuration file to the CM.

6.7.2 SyncE Control Plane over DOCSIS

In an I-CMTS system, the SyncE-to-DOCSIS IWF resides at the I-CMTS; in a DAA system, the SyncE-to-DOCSIS IWF resides at the RPD/RMD. In both I-CMTS and DAA systems, the DOCSIS-to-SyncE IWF resides at the CM.

In this spec, the SyncE Control Plane refers to the SyncE Ethernet Synchronization Messaging Channel (ESMC) message. The SyncE-to-DOCSIS IWF sends ESMC messages to the DOCSIS-to-SyncE IWF to provide traceability of the synchronization signals. The transport mechanism used to carry the ESMC is later discussed in Section 6.7.3.

The rate at which the ESMC is sent is the rate defined by the profile in use by the SyncE-to-DOCIS IWF and on events as defined in [G.8264].

6.7.3 Transport Mechanism for PTP and SyncE Control Plane in DOCSIS

6.7.3.1 Assumptions

SyncE has a message known as the Synchronization Status Message (SSM) carried over the ESMC, which is transported over the 802.3 Organization Specific Slow Protocol (OSSP). This message rate is once per second or when there is a change, with a max of 10 per second.

In the PTP [G.8275.1] profile, the Announce message is a layer 2 link-local multicast message. It is not an IP packet. The same is true for SyncE. In PTP [G.8275.2] profile, the Announce message uses only IP packets and unicast addresses.

The IP address of the Special PTP port (discussed in Section 8.5.2) of the CM can be the same as the one for the CM management IP address.

6.7.3.2 Remote PHY Procedure for Full Timing Support

Because only the CMTS Core can inject L2 or L3 messages into the RF interface (the RPD cannot), the following procedure needs to be followed for the RPD to send a PTP or SyncE Control Plane message to the CMs.

In this section, we refer only to the RPD since the RMD procedure is similar to that of the I-CMTS, which is discussed in Section 6.7.3.3.

1. The RPD generates the PTP/SyncE Control Plane message.
2. The RPD makes any required modifications to the PTP/SyncE Control Plane message. For example, the RPD increases the steps-removed field of the PTP Announce message by one.
3. The RPD encapsulates the PTP/SyncE Control plane message, depending on the PTP profile in use and whether it is using SyncE:

   When using PTP [G.8275.1] profile, the RPD encapsulates the PTP Control Plane message into an L2 Ethernet frame. The source MAC address is the MAC address associated with the Special PTP Port of the RPD, and the destination MAC address is the non-forwardable multicast address 01:80:C2:00:00:0E. The EtherType is 0x88F7. The messages are sent with DTP PW Transmission Unit Payload Type of 1.

   When using SyncE, the RPD encapsulates the ESMC message into an Ethernet frame based on the ESMC PDU format defined in [G.8264]. The source MAC address is that of the Ethernet Port of the RPD from where the ESMC message is sent out, and the destination MAC address is 01-80-C2-00-00-02, as indicated in [G.8264]. The EtherType is 0x8809. The messages are sent with DTP PW Transmission Unit Payload Type of 0.

4. The RPD sends the PTP/SyncE Control plane message to the CMTS Core over an L2TPv3 DTP pseudowire (PW). It is a unique L2TPv3 pseudowire that has its own session ID. The message over the PW is represented as step 3 in Figure 19.
5. The CMTS Core removes the PTP/SyncE Control plane message from the L2TPv3 DTP pseudowire, and transmits it over the DOCSIS network using multicast DSID forwarding using the previously assigned SyncE-specific or PTP-specific DSID. The CMTS Core is not expected to modify the PTP/SyncE Control plane message. The message over the DOCSIS network is represented by steps 4 and 5 in Figure 19. The CMTS can replicate PTP/SyncE control plane messages in order to reach all CMs that are expected to be the recipients of these messages. The replication rules as well as the selection of the transmission paths to reach DTP CMs are outside of the scope of this specification. The downstream transmission method for PTP multicast messages and QoS is expected to conform to the rules described in the section entitled "Other Multicast and Broadcast Traffic" of [MULPIv3.1].
6. The CM recovers the PTP/SyncE Control Plane message.

   When using PTP [G.8275.1] profile, the CM filters the DOCSIS MAC frame based on the PTP-specific DSID. The CM extracts the PTP Control Plane message and forwards it to the Special PTP Port.

   When using SyncE, the CM filters the DOCSIS MAC frame based on the SyncE-specific DSID. The CM extracts the SyncE ESMC and forwards it to the SyncE software stack.

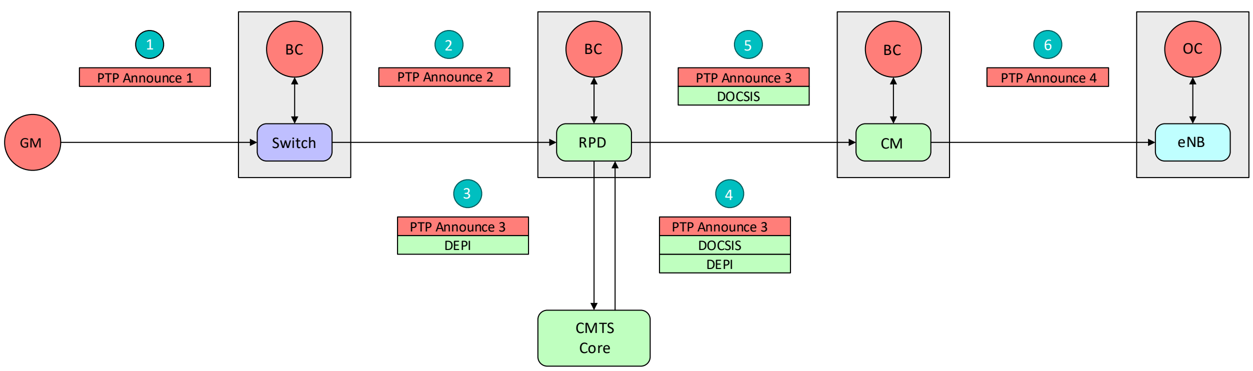

Figure 19 - PTP Control Plane over DOCSIS - DAA procedure - full timing support

6.7.3.2.1 DTP Pseudowire Transmission Unit Formats

The DTP pseudowire is using the Legacy PSP format explained in the section "PSP Sub-Layer Header" of [R-UEPI].

Each PSP transmission unit is formatted as shown in Figure 20 and further explained in Table 3.

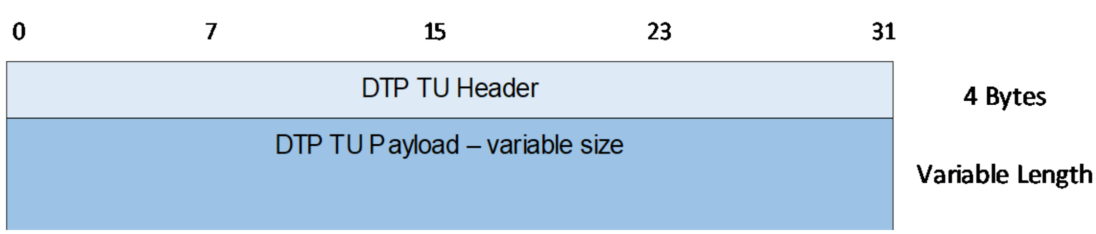

Figure 20 - DTP Pseudowire Transmission Unit Format

Table 3 - Composition of the DTP Pseudowire Transmission Unit (TU)

Field	Size	Function
DTP TU Header	4 bytes	DTP transmission unit header.
DTP TU Payload	variable	The payload of the transmission unit, e.g. a PTP packet.

Please note that the DTP pseudowire transmission unit can be fragmented into several PSP segments per PSP fragmentation rules. The DTP TU Header is only present in the PSP segments marked with the "B" bit. For more detailed explanation of the PSP fragmentation rule please refer to [R-DEPI] and [R-UEPI].

The format of the DTP TU Header is shown in Figure 21 and further explained in Table 4.

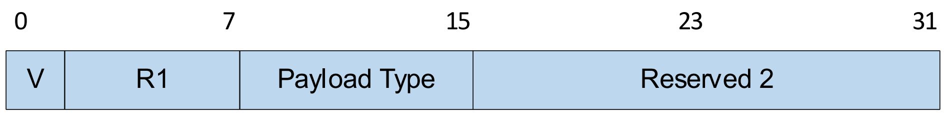

Figure 21 - DTP Transmission Unit Header

Table 4 - DTP Transmission Unit Header Format

Field	Size	Function
V	2 bits	Header Version Number. 00 = Version 1 01, 10, 11: Reserved
R1	6 bits	Reserved
Payload Type	8 bits	An 8-bit unsigned enumerated value indicating payload type. 0 - Fully formatted Ethernet frame with SyncE packet. 1 - Fully formatted Ethernet frame with PTP packet for G.8275.1 operation e.g. a PTP Announce message. Values 2-255 are reserved.
Reserved 2	16 bits	Reserved.

Note: A fully formatted Ethernet frame starts with the destination MAC address and ends with the CRC-32. The payload of the CRC-32 is not validated by the receiver.

In general, the lengths of PTP and SyncE packets are much shorter than the standard Ethernet MTU. For this reason, the following requirements are specified at the recommendation level.

The CMTS Core SHOULD support fragmentation of DTP TUs.

The RPD SHOULD support fragmentation of DTP TUs.

The CMTS Core SHOULD support reassembly of fragmented DTP TUs.

The RPD SHOULD support reassembly of fragmented DTP TUs.

Neither the RPD nor the CMTS Core are expected to implement PSP concatenation of DTP TUs.

6.7.3.3 CMTS Procedure for Full Timing Support

The following procedure needs to be followed for the I-CMTS or RMD, equivalent to CMTS, to send a PTP or SyncE Control Plane message to the CMs.

1. The CMTS generates the PTP/SyncE Control Plane message.
2. The CMTS makes any required modifications to the PTP/SyncE Control Plane message. For example, the CMTS increases the steps-removed field of the PTP Announce message by one.
3. The CMTS encapsulates the PTP/SyncE Control plane message, depending on the PTP profile in use and whether it is using SyncE:

When using PTP [G.8275.1] profile, the CMTS encapsulates the PTP Control Plane message into an L2 Ethernet frame. The source MAC address is that of the Special PTP Port of the CMTS, and the destination MAC address is the non-forwardable multicast address 01:80:C2:00:00:0E. The EtherType is 0x88F7. This Ethernet frame is then encapsulated in a DOCSIS Packet PDU MAC frame containing a PTP-specific multicast DSID.

When using SyncE, the CMTS encapsulates the ESMC message into an Ethernet frame based on the ESMC PDU format defined in [G.8264]. The source MAC address is that of the SyncE-associated MAC address of the CMTS, and the destination MAC address is the 01-80-C2-00-00-02, as indicated in [G.8264]. The EtherType is 0x8809. This Ethernet frame is then encapsulated in a DOCSIS Packet PDU MAC frame containing a SyncE-specific multicast DSID.

The CMTS can replicate PTP/SyncE control plane messages in order to reach all CMs that are expected to be the recipients of these messages. The replication rules as well as the selection of the transmission paths to reach DTP CMs are outside of the scope of this specification. The downstream transmission method for PTP multicast messages and QoS is expected to conform to the rules described in section entitled "Other Multicast and Broadcast Traffic" of [MULPIv3.1].

4. The CMTS places the DOCSIS MAC frame into the DOCSIS downstream.
5. The CM recovers the PTP/SyncE Control Plane message:

   When using PTP [G.8275.1] profile, the CM filters the DOCSIS MAC Frame based on the PTP-specific DSID. The CM extracts the PTP Control Plane message and forwards it to the Special PTP Port.

   When using SyncE, the CM filters the DOCSIS MAC frame based on the SyncE-specific DSID. The CM extracts the SyncE ESMC and forwards it to the SyncE software stack.

6.7.3.4 Configuration Considerations for Full Timing Support

Note that two different DSIDs are needed to enable distinguishing the PTP Control Plane messages from the SyncE ones.

When using PTP, the I-CMTS, CMTS Core, or RMD requires the following configurations:

- When using PTP [G.8275.1] profile, the PTP-specific multicast DSID.

When using SyncE, the I-CMTS, CMTS Core, or RMD requires the following configurations:

- The SyncE-specific multicast DSID.

Announcing the PTP-specific and SyncE-specific DSIDs in the MAC Domain Descriptor (MDD) message so that the CMs acquire this information during pre-registration is for further study. When the PTP [G.8275.1] profile is in use, the MDD approach would allow the CM to receive the PTP Announce message during pre-registration. Adding support for the PTP-specific and SyncE-specific DSIDs in the MDD message would require adding support for new TLV encodings in the MDD.

When the RPD supports DTP, it MUST enable the sending of the PTP Control Plane messages to the CMTS Core.

When the RPD supports SyncE, it MUST enable the sending of SyncE ESMC messages to the CMTS Core.

The DTP PW will be set up via L2TPv3.

When using PTP, to DOCSIS-to-PTP IWF, i.e., the CM, requires the following configuration:

- Whether the PTP-to-DOCSIS IWF is using PTP [G.8275.1] or [G.8275.2] profile.

In terms of overall PTP/DTP configuration and operation, the following steps are informational and reflect how a CMTS/RMD configuration can take place:

- The CMTS is initialized.
- The PTP slave clock of the CMTS achieves phase aligned state.
- The CMTS is operational.

- The CM receives PTP/SyncE configuration through DOCSIS Configuration file.
- The CMTS receives a registration request from a CM. The CM announces in its set of capabilities a DTP mode that is compatible with the one(s) supported by the CMTS, and its support for SyncE.
- In the registration response, the CMTS indicates to the CM what DTP mode to use. Since the CMTS is using PTP [G.8275.1], it also includes the PTP-specific DSID that the CM should use to filter the PTP messages.
- The CM continues its regular procedure to become operational.
- The CMTS sends PTP Announce messages to the CM.
- The DTP protocol is run periodically to compute the DTP time adjustment. The DTP protocol runs every time that the ranging value changes for a CM.

Note: The operation of the CM to its own slave clock is under study.

In terms of overall PTP/DTP configuration and operation, the following steps are informational and reflect how an RPD configuration can take place:

1. The RPD is initialized.
2. The PTP slave clock of the RPD achieves phase aligned state.
3. The CMTS Core and RPD are operational.
4. The DTP pseudowire is established between the RPD and the CMTS Core.
5. The RPD starts sending PTP Announce messages through the DTP pseudowire.
6. The CMTS Core receives a registration request from a CM. The CM announces in its set of capabilities a DTP mode that is compatible with the one(s) supported by the CMTS, and its support for SyncE.
7. Since the RPD is using PTP [G.8275.1], the CMTS Core allocates a PTP-specific DSID that the CM should use to filter the PTP messages (if no such DSID had been previously allocated in the same MAC Domain).
8. In the registration response, the CMTS Core indicates to the CM what DTP mode to use. Since the RPD is using PTP [G.8275.1], the CMTS Core also includes the PTP-specific DSID that the CM should use to filter the PTP messages.
9. The CM continues its regular procedure to become operational.
10. The DTP protocol is run periodically to compute the DTP time adjustment. The DTP protocol runs every time that the ranging value changes for a CM.

Note: The operation of the CM to its own slave clock is under study.

6.7.3.5 CMTS/CM Performance Considerations

For full timing support, the CMTS Core MUST handle up to 8 PTP Announce message per second, and 1 ESMC per second, per RPD.

7 PHYSICAL LAYER TIMING SUPPORT FOR FREQUENCY SYNCHRONIZATION

This scenario supports frequency synchronization distribution to the end application mobile base station.

7.1 Architecture, Use Cases

For this use case, the CMTS/RPD/RMD is synchronized using SyncE, and the CM provides the frequency reference to the WEA using SyncE; therefore, the CM is a synchronous Ethernet equipment clock (EEC) as specified in [G.8262] and compliant with the ESMC from [G.8264].

The support for frequency physical layer synchronization for an RPD is detailed in Section C.4.

The following is the end-to-end physical layer synchronization flow.

- A fully compliant SyncE signal is input to the DOCSIS equipment from the backhaul network, meeting [G.8261] network limits and carrying the ESMC according to [G.8264].
- The DOCSIS equipment converts the SyncE to the DOCSIS physical layer clock and transfers the SyncE Quality Level (QL) information to the CM.
- The CM converts the DOCSIS physical layer clock back to an Ethernet layer clock for transmission to the end application mobile base station; it also sends the QL information in a properly formatted ESMC to the end application mobile base station.

Within this use case, the CM distributes the frequency reference on the Ethernet traffic interface. The desired performance target for frequency accuracy is ±16 ppb [G.8261.1], based on the requirement of a ± 50 ppb radio frequency accuracy.

A list of applicable SyncE interfaces is listed in [G.8262], Appendix III.

7.2 ITU-T Frequency Error Budgeting

In this scenario, the end-to-end architecture for the physical layer SyncE clock should consider the DOCSIS system to be at least two [G.8262] components from the [G.803] reference chain (from an allowed total of up to 60 clocks, in the longest allowed chain).

7.3 SyncE Profile Requirements on DOCSIS Components

For an end-to-end view of the synchronization flow, see Section 5.6.1.

7.3.1 Operation from SyncE-to-DOCSIS Timing

In an I-CMTS system, the SyncE-to-DOCSIS IWF resides at the I-CMTS; in a DAA system, the SyncE-to-DOCSIS IWF resides at the RPD/RMD. In both I-CMTS and DAA systems, the DOCSIS-to-PTP IWF resides at the CM.

In an I-CMTS system, the CMTS MUST implement the SyncE-to-DOCSIS IWF that follows the operation as described in [G.8264] for an EEC with the additional considerations included in this section. In a DAA system, the RPD or the RMD MUST implement the SyncE-to-DOCSIS IWF that follows the operation as described in [G.8264] for an EEC with the additional considerations included in this section. The SyncE-to-DOCSIS IWF sending timing downstream from SyncE to DOCSIS RF performs several functions.

7.3.1.1 Native Ethernet Ports

The native Ethernet PTP ports operate as described in [G.8264]. One of the upstream-facing native Ethernet SyncE ports is selected as the best frequency source for the equipment clock.

7.3.1.2 DOCSIS Ports

The DOCSIS RF ports typically would be configured so that they are excluded from the clock selection process (e.g., operator lockout). The DOCSIS SyncE port needs to convey the physical layer QL and other information carried in the ESMC by using the mechanism defined in Section 6.7.2.

7.3.2 DOCSIS Port to Physical Layer Clock

The CM MUST implement the DOCSIS-to-SyncE IWF that follows the operation as described in [G.8264] with the additional considerations included in subsections below. The IWF sending timing downstream from DOCSIS port to physical layer clock performs several functions.

7.3.2.1 DOCSIS Port

The DOCSIS port typically would be configured to be the only available reference for selection consideration. The QL information within the ESMC feeds into the [G.8264] reference selection process; typically during normal operation, the DOCSIS port is selected as the best source for the CM.

7.3.2.2 DOCSIS Port Failure

After a period of normal operation, a loss of downstream synchronization (e.g., physical sync lock, ESMC messages, or a cable cut) from the DOCSIS interface normally would result in an immediate signal fail alarm in the [G.8264] operation because of the loss of incoming ESMC messages over the DOCSIS port. Other more exotic failures should be treated as an implementation-specific signal fail.

Where possible (e.g., excluding total power failure), the implementation-specific signal fail should typically result in similar [G.8264] state behavior as a loss of ESMC (with the slave clock deselecting the previous input and reverting to its local oscillator for holdover).

7.3.2.3 Native Ethernet PTP Ports

The downstream-facing native Ethernet ports operate as described in [G.8264] for an EEC. They typically would be configured so that they are excluded from the reference selection process (e.g., operator lockout).

7.4 Performance of DOCSIS Timing

Single box performance refers to the performance of each component within a DOCSIS system individually. Two box performance refers to the performance of a whole DOCSIS system viewed together as a two-box system.

7.4.1 Single Box Performance for SyncE-to-DOCSIS IWF

In an I-CMTS system, the CMTS MUST implement the SyncE-to-DOCSIS IWF that complies with [G.8262].

In a DAA system, the RPD or the RMD MUST implement the SyncE-to-DOCSIS IWF that complies with [G.8262].

7.4.2 Single Box Performance for DOCSIS-to-SyncE IWF

The CM MUST implement the DOCSIS-to-SyncE IWF that follows one of these two scenarios:

- The DOCSIS-to-SyncE IWF is assumed to be minimal impact (treated similarly to a transport card in a chassis system with high bandwidth). In this case, refer to Section 7.4.3 for testing the equipment in a back-to-back configuration.
- The DOCSIS-to-SyncE IWF complies with [G.8262].

7.4.3 Two Box Performance

This section only applies when the DOCSIS-to-SyncE IWF does not comply with [G.8262] (see Section 7.4.2).

The combination of SyncE-to-DOCSIS IWF and DOCSIS-to-SyncE IWF is expected to have similar performance requirements of either:

- a single [G.8262] network element or
- two [G.8262] network elements back-to-back.

8 FULL TIMING SUPPORT FOR PHASE SYNCHRONIZATION

This scenario supports phase distribution to the end application mobile base station. Although not explicitly stated in the title, this scenario also supports frequency synchronization distribution to the end application.

8.1 Architecture Use Cases

There are two ways to position the master clock, as a centralized PRTC or as a distributed PRTC.

8.1.1 DOCSIS Network Used for Timing Distribution

In the centralized PRTC case, the DOCSIS network is used as the last drop, and the clock signaling is transferred by using the coax network, as shown in Figure 22.

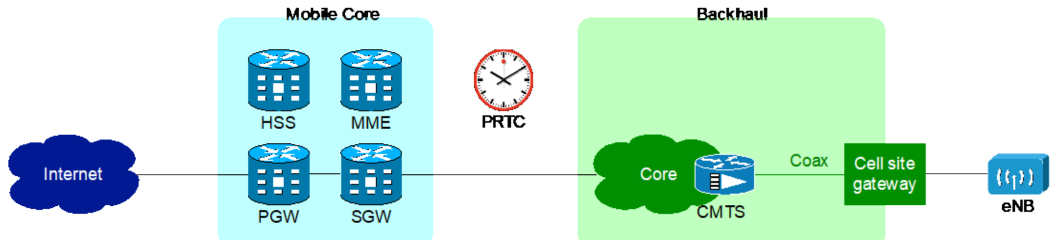

Figure 22 - Centralized PRTC

8.1.2 DOCSIS Network Not Used for Timing Distribution

In the distributed PRTC case, the PRTC is directly attached to eNB. There are two situations for this case:

- the PRTC is attached to each end application, or
- the PRTC is attached to one end application that acts as the master clock for the others.

The timing distribution schemes for which the DOCSIS network is not used for timing distribution are not specified or covered in detail in this specification.

8.1.2.1 PRTC Attached to Each End Application

As shown in Figure 23, the GNSS receiver is positioned in each end application, so the network does not need to transfer any clock reference. If the DOCSIS network is used as the last drop, this situation does not have any specific requirement for clock transport over the DOCSIS network.

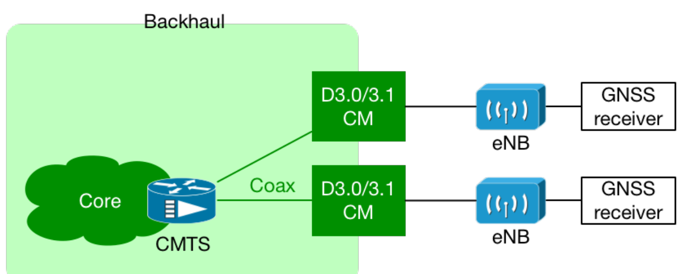

Figure 23 - Distributed PRTC in which Each eNB Is Attached to a GNSS Receiver

8.1.2.2 *Providing Synchronization Services Upstream From the CM*

In this case, as shown in Figure 24, the GNSS receiver is only attached to one end application that acts as the PRTC for all other end applications attached to the same network. This particular case cannot be implemented by using a DOCSIS network because cable networks are not able to transport clock reference in uplink by using DTP (the same situation happens when PON is used, for example).

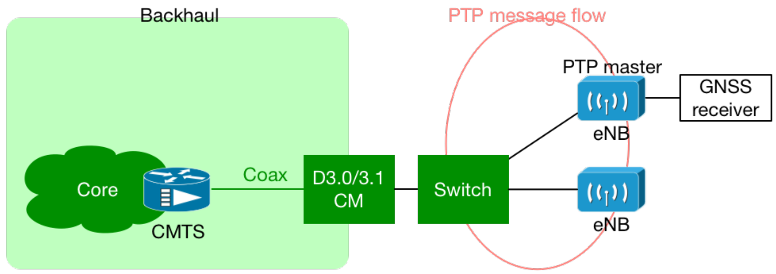

Figure 24 - Distributed PRTC in which the eNB Attached to a GNSS Receiver is a PTP Master

8.2 Protection/Holdover

An example deployment scenario is shown in Figure 25. In this example deployment, the operator has two PRTC/T-GM equipment for failure redundancy and protection.

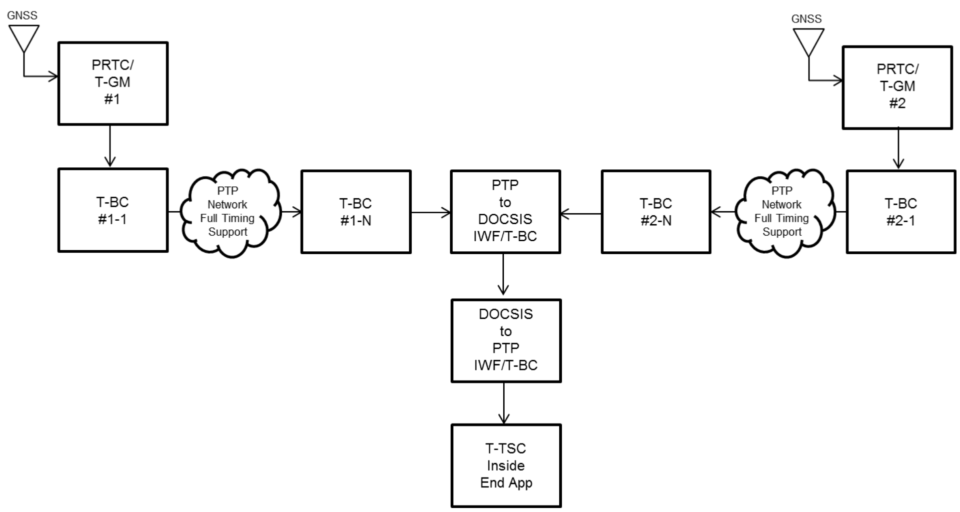

Figure 25 - PTP Deployment with Two PRTC/T-GM

In this example deployment scenario, PRTC/T-GM #1 can be the preferred source of synchronization for the T-TSC embedded inside the end application and that, upon failure of PRTC/T-GM #1, the synchronization flow will change and the T-TSC will select PRTC/T-GM #2 as the synchronization source.

During this failover period, there could be synchronization performance requirements for the end application that still need to be met. In order to do so, the operator can plan its deployment to have holdover capability at one or more places in order to ensure that, synchronization performance degradation is limited during rearrangements that occur after PRTC/T-GM#1 failures.

The design of the synchronization in the network can be such that the holdover capability is located in one or more of the following locations:

- an upstream switch/router (e.g., T-BC #1-N);

- the PTP-to-DOCSIS IWF;
- the T-TSC embedded inside the end application; or
- the end application clock itself.

The CM is not expected to support holdover in a deployment, and is therefore not included in the list above. The holdover capability required for the network can depend on the target performance of the end application, as well as on the length of the expected outage of an available PRTC/T-GM or the duration of the lack of visibility of the PRTC/T-GM by the T-TSC.

8.3 ITU-T Time Error Budgeting

8.3.1 Budgeting without DOCSIS

A common synchronization performance requirement for mobile backhaul is to ensure that the radio interfaces on each base station are aligned in phase to within 3 µs. A network operator can design its synchronization network such that the synchronization between a single base station and a global time reference (such as UTC) is within ±1.5 µs, in order to ensure that the requirement for 3 µs between base stations deployed within the network is satisfied.

A generic example deployment scenario for a network that does not include any DOCSIS equipment is shown in Figure 26; it is similar to that used within [G.8271] and [G.8271.1].

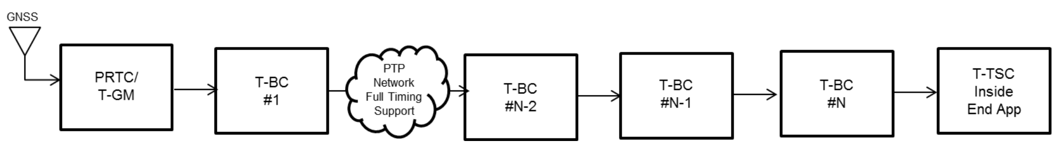

Figure 26 - PTP Deployment without DOCSIS Equipment

With the ±1.5 µs phase synchronization target in mind, a synchronization budget or plan can be developed for specific points in the network and for individual equipment. Referring to [G.8271.1], Appendix V, "Example of design options," there are six example budgets provided, taking into consideration the following:

- two T-BC classes, class A and the more accurate class B, which permits a larger #N of T-BC to be installed in the network path, and
- three failure scenarios, T-GM rearrangement with holdover in the end application, short GNSS interruption with holdover in the network, and a long holdover period.

At a high level, Table 5 summarizes budget values assigned to various aspects of the synchronization chain, referencing [G.8271.1] for the assumption of T-BC class A equipment and holdover protection in the network. Other scenarios can be valid for DOCSIS deployment, but they are not shown in Table 5. Refer to [G.8271.1], Appendix V, "Example of Design Options," Table V.4, for additional scenarios not shown in Table 5.

Table 5 - Network Synchronization Budget Planning

Budget Component	Time Error Allocation [ns]
PRTC/T-GM	100
Holdover in the network and PTP rearrangements in the network	400
Random error and SyncE rearrangements in the network	200
Total constant error for all T-BC (10 elements)	500
Constant error for T-TSC or the intra-site connection from T-TSC to end application	50
Total constant error for link asymmetries in the network	100

Budget Component	Time Error Allocation [ns]
Subtotal (Input to the End Application)	**1350**
Short holdover in end application and rearrangements	N/A
End application	150
Total (Output from the End Application)	**1500**

8.3.2 Budgeting Approach for DOCSIS IWF

A second generic example deployment scenario is shown in Figure 27. It is similar the scenario shown in Figure 26, but two of the T-BC are replaced by DOCSIS equipment. Here, the PTP-to-DOCSIS IWF / T-BC can be the I-CMTS, RPD, or RMD, and the DOCSIS-to-PTP IWF / T-BC can be the CM.

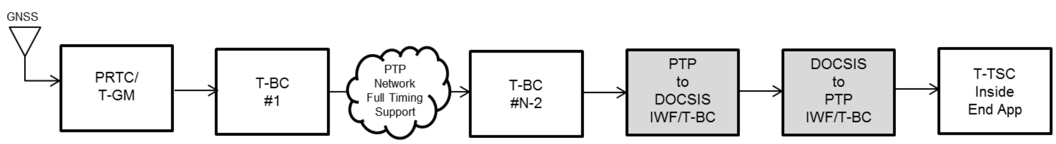

Figure 27 - PTP Deployment with DOCSIS Equipment

For additional information about the replacement of two T-BC with DOCSIS equipment, the following useful references are available from ITU-T. These references cover aspects of network architecture, network budgeting, equipment performance, and testing and measurement.

- [G.8271-A1], Clause 8.1, "Access section of HRM with PTP/native access IWF"
- [G.8271.1], Appendix IX, "Models for Budgeting in a chain of xPON or xDSL Devices";
  contains additional useful diagrams and information on this topic from a performance perspective
- [G.8273.2], Appendix V, "Performance Estimation for Cascaded Media Converters acting as T-BCs"
- [G.8273], Clause A.6, "Clocks containing media converters"

8.4 Full Timing Support Budget When Deploying a DOCSIS Network

The time error (TE) budget for a PTRC to a base station that runs over a participant DOCSIS network is shown in Table 6 and explained in this section. Table 6 shows a particular combination of network components that are Class A and the resulting BC count. A higher BC count can be achieved by using different combinations of Class B components.

Table 6 is also a comprehensive view of the total end-to-end performance budget of 1.5 µs for max|TE|. It includes three sections. The first and third sections are taken from [G.8271.1] network limits and show a mixture of dynamic time error (dTE) and constant time error (cTE). The second section covers DOCSIS networks, the focus of this document, and primarily focuses on cTE. Note that "Network Dynamic TE and SyncE rearrangements" in the first section covers dynamic error end-to-end across most of the network, including dynamic time error for DOCSIS equipment. More details on dynamic time error of DOCSIS equipment are provided in the following text, and requirements are covered in Section 7.4, Performance of DOCSIS Timing.

Table 6 - DOCSIS and HFC Time Error Profile

Budget Component	ITU-T Reference	I-CMTS n	I-CMTS @	I-CMTS TE	DAA n	DAA @	DAA TE
PRTC *(Class A is 100 ns, Class B is 40 ns, ePRTC is 30 ns)*	100	Class A		100	Class A		100
Network holdover and PTP rearrangements	NA or 400			200			200
Network dynamic TE and SyncE rearrangements	200 for 10 BC			200			200
T-BC *(Class A is 50 ns, Class B is 20 ns)*	500 for 10 BC	2	50	100	4	50	200
Link asymmetry	250 for 10 BC			50			50
Ethernet and Dynamic Aspects of Ethernet TE Budget	**1050**			**650**			**750**
CMTS *(Class A is 200 ns, Class B is 100 ns)*		Class A		200	Class A		200
DTP				50			50
HFC path				50			10
HFC node				50			10
HFC amp/LE		N+5	10	50	N+3	10	30
CM *(Class A is 250 ns, Class B is 100 ns)*		Class A		250	Class A		250
DOCSIS Network TE Budget				**650**			**550**
Rearrangements and short holdover in the end application	250 or 0			0			0
Base station slave or intra-site distribution	50	Class A		50	Class A		50
Base station RF interface	150			150			150
Base Station Network TE Budget	**450**			**200**			**200**
Total TE Budget	**1500**			**1500**			**1500**

8.4.1 Ethernet Network TE

This section is informative as values are derived from the [G.8271.1] recommendation. To support the addition of a DOCSIS network, a portion of the TE budget from the Ethernet portion of the network is reallocated to the DOCSIS part of the network.

8.4.1.1 PRTC TE

The PRTC couples the timing signal from a GNSS to a terrestrial Ethernet system.

There are three classes of time error for the PRTC that have been defined by the ITU:

- PTRC Class A is 100 ns,
- PRTC Class B is 40 ns, and
- enhanced PRTC (ePRTC) is 30 ns.

A T-GM can be included in Table 5; the T-GM is part of the PRTC budget.

8.4.1.2 Network Holdover and PTP Rearrangements TE

This system budget value is for holdover that can be implemented on at least one network element, such as a PRTC, a boundary clock, the I-CMTS, or the base station. The RPD/RMD and CM typically does not support holdover.

In a DOCSIS deployment scenario, the value of 400 ns in the ITU-T specifications is reduced to 200 ns.

8.4.1.3 Network Dynamic TE and Synchronous Ethernet Rearrangements

This number includes the dynamic time error between the PTRC and the CM, as well as any rearrangements in the SyncE network between the PRTC and the CMTS. The value of 200 ns assumes ten class A T-BC or twenty class B T-BC or some combination thereof.

This number, in theory, could be reduced if the number of T-BC deployed is less than these limits, but it is recommended that it not be reduced below 100 ns.

8.4.1.4 Telecom Boundary Clock (T-BC) TE

This value is the number of network switching elements in the packet network between the PRTC and the CMTS or RPD/RMD.

cTE is measured from an input Ethernet port to an output Ethernet port. There are three classes of cTE for the Ethernet switches that have been defined by the ITU:

- T-BC Class A has cTE of 50 ns or less,
- T-BC Class B has cTE of 20 ns or less,
- T-BC Class C has cTE of 10 ns or less, and
- T-BC Class D is for further study by ITU-T.

In a practical system with multiple T-BC switch hops, there can be a mixture of T-BC classes.

If the RPD is used in a daisy-chain mode in which Ethernet packets switch from one Ethernet port to another Ethernet port of the RPD/RMD, then each hop in the daisy-chain is considered as counting towards the T-BC budget.

8.4.1.5 Link Asymmetry TE

This budget is for the sum of all differences in the transmit and receive network paths between the PRTC and the base station, excluding the DOCSIS portion of the network, which is separately budgeted. For example, this difference in path delay is typically 1.5 ns per foot of fiber cable divided by 2.

8.4.2 DOCSIS Network TE Budget

The values in this section are normative. These values are not currently included in the ITU-T G.827x series of synchronization recommendations.

8.4.2.1 CMTS TE

For an I-CMTS system, this value refers to the time error measured from the NSI Ethernet port of the CMTS to the DOCSIS downstream RF port of the CMTS. For a DAA system, this refers to the time error measured from the CIN Ethernet port to the DOCSIS downstream RF port of the DAA RPD or RMD.

There are two classes of CMTS that have different time errors defined.

- A CMTS Class A MUST support a cTE of 200 ns or less.
- A CMTS Class B MUST support a cTE of 100 ns or less.

The CMTS receives [IEEE 1588-2008] messages from the packet network and outputs a DOCSIS 3.1 64-bit timestamp.

The SC-QAM-based DOCSIS 3.0 systems require the maximum DOCSIS timestamp jitter to be 500 ns peak-to-peak. This number relates to the variation in time between when a SYNC message is internally generated and when it is delivered to the CMTS downstream transport.

The OFDM-based DOCSIS 3.1 systems decreased this jitter value to 5–10 ns (1/204.8 MHz plus phase noise jitter).

Thus, the CMTS has a nominal delay in the delivery of the DOCSIS timestamp irrespective of jitter. For a CMTS to be compliant to this specification, it would use a DTP value that represents the nominal delay from the NSI Ethernet port to the delivery of the DOCSIS timestamp to the DOCSIS downstream RF port. The CMTS cTE would then be the difference between the stated DTP delay and the actual CMTS path delay.

8.4.2.2 DTP TE

The DTP TE is the overall TE contributed by the DTP algorithm. It is an additional time error budget above and beyond the time error budget of each individual DTP element.

If the DTP algorithm is implemented on the CM, the CM MUST ensure that the DTP algorithm contributes less than 50 ns of additional time error.

If the DTP algorithm is implemented on the CMTS, the CMTS MUST ensure that the DTP algorithm contributes less than 50 ns of additional time error.

This budget is for the DTP algorithm only and does not include measurement errors in individual DOCSIS or HFC network elements. For testing purposes, this budget is additive to the budget of the network element that implements the DTP master function.

8.4.2.3 HFC Path TE

The TE from the HFC path is due to any path asymmetries that can exist between the forward path and the reverse path. This includes asymmetries such as due to the insertions of DWDM equipment. The TE is half of the asymmetry error, which is the net difference in forward and reverse path lengths.

For the case of an I-CMTS, the HFC path TE includes the optical and coax portions of the HFC plant. Some of the asymmetry errors can arise from the fact that the forward and reverse fibers are terminated in different racks within the hub and can have slightly different path lengths.

For the case of DAA, the HFC path TE includes only the coax portion of the HFC plant because the optical path is covered under the Ethernet switch budget.

The TE budget for the HFC path is described in Table 6.

The forward and reverse signals are always within the same coax but are at different frequencies. There can be up to 300 m of coax between each node/amp.

8.4.2.3.1 Minimizing the Impact of Group Delay on HFC Path Delay

The value of the HFC path delay can be affected by group delay distortion.

In the downstream direction, the HFC path is the PLC channel in the primary DOCSIS downstream.

In the upstream direction, the HFC path can be either an OFDMA channel or a SC-QAM channel; each upstream channel is individually ranged, and those ranging parameters will impact the value of TRO for DTP. The goal is to have equal group delay in the upstream and downstream path, which is achieved by minimizing the impact of group delay. When looking at this impact, it is important to understand:

- *The frequency ranges where group delay is most prevalent*. Group delay tends to be most prevalent at and near the edges of the diplex filter transition region (e.g., 42 MHz in the upstream and 54 MHz in the downstream). It also can be prevalent at the bottom end of the upstream spectrum (5 MHz to about 10 MHz) because of the AC bypass circuitry in some network devices. The downstream upper band edge is not adjacent to a diplex filter transition region, but frequency response rolloff at the band edge could cause group delay.
- *Amplitude ripple*. Impedance mismatches that cause micro-reflections result in standing waves or amplitude ripple, which in turn can cause group delay ripple.
- *The factors affecting the amount of group delay*. The amount of group delay depends on the following: One is the design of the diplex filter (for instance, a sharper filter cutoff and a narrower transition region bandwidth between the upper edge of the upstream and lower edge of the downstream result in more group delay near the edges). Another is the number of cascaded diplex filters. For instance, each amplifier has two diplex filters, so as more amplifiers are cascaded, the number of diplex filters in cascade increases (as does the group delay). But in a node+0 design, there is only the diplex filter in the node. (Note: There might

be other diplex filters in in-line equalizers or perhaps in subscriber drop amplifiers and/or some passive devices).

Overall, signals operating on frequencies near the diplex filter band edges are most susceptible to group delay. Signals at other frequencies will generally have little group delay to contend with. For instance, assume a typical sub-split band plan (5 MHz to 42 MHz upstream, 54 MHz to 1 GHz downstream). The upstream group delay will be worst near 42 MHz (and near 5 MHz), and the downstream group delay will be worst near 54 MHz. But if an OFDM signal is carried at, say, 258 MHz to 450 MHz, there will generally be negligible group delay across the entire OFDM signal.

Choosing the downstream and upstream channels for the HFC path for the TRO measurements should take into the above mentioned factors to minimize the impact of group delay.

Specific values related to the impact of group delay distortion in both upstream and downstream are under study.

8.4.2.4 HFC Node TE

In the I-CMTS forward path case, the RF spectrum is sent over the analog modulated fiber link and then down-converted onto the coax. The return path can be either analog or digital. In the analog case, the reverse path RF spectrum is coupled from the coax onto an analog wavelength on the fiber and sent to the hub. In the digital case, the RF spectrum is digitally sampled and placed onto a digital transmission over the fiber. This technique is used in HFC digital returns. Operation with digital returns in the upstream path can increase upstream latency and increase asymmetry.

The optical node is an analog network delay element that inserts in the HFC but does not participate in the DTP. The link budget for the analog optical node also includes the coax path from the CMTS to and including the optical transmitters and receivers at the hub site, the optical fiber path, and the optical node. The TE for the node is half the difference between the forward path delay and the reverse path delay.

For a DAA system, this TE is contributed by the combination of the RPD/RMD and RF components in the DAA node. The TE for the optical link is covered separately in the Ethernet network budget.

The amplifier delays for an analog forward path and analog reverse paths are similar and low in value. However, the upstream path has a tighter RF passband, and the analog filters add delay. The asymmetry and delay are impacted by the choice of operating frequency for the DOCSIS timestamp in the downstream and the ranging path in the upstream.

- An analog optical node MUST support a cTE of 50 ns or less.
- A DAA node MUST support a cTE of 10 ns or less.

8.4.2.5 HFC Amplifier/Line Extender TE

The TE for the amplifier (amp) and line extender (LE) is half the difference between the forward path delay and the reverse path delay. Similar to the node, the forward and reverse path delays are determined in part by amplifier delay and part by RF band pass filtering.

It is worth noting that for any particular CMTS-to-CM path, the number of amplifiers is not known. On an N+5 plant, the number of amplifiers in a CMTS-to-CM path could be from 0 to 5 or more. N+5 is a maximum value rather than an absolute value. If the DTP algorithm assumes the maximum number of amplifiers, then some CMTS-to-CM paths can simply have better performance.

This specification assumes that an HFC amplifier or line extender supports a cTE of 10 ns or less. Equipment that does not meet this requirement can cause unacceptable errors.

8.4.2.6 CM TE

The TE contributed by the CM is measured between the DOCSIS downstream RF port and the CMCI Ethernet port. There are two classes of time error for the CM that have been defined.

- A CM that claims to be Class A MUST support a cTE of 250 ns or less.
- A CM that claims to be Class B MUST support a cTE of 100 ns or less.

The CM manufacturer can internally apply asymmetry correction factors to its equipment in order to meet these budgets. In DTP, the TRO is a critical value that is measured by the CM. The round-trip delay is derived from this value. The value of TRO also changes with DOCSIS ranging, and this parameter is intended to represent that change over time.

8.4.3 eNB Network TE

This section is informative as values are derived from the ITU-T [G.8271.1] recommendation.

8.4.3.1 Rearrangements and Short Holdover in the End Application TE

In this scenario, the network provides holdover, and therefore, the base station does not require a holdover budget; it will always synchronize to the CM PTP master. If the PRTC fails, the rearrangement to select a new PRTC will be done by equipment on the network segment between the PRTC and the CMTS, which is covered in the earlier rearrangement budget. In alternate scenarios, the base station can go into holdover during PRTC failure rather than follow the CM PTP master while the rearrangement is occurring.

In a typical DOCSIS scenario, this budget value is usually set to 0 ns.

8.4.3.2 Base Station Slave or Intra-Site Distribution BC

Intra-site distribution refers to an alternate clock path from a CM to a base station that is not PTP over Ethernet (e.g., Network Listen). This budget of 50 ns also includes the TE from the Ethernet port of the base station to its internal clock reference.

The timing budget is derived from [G.8271.1].

8.4.3.3 Base Station RF Interface TE

This TE is from the internal clock reference of the base station to its air interface. The value of 150 ns is derived from an assumption on how base stations are designed and from [G.8271.1].

8.5 Profile Requirements on DOCSIS Components

8.5.1 IWF T-BC Models

When DOCSIS equipment is inserted in the synchronization chain, as shown in Figure 27 (Section 8.3.2), it can be modeled as a first IWF used to convert PTP to the DOCSIS protocol (running on the I-CMTS, RPD, or RMD) and as a second IWF used to convert the DOCSIS protocol (running on the CM) back to PTP.

8.5.1.1 IWF Approaches

The intention of the IWF shown in Figure 27 is to faithfully replicate the functionality of [G.8275.1] from a PTP profile point of view. That includes the operation of the Best Master Clock Algorithm (BMCA), the transfer of all PTP fields (such as those in the Announce messages), and other information. Within [G.8275.1], an Ethernet PTP interface handles both synchronization aspects (Sync, Follow_Up, Delay_Req, and Delay_Resp messages) and control plane aspects (Announce messages). For non-Ethernet interfaces, there are two approaches that can be considered from ITU-T or [IEEE 1588-2008]: virtual PTP ports and Special PTP ports.

Virtual PTP ports do not use PTP for either synchronization (Sync, Follow_Up, Delay_Req, Delay_Resp messages) or control plane (Announce messages) aspects and are typically used to model GNSS inputs or proprietary interfaces within equipment. [G.8275], Annex B, "Inclusion of an external phase/time interface on a PTP Clock," contains a useful list of PTP parameters that are required to be transferred through the IWF when using virtual PTP ports in order to ensure compatibility with the PTP equipment on either side of the IWF. This IWF model approach is not used for the DOCSIS network.

Special PTP ports do not use PTP for synchronization aspects but do use PTP for control plane aspects. This IWF model approach is used for the DOCSIS network.

The following useful references are available from ITU-T. They relate to PTP profiles and network limits, equipment performance, and testing and measurement.

- [G.8275], Appendix III, "Generic IWF PTP Clock"
- [G.8275.1-A1], Appendix XI, "Considerations on Native Access Equipment"
- [G.8275.1], Annex C, "Inclusion of an external phase/time input interface in a T-BC"
- [G.8275], Annex B, "Inclusion of an external phase/time interface on a PTP Clock"

8.5.2 ITU-T G.8275.1 IWF Using Special PTP ports

A Special PTP port fits well with the DOCSIS model in which PTP synchronization is replaced with native DOCSIS methods (TRO, DTP), but PTP control messages can still be exchanged between the DOCSIS equipment. The use of a Special PTP port then allows the DOCSIS equipment to follow faithfully [G.8275.1] using the defined Announce messages and BMCA while also transferring the synchronization through established methods of TRO and DTP.

A diagram of an IWF containing a Special PTP port is shown in Figure 28 (copied from [G.8275.1], Figure XI.1).

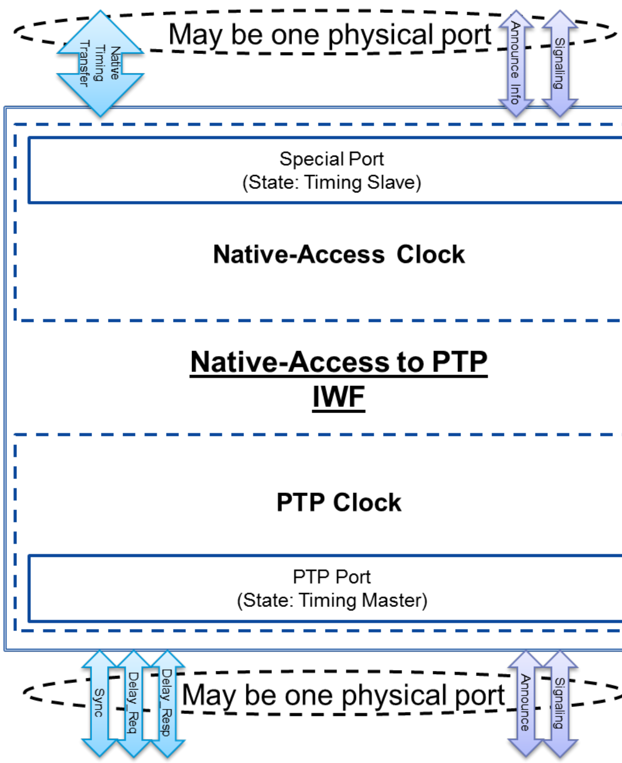

Figure 28 - Timing Flow between Native PTP and Native Access Media (from ITU-T [G.8275.1], Figure XI.1)

8.5.2.1 Special PTP Port and Announce Message Transfer

The transfer of the Announce message of a Special PTP port is typically expected to be in the native Ethernet port (Announce message datagram carried directly over Ethernet encapsulation). The Announce message contents/fields need to be carried to the next hop in the synchronization chain in order to ensure correct operation of the PTP control plane. In [G.8275.1], the Announce messages are transferred at 8 packets per second. Note that Announce messages do not require QoS from the network as they are not time sensitive (e.g., they are not sensitive to packet network delay and jitter, unlike Sync or Delay_Req messages).

If desired, the Announce message contents can be transferred through a technology-specific alternate mechanism. The Announce message header is defined in [IEEE 1588-2008], and the field values are fully specified in [G.8275.1].

How the Announce message fields are transferred is described in Section 6.7.3.

8.5.3 IWF Implementation in DOCSIS Equipment

Figure 29 exhibits the IWF implementation in DOCSIS equipment using Special PTP ports. A PTP-to-DOCSIS IWF is implemented on the CMTS, and a DOCSIS-to-PTP IWF is implemented on the CM. The details of the IWF operations are described in Section 8.5.4 and Section 8.5.5. Note that in Figure 29, it is assumed the network segments outside DOCSIS equipment (i.e., before the CMTS or after the CM) comply with the same ITU profile. If the network complies with [G.8275.1], then the PTP control plane only contains Announce messages.

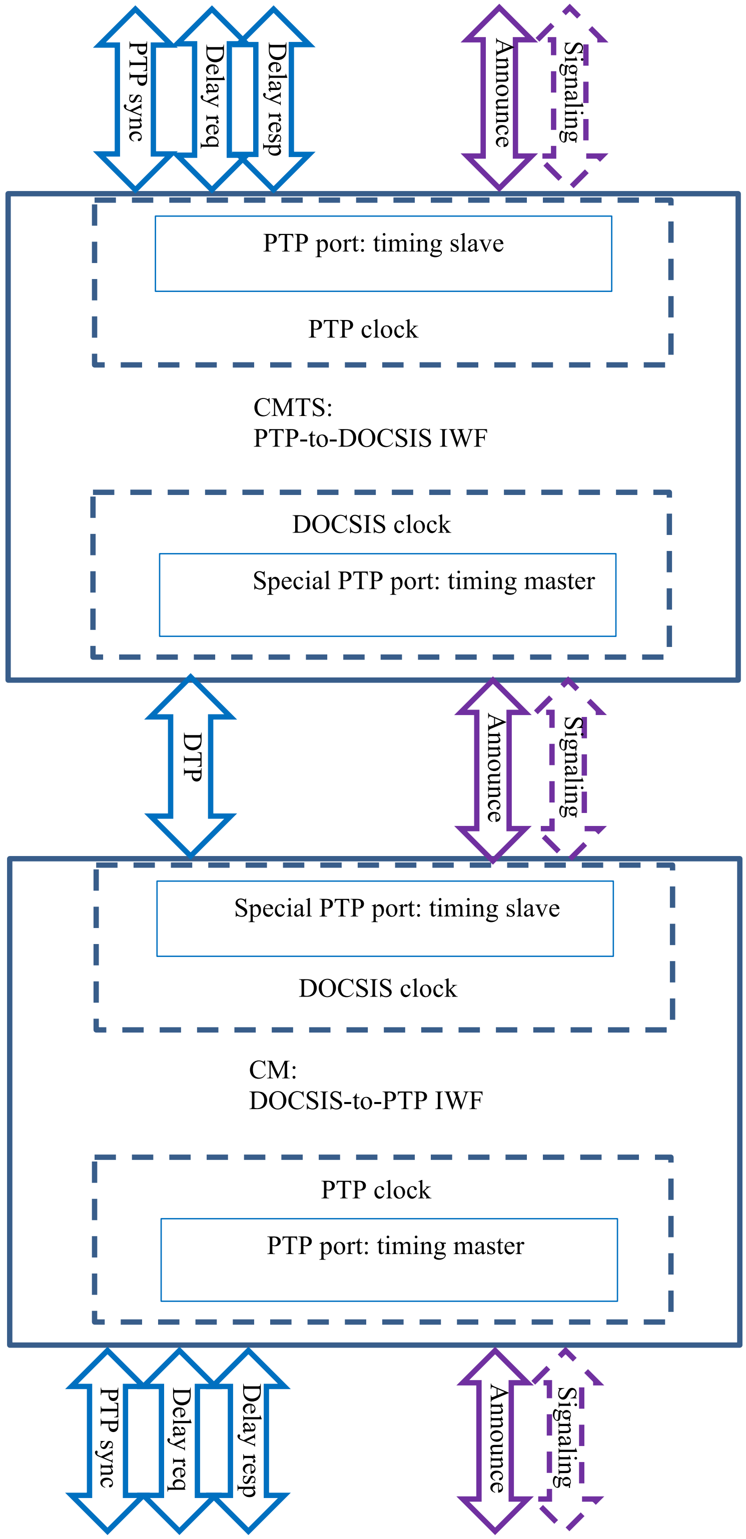

Figure 29 - IWF Implementation in DOCSIS Equipment Using Special PTP ports

8.5.4 PTP-to-DOCSIS IWF T-BC Operation

The IWF follows the operation as described in [G.8275.1] for a T-BC, with the additional considerations included in this section. The IWF sending timing downstream from PTP to the DOCSIS network performs several functions.

8.5.4.1 Native Ethernet PTP Ports

The native Ethernet PTP ports operate as described in [G.8275.1]. One of the upstream-facing native Ethernet PTP ports would be selected as the best master for the T-BC.

8.5.4.2 DOCSIS Special PTP Ports

The downstream-facing DOCSIS Special PTP port typically would be configured as masterOnly (i.e., portDS.masterOnly of TRUE). The DOCSIS Special PTP port needs to use DOCSIS native support (TRO and DTP, described in Section 6) to convey the synchronization. In an I-CMTS system, the CMTS MUST implement a downstream-facing DOCSIS Special PTP port that conveys the control plane information carried in an Announce message (see Section 6.7.3). In a DAA system, the RPD MUST implement a downstream-facing DOCSIS Special PTP port that conveys the control plane information carried in an Announce message (see Section 6.7.3).

Note that the network synchronization traceability information that is sent in the Announce message field, covering operation of a T-BC with a SyncE input or without a SyncE input, is detailed in [G.8275.1], Table 2, "Applicable clockClass values," and Appendix V, "Description of PTP clock states and associated contents of Announce messages." The traceability information propagated through the Announce message is that of the PTP connection, not that of the SyncE connection (e.g., ESMC message and [G.8264] traceability chain).

8.5.5 DOCSIS-to-PTP IWF T-BC Operation

The IWF follows the operation as described in [G.8275.1], with the additional considerations included in this section. The IWF sending timing downstream from the DOCSIS network to PTP performs several functions.

8.5.5.1 DOCSIS Special PTP Ports

The upstream-facing DOCSIS Special PTP port typically would be configured as receive-only (such as a slave-only configuration on a PTP port). The Announce messages or content received on the Special PTP port feeds into the [G.8275.1] best master selection process. Typically, during normal operation, the Special PTP port is selected as the best master for the T-BC.

8.5.5.2 DOCSIS Port Handling

In an I-CMTS system, the CMTS MUST implement the DOCSIS Special PTP port that follows the port state protocol as defined in [IEEE 1588-2008].

In a DAA system, the RPD or the RMD MUST implement the DOCSIS Special PTP port that follows the port state protocol as defined in [IEEE 1588-2008].

The CM MUST implement the DOCSIS Special PTP port that follows the port state protocol as defined in [IEEE 1588-2008].

A failure of the DOCSIS interface would eventually result in an announceReceiptTimeout alarm in the PTP profile because of a loss of incoming Announce messages over the Special PTP port. The DTP synchronization process is mapped to IEEE1588 SYNCHRONIZATION_FAULT as defined in section 9.2 of [IEEE 1588-2008]. Therefore:

- If the CM is fully synchronized using DTP without any DTP alarm (e.g., timeout), then the CM MUST set SYNCHRONIZATION_FAULT to FALSE; otherwise, the CM MUST set it to TRUE. The default value is TRUE.
- In the LISTENING state, when an Announce message is received from upstream (RPD or CMTS), the port will transition to UNCALIBRATED state. The CM will use the ACQUIRING feature in [G.8275] Appendix VIII to delay the advertisement downstream (towards the end application) of updated clockClass information while it remains in the UNCALIBRATED state.

- In the UNCALIBRATED state, when the CM is fully synchronized to the DTP t-adj, then it MUST clear the SYNCHRONIZATION_FAULT alarm and transition to SLAVE state.
- In the SLAVE state, when there is a loss of DTP information (e.g., timeout), the CM MUST implement the Special PTP port that sets SYNCHRONIZATION_FAULT to TRUE and the port will fall back to UNCABLIRATED state.
- Handling of announce messages is as defined in [IEEE 1588-2008].

A simplified version of the state protocol for the special PTP port in the CM is shown below as an example.

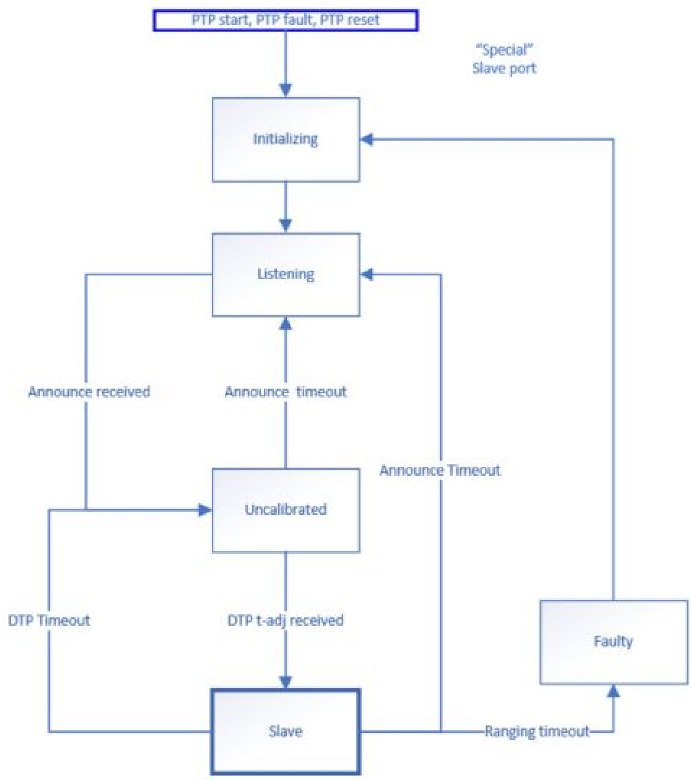

Figure 30 - Example State Protocol for Special PTP Port in CM

As it relates to the degradation of the clockClass the following scenarios are considered:

- When DTP information is lost, then the CM needs to degrade from the ingress Announce clockClass value received to 135 and/or 165 depending if the holdover performance is "within holdover specification" or "out of holdover specification" as shown in Table 2 of [G.8275.1]. It should be considered that the CM is always syntonized by the physical layer clock and therefore the frequencyTraceable flag is TRUE, and thus the CM may stay "within holdover specification" (i.e., clockClass 135) for a very long duration. In case the CM detects a significant change in the TRO value while DTP is absent, the CM can decide to change its holdover performance to "out of holdover specification" (i.e., clockClass 165).
- When Announce information is lost (i.e., announceReceiptTimeout) then the cable modem needs to degrade from the ingress Announce clockClass value received to 135 and/or 165 depending if the holdover performance is "within holdover specification" or "out of holdover specification" as shown in Table 2 of [G.8275.1]. As the DTP information traceability is unknown when the announce message is absent, a conservative approach may be to immediately advertise frequencyTraceable and timeTraceable flags as FALSE as well as clockClass of 165.

When DTP and Announce information are both lost, then a conservative implementation may immediately advertise frequencyTraceable FALSE, timeTraceable FALSE and clockClass 248.

8.5.5.3 Native Ethernet PTP Ports

The downstream-facing native Ethernet ports operate as described in [G.8275.1] for a T-BC. Typically, they would be configured as masterOnly operation (i.e., portDS. masterOnly).

8.5.5.4 Generation of Physical Layer Clock and QL

It is possible for the IWF to generate an Ethernet output with a physical layer clock traceable to the PTP synchronization chain, such as shown in [G.8275], Appendix VI, "Use cases for mapping from PTP clockClass values to quality levels." Refer to [G.8275.2-A1], Annex F, "Mapping from PTP clockClass values to quality levels," for the mapping table.

Referring to Section 6.7.1, it is noted again that the traceability information received on the Special PTP port of the IWF is that of the PTP connection and not that of the SyncE connection.

8.6 Performance of DOCSIS Timing Equipment

Single box performance refers to the performance of each component within a DOCSIS system individually. Two box performance refers to the performance of a whole DOCSIS system viewed together as a two-box system.

8.6.1 Two Box Performance

In order to insert [IEEE 1588-2008]-capable DOCSIS equipment within the network, the total DOCSIS synchronization portion of the chain typically should meet the following performance requirements when measured in isolation, between the PTP input on the first IWF (PTP-to-DOCSIS) and the PTP output on the second IWF (DOCSIS-to-PTP). The performance is covered in [G.8273.2], Appendix V, “Performance Estimation for Cascaded Media Converters acting as T-BCs” (from which are extracted the data in Table 7), which summarizes noise generation estimation for a pair of media converters based on the Class A and Class B T-BC noise generation specifications.

Table 7 - Noise Generation Estimation for a Pair of Media Converters (from [G.8273.2], Table V.1)

	Based on Class A T-BC			Based on Class B T-BC		
	Single T-BC	Pair	Pair DOCSIS Class A IWF	Single T-BC	Pair	Pair DOCSIS Class B IWF
cTE (ns)	±50	±100	±500	±20	±40	±250
dTE_L MTIE (ns)	40	60	60	40	60	60
dTE_L TDEV (ns)	4	6	6	4	6	6
dTE_H (peak-to-peak, ns)	70	70	70	70	70	70
max|TE| (ns)	100	160	560	70	100	310

Note: The values for cTE are obtained from Table 6, rows “CMTS”, “DTP”, and “CM” by linear addition. The values for max|TE| are the sums of cTE and dTE_L. The remaining values are taken directly from [G.8273.2], Appendix V.

Note: The values in Table 7 (specifically max|TE| and cTE) are for I-CMTS. For the case of DAA, these numbers should be increased by 10 ns to account for the HFC node shown in Table 6.

Note: The values in Table 7 do not include any errors introduced by the test environment, such as cables. The test environment and setup need to be properly calibrated to minimize additional errors.

See Section 8.4 for a total network budget, which includes DOCSIS equipment and interconnection within the network. In that section, the cTE of the original [G.8271.1] has been redistributed in order to allocate a larger value to the DOCSIS equipment and network.

8.6.2 Single Box Performance

It is the intention of this specification to enable the development of third-party test equipment that can measure single box performance. To accomplish this, the specification needs to define a demarcation point somewhere on the DOCSIS RF path (e.g., device coax connector or within the coax path) where the test equipment can be connected to the DUT. The definition of this demarcation point is under study.

8.6.2.1 PTP-to-DOCSIS IWF

In an I-CMTS system, the CMTS MUST implement the PTP-to-DOCSIS IWF that complies with [G.8273.2] except for including a larger allowance for cTE.

In an I-CMTS system, the CMTS MUST implement the PTP-to-DOCSIS IWF that complies with Table 8 of this document for cTE and max|TE|, excluding DTP.

In a DAA system, the RPD MUST implement the PTP-to-DOCSIS IWF that complies with [G.8273.2] except for including a larger allowance for cTE.

In a DAA system, the RPD MUST implement the PTP-to-DOCSIS IWF that complies with Table 8 of this document for cTE and max|TE|, excluding DTP.

Table 8 - PTP-to-DOCSIS IWF Performance

Class	cTE (ns)		max|TE| (ns)	
	T-BC [G.8273.2]	T-BC-DOCSIS IWF	T-BC [G.8273.2]	T-BC-DOCSIS IWF
Class A	±50	±200	100	250
Class B	±20	±100	70	150

NOTE: The values in Table 8 for cTE are obtained from “CMTS” values in Table 6. The values for max|TE| are obtained by first calculating the additional allowance between [G.8273.2] and DOCSIS IWF for cTE, and then adding that value to cTE.

8.6.2.2 DOCSIS-to-PTP IWF

The CM time error is not specified to fully follow [G.8273.2]. The CM, which is the equipment where the DOCSIS-to-PTP IWF resides, MUST comply with only the following max|TE| and cTE requirements from Table 9, excluding DTP.

Table 9 - DOCSIS-to-PTP IWF Performance

Class	cTE (ns)		max|TE| (ns)	
	T-BC [G.8273.2]	T-BC-DOCSIS IWF	T-BC [G.8273.2]	T-BC-DOCSIS IWF
Class A	±50	±250	100	300
Class B	±20	±100	70	150

Note: The values in Table 9 for cTE are obtained from “CM” values in Table 6. The values for max|TE| are obtained by first calculating the additional allowance between [G.8273.2] and DOCSIS IWF for cTE, and then adding that value to cTE.

8.6.2.3 Other Components

For other components included in the HFC plant, refer to Section 8.4, specifically Table 6, for performance requirements.

8.6.3 Performance Measurement

The measurement methodology is covered in Annex B of this document. This annex is based on [G.8273], Clause A.6, "Clocks containing media converters," for the above DOCSIS synchronization portion. This covers the total error introduced between the PTP input on the first IWF (PTP-to-DOCSIS) and the PTP output on the second IWF (DOCSIS-to-PTP).

Annex A PTP and DOCSIS Timestamp Conversion (Normative)

The [IEEE 1588-2008] Precision Time Protocol (PTP) timestamp is 80 bits long; it is a count of the number of seconds and nanoseconds that have passed since 00:00:00 January 1, 1970. The 48 most significant bits represent seconds, and the remaining 32 bits represent nanoseconds. The [IEEE 1588-2008] PTP timestamp will roll over in roughly 8.9 million years.

The DOCSIS 3.1 extended timestamp is 64 bits long and is a measure of clock periods passed since the same start time of 00:00:00 January 1, 1970. It is an evolution of the 32-bit DOCSIS 3.0 timestamp, which is placed roughly in the center of the 64 bits and increments at a rate of 10.24 MHz for a period of approximately 97.66 ns. This 32-bit counter rolls over every 419.4304 seconds, or about 6.99 minutes. A 23-bit binary epoch field is added, which extends the maximum count to 55 bits at a rate of 10.24 MHz, which would roll over after about 112 years, in the year 2082.

For finer time resolution, 5 additional least significant bits operating as a modulo 20 counter increment at a rate of 20×10.24 MHz, or 204.8 MHz, for a period of approximately 4.88 ns. An additional 4 least significant bits operating as a modulo 16 counter increment at a rate of 320×10.24 MHz, or 3276.8 MHz, for a period of approximately 305 ps.

Both timestamps are based on International Atomic Time (TAI) starting 00:00:00 January 1, 1970. Thus, no starting offset is required, and neither timestamp is affected by leap seconds.

A method to convert an [IEEE 1588-2008] PTP timestamp to a 64-bit DOCSIS 3.1 timestamp is shown in Figure 31, and conversion in the opposite direction is shown in Figure 32. The term “Rem” stands for the remainder of a division operation.

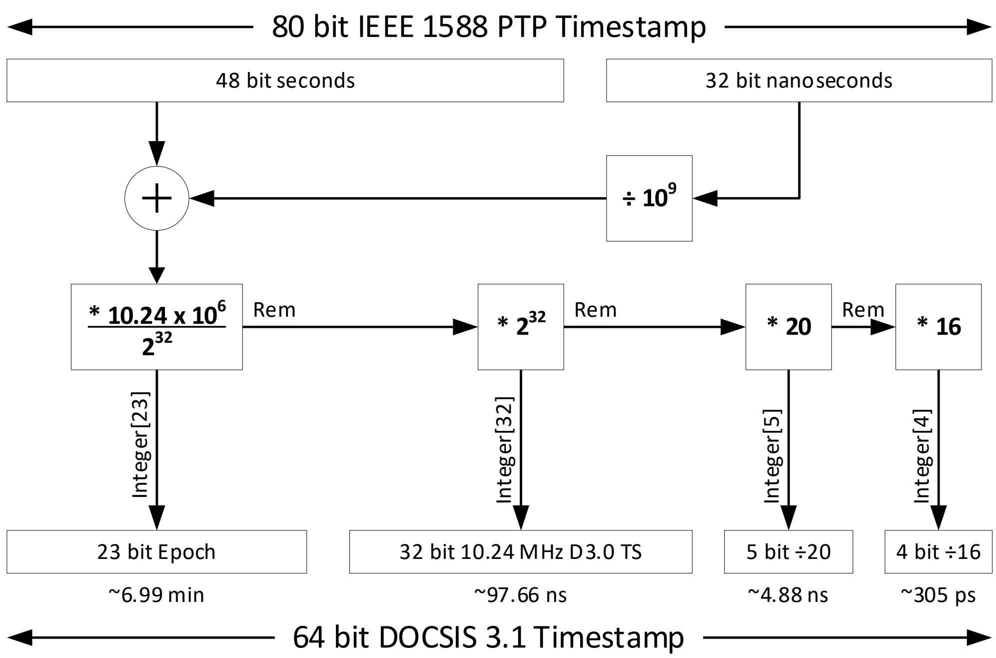

Figure 31 - Conversion from [IEEE 1588-2008] PTP Timestamp to DOCSIS 3.1 Timestamp

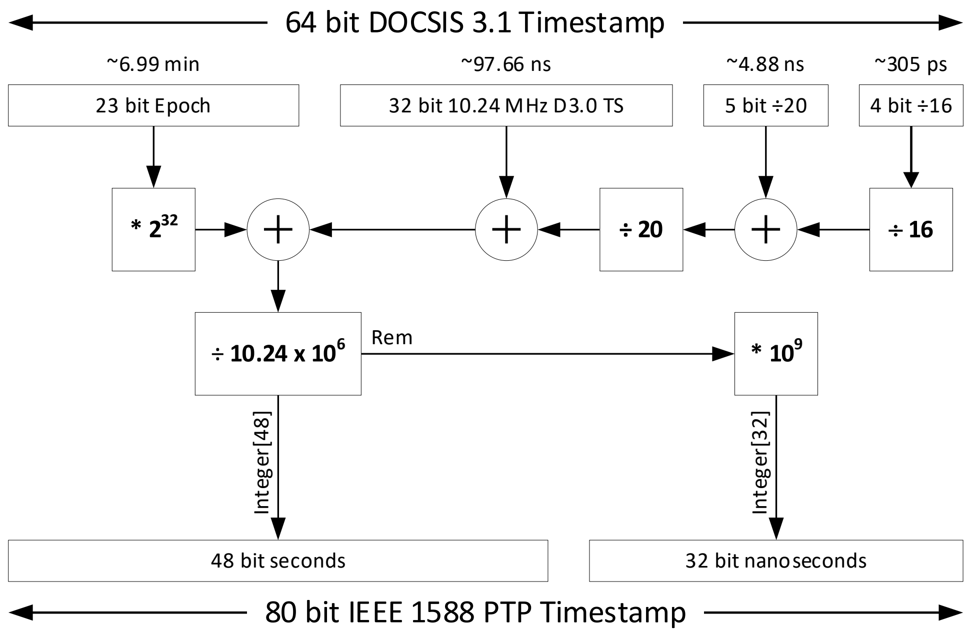

Figure 32 - Conversion from DOCSIS 3.1 Timestamp to [IEEE 1588-2008] PTP Timestamp

Annex B Testing and Validation (Normative)

B.1 DTP Timing Performance Test Environment

B.1.1 Introduction

Figure 33 shows the reference diagram for the synchronization system. The goal is to align the clock references to within the limits defined in ITU-T Recommendation [G.8271.1].

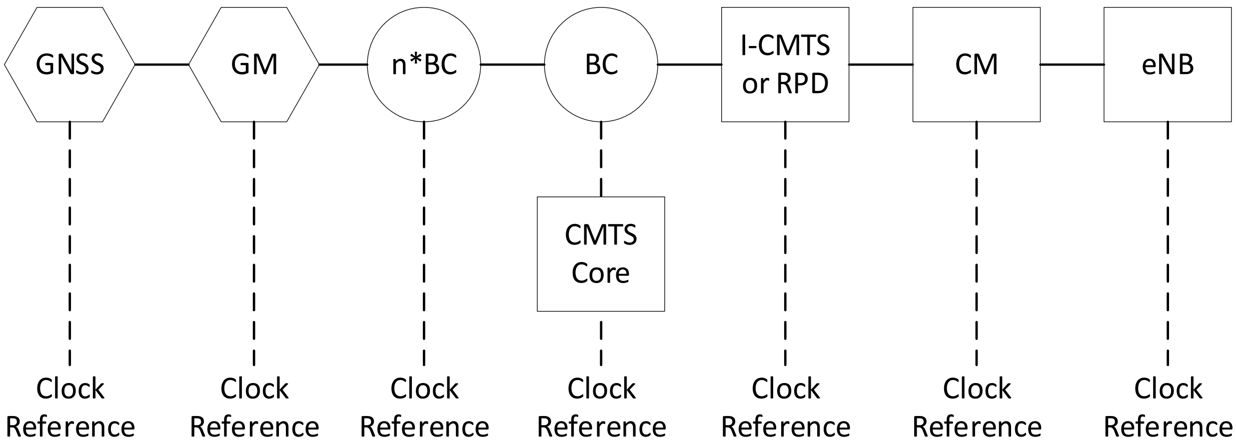

Figure 33 - GNSS DOCSIS Reference System for Testing

In effect, therefore, from a timing and synchronization point of view, there is a reference clock, a synchronization network, the cable system itself, and the timing consumer (the eNB), as shown in Figure 34.

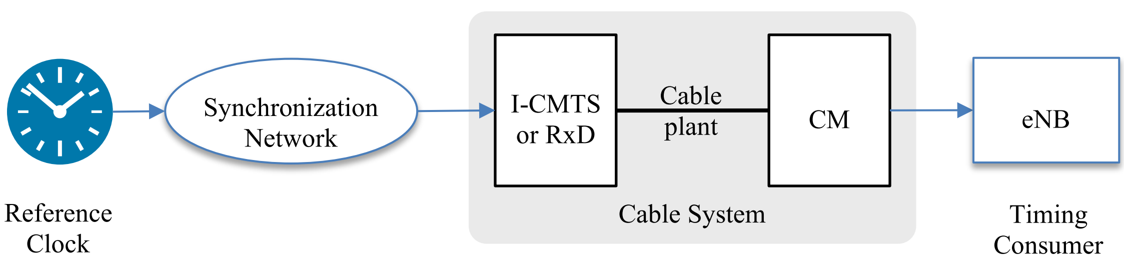

Figure 34 - Simplified View of the Synchronization Path

Three ITU-T recommendations ([G.8271.1], [G.8272], [G.8273.2]) define the synchronization specifications for the non-cable part of the chain. Appendix V of [G.8271.1] shows how to calculate a timing budget for this part of the synchronization chain. Using ITU-T as a model, the timing budget for a cable system is described in Section 8.4 of this document. Different budget allocations can be applicable in other scenarios such as APTS or PTS.

B.1.2 Measuring the Timing Performance of the I-CMTS/CM Combination

Testing of synchronization components (T-GMs, T-BCs, T-TSCs, etc.) is normally done in isolation so that the performance of the individual clocks can be measured without being affected by other components in the system. However, in the case of access systems such as cable, it might not be possible to probe on the access media itself. Such systems can be measured in a "back-to-back" configuration, as shown in Figure 35, taken from Annex A.6 of [G.8273].

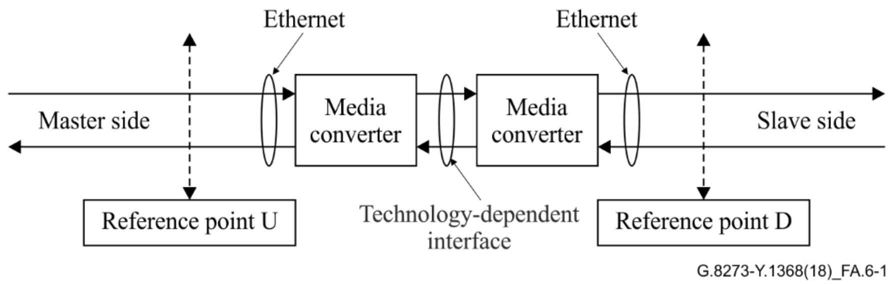

Figure 35 - Demarcation of Measurement Points for Testing Media Converter Nodes

In a laboratory situation (i.e., where the I-CMTS and CM are physically close, such that they can be tested together), example test equipment normally consists of a reference clock, coupled with a timing master and a timing slave, and the ability to impair the time or frequency of the master output (see Figure 36). The 1pps output of the CM is optional.

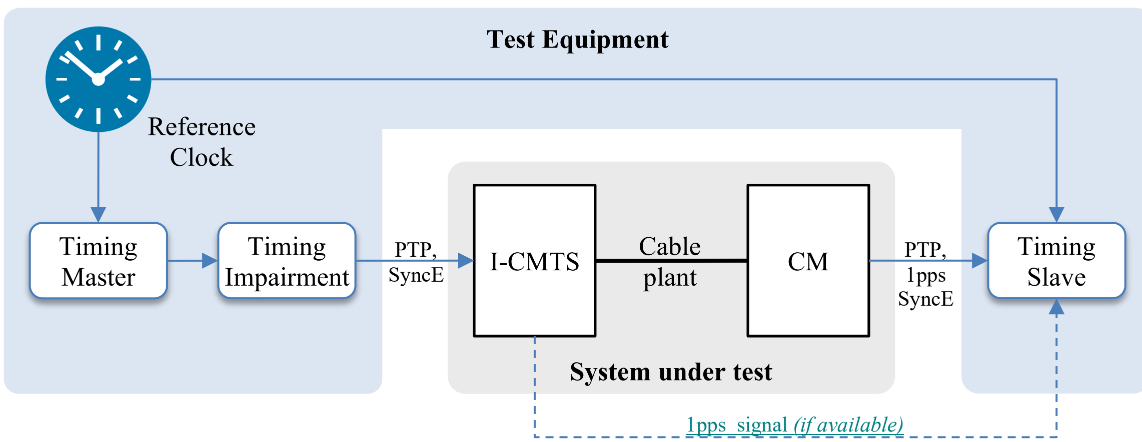

Figure 36 - Example Laboratory Test System for I-CMTS

The timing impairment block can be used to emulate the effect of a network or to apply specific patterns to measure the tolerance or behavior of the network to certain noise types. The timing slave measures the output of the system under test and compares it to the reference clock.

This type of testing treats the entire cable system as a “black box” for timing purposes; a known timing signal is applied at the input, and the response is measured at the output. The timing signal can take the form of PTP (time and frequency), SyncE (frequency only), or 1 PPS with a serial time-of-day message channel (time and frequency). If the I-CMTS node has a synchronization output signal, such as a 1 PPS output, this can also be measured.

For an RPD system, an additional CMTS core node is required for the system to function. For an RMD system, a MAC Manager is required. If the RxD node has multiple independent Ethernet ports on the CIN side, then the RxD can be connected directly to the PTP Master on one port and to the CMTS Core on the second port (see Figure 37). If there is only a single Ethernet port on the RxD node, then an additional T-BC needs to be inserted in order to connect the CMTS core node (see Figure 38).

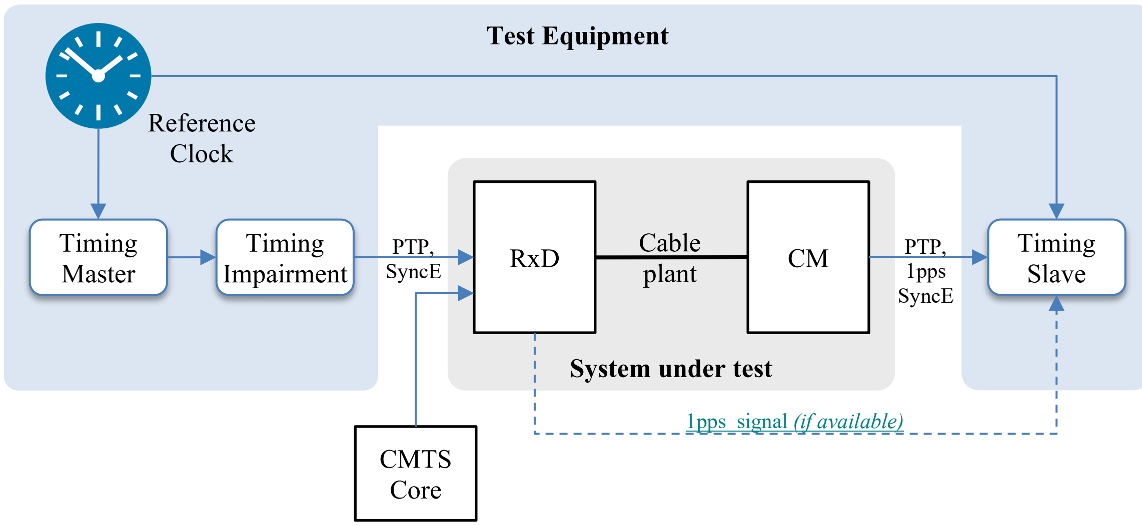

Figure 37 - Example Laboratory Test System for RxD Systems (CMTS Core Connected Directly)

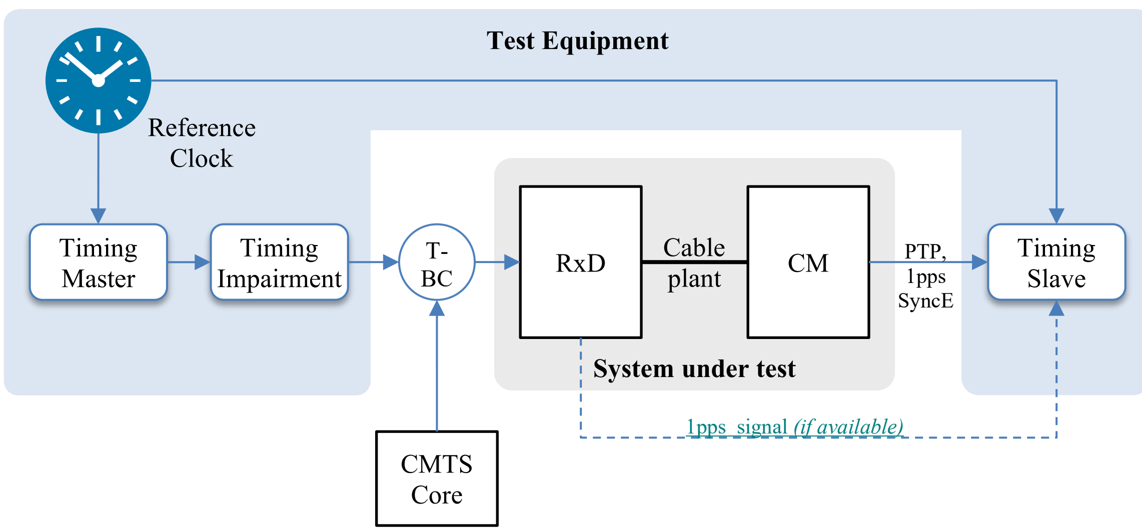

Figure 38 - Example Laboratory Test System for RxD Systems (RxD Connected via T-BC)

B.1.3 Timing Performance Categories

Timing performance of equipment is specified under the following categories.

1. **Noise generation** – the amount of timing noise added to the synchronization signal by the system under test. This can be tested by applying a clean timing signal to the system under test and measuring the output signal. The timing budget for an I-CMTS or DAA cable system, described in Table 5 (Section 8.4), can be used as a suitable limit in this test.
2. **Noise tolerance** – the ability of the system under test to function in the presence of timing noise. This can be tested by applying the maximum amount of noise that the system is expected to tolerate to the input timing signal and verifying that the system still functions correctly. The timing budget for the Ethernet network, described in Table 5 (Section 8.4), can be used as a suitable limit in this test.

3. **Noise transfer** – this measures the time transfer bandwidth of the system. Normally, timing components act as a low-pass filter to timing noise. This can be tested by applying "noise tones" at different frequencies, and comparing the output amplitude of the tones to the input. The bandwidth of the cable system is further study.
4. **Transient response** – this measures the response of the system to time transients on the input, such as might be caused by rearrangement operations in the synchronization system. The transient response of the cable systems is for further study [G.8273.2].
5. **Holdover performance** – this measures the response of the system to loss of the synchronization signal at the input. The holdover aspect of the cable system is discussed in Section 8.2 and Section 8.4.1.2.

As discussed earlier, these tests all consider the system under test as a "black box." Any internal functions or configurations that affect the timing performance should be considered. For example, tests such as noise generation could be repeated with different configurations if it is thought that they can affect the performance. Specific configurations or settings that can affect timing are for further study.

Similarly, if the above tests indicate a failure, they do not provide any information about the cause of the failure or the location within the cable system. It might be necessary to consider probing at various points in the system, for example the RF signal on the cable plant. Methods of probing might include use of a "golden" cable modem of known performance and function.

B.1.4 Measuring the Timing Performance in the Field

In the field, the I-CMTS and CM might not be physically close enough to use a single piece of test equipment with a common reference clock. In this scenario, a GNSS-connected test set is required, such that the test equipment is referenced back to the same ultimate time standard as the overall system. This setup is shown in Figure 39.

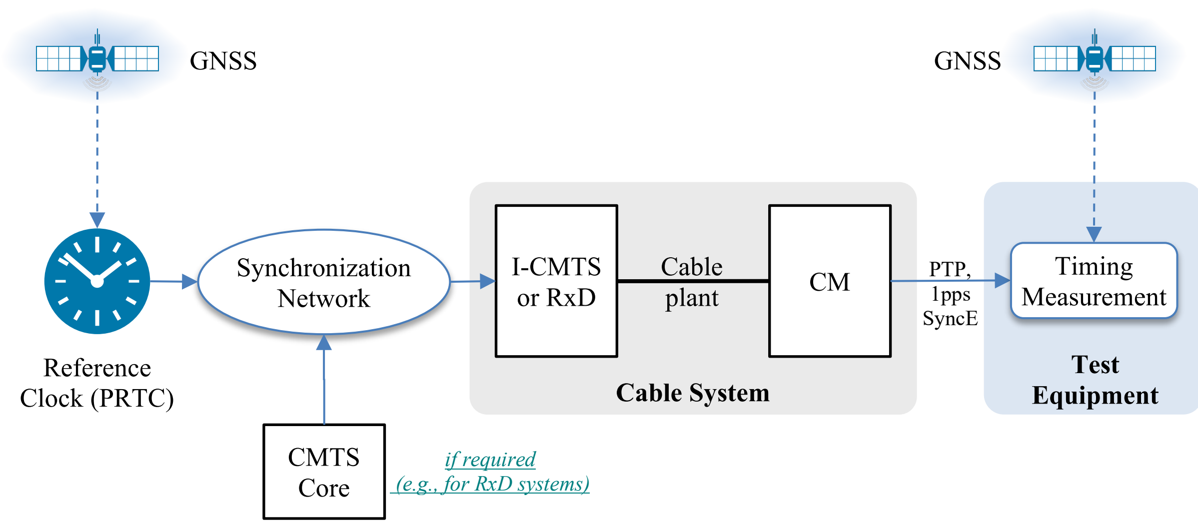

Figure 39 - Testing Synchronization in the Field

As before, the timing measurement block acts as a slave device, comparing the timing of the output the cable system to the GNSS reference. Timing signals can include PTP (time and frequency), SyncE (frequency only), or 1 PPS/serial time-of-day (time and frequency).

In this scenario, the accuracy of the two GNSS receivers (in the reference clock and in the test equipment) needs to be taken into account when evaluating the time error of the system. For example, if each GNSS receiver has an accuracy of ±x ns, then the potential error in the measurement is at least ±2x.

B.2 DTP and PTP Timing Protocol Testing

B.2.1 PTP Protocol Testing

PTP Protocol testing is not covered in this version of the specification.

B.2.2 DTP Protocol Testing

DTP Protocol testing is not covered in this version of the specification.

Annex C Requirements on Supporting Mobile Xhaul Service over DOCSIS Distributed Access Architecture (Remote PHY) (Normative)

This section defines mobile backhaul requirement deltas on the RPD. The RPD configuration requirements are expected to be contained in the R-PHY suite of specifications.

C.1 Introduction

C.1.1 General

When supporting mobile backhaul (MBH) over Distributed Access Architecture (DAA) in general and Remote PHY (R-PHY) in particular, there are some considerations that need to be taken when designing the timing delivery. The main factor is that R-PHY itself has timing requirements specified in [R-DTI] that are different from the timing requirements for MBH support, i.e., the timing accuracy requirements (for frequency and phase) and the timing delivery requirements (profile, 1588/SyncE, etc.). The challenge is to have the R-PHY Device (RPD) clock support two different timing applications with different requirements when the set of requirements for one application is not a superset of the other.

The other factor is that the RPD does not communicate directly with the CM (the CMTS Core does); therefore, any communication needed to exchange information between the PTP-to-DOCSIS interworking function (IWF) nodes (such as DTP, PTP announce, and ESMC) requires special handling compared to the I-CMTS case described in this document.

This annex includes requirements specifically for RPD MBH support. It is an integral part of this specification.

C.1.2 R-PHY Timing Requirements

RPD and CCAP Core R-PHY timing requirements are specified in [R-DTI]. Related timing configuration attributes of the RPD are specified in [R-PHY]. The following are the main R-PHY timing requirements and configuration items that are part of the R-PHY suite of specifications. Sections C.2, C.3, and C.4 discusses the difference between the R-PHY requirements and the MBH requirements for each use case and sets requirements.

C.1.2.1 RPD Timing Configuration Items

An RPD is configured by the Principal Core for its timing parameters. The parameters listed below are solely for the operation of R-PHY; therefore, configuration items that are not required for R-PHY operation (such as SyncE or BC configuration) are not included in the RPD configuration.

Table 10 provides the list of parameters that can be configured based on [R-PHY]. This table is informational only for the purposes of this specification.

Table 10 - R-PHY PTP Configuration Attributes

TLV Name	Object Type	TLV Type	TLV Value Field Length	Constraints	Comments
RdtiConfig	Complex TLV	97	variable		
RpdRdtiMode	UnsignedByte	97.1	1	R/W	
RpdPtpDefDsDomainNumber	UnsignedByte	97.2	1	R/W	
RpdPtpDefDsPriority1	UnsignedByte	97.3	1	R/W	
RpdPtpDefDsPriority2	UnsignedByte	97.4	1	R/W	
RpdPtpDefDsLocalPriority	UnsignedByte	97.5	1	R/W	
RpdPtpProfileIdentifier	MacAddress	97.6	6	R/W	
RpdPtpProfileVersion	HexString	97.7	3	R/W	

TLV Name	Object Type	TLV Type	TLV Value Field Length	Constraints	Comments
RpdPtpPortConfig	Complex TLV	97.8	variable		
RpdEnetPortIndex	UnsignedShort	97.8.1	2		
RpdPtpPortIndex	UnsignedShort	97.8.2	2		
RpdPtpPortAdminState	AdminStateType	97.8.3	1	R/W	
RpdPtpPortClockSource	IpAddress	97.8.4	4 or 16	R/W	
RpdPtpPortClockAlternateSource	IpAddress	97.8.5	4 or 16	R/W	
RpdPtpPortClockSelectAlternateSourceFirst	Boolean	97.8.6	1	R/W	
RpdPtpPortTransportType	UnsignedByte	97.8.7	1	R/W	IPv4, IPv6
RpdPtpPortTransportCos	UnsignedByte	97.8.8			
RpdPtpPortTransportDscp	UnsignedByte	97.8.9	1	R/W	
RpdPtpPortDsLocalPriority	UnsignedByte	97.8.10	1	R/W	
RpdPtpPortDsLogSyncInterval	UnsignedByte	97.8.11	1	R/W	Base 2 scale
RpdPtpPortDsLogAnnounceInterval	UnsignedByte	97.8.12	1	R/W	Base 2 scale
RpdPtpPortDsLogDelayReqInterval	UnsignedByte	97.8.13	1	R/W	Base 2 scale
RpdPtpPortDsAnnounceReceiptTimeout	UnsignedByte	97.8.14	1	R/W	
RpdPtpPortUnicastContractDuration	UnsignedByte	97.8.15	2	R/W	
RpdPtpPortClockSrcGw	IpAddress	97.8.16	4 | 16	R/W	
RpdPtpPortClockAltSrcGw	IpAddress	97.8.17	4 | 16	R/W	

C.1.2.2 RPD Timing Requirements for R-PHY

The following are the main R-PHY timing requirement for the RPD based on [R-PHY]. This list is informational only for the purposes of this specification.

- RPD supports PTP messages over the following encapsulations:
    - PTP over Ethernet/IEEE802.3,
    - PTP over UDP over IPv4, and
    - PTP over UDP over IPv6.
- RPD supports the unicast model defined in [IEEE 1588-2008].
- RPD supports the 1588 OC ordinary clock slave.
- RPD meets a time/phase synchronization accuracy of ±1 ms in reference to the 1588 GM.
- RPD complies with the T-TSC-P requirements of [G.8275.2].
- RPD's frequency does not drift more than 10^{-8} per second (10 ppb/s).
- RPD's phase does not perform a "step" function.

C.1.2.3 RPD Precision Timing Requirements in R-DTI

In the "Precision Timing Services" section of [R-DTI], there are requirements for supporting precision timing services such as MBH. The requirements in this specification override the requirements specified in R-DTI for precision timing services for MBH.

C.2 Full Timing Support for Phase Synchronization on RPD

Section 8 of this document describes the requirements for supporting full timing support for phase synchronization. Table 11 lists the differences between the R-PHY requirements as specified in [R-DTI] and [R-PHY] and the MBH requirements specified in Section 8.

Table 11 - R-PHY Requirements vs. MBH "Full Timing Support for Phase"

Item	R-PHY	MBH	R-PHY requirements when supporting MBH precision timing services
Lock threshold	1 ms	50 ns	See Section C.2.1
Phase lock time	Few minutes	Not defined (should be short)	See Section C.2.2
Profile	[G.8275.2]	[G.8275.1]	See Section C.2.3
SyncE	Recommended	Required	See Section C.2.4
Holdover requirements and duration	Not specified	[G.8273.2]	See Section C.2.5
Phase steps	Not allowed when locked	Not specified	See Section C.2.6
Frequency change rate	10 ppb/s	Not specified	See Section C.2.6
Precision timing frequency and phase budget	Table based on old DTP section	Specified in Section 8 of this spec	See Section C.2.7
"soft reset" support	The RPD holds in holdover for <1 min during a soft reset in order to have a quick reset using a warm start. The RPD goes operational even before it re-locks to the GM.	Convergence after soft reset is for further study.	See Section C.2.8
BC functionality	Allowable	Required on every Ethernet hop	See Section C.2.9

C.2.1 Lock Threshold

When supporting MBH precision timing services, the RPD MUST meet the thresholds defined in Section 8 for its R-PHY operation. The RPD MUST send a "phase locked" notification when its accuracy meets what is defined in Section 8.

The RPD SHOULD use the configured profile in order to set the required threshold ([G.8275.2] for R-PHY and [G.8275.1] for MBH).

The RPD MAY use the configured Timing Application (new attribute) in order to set the required threshold ([G.8275.2] for R-PHY and [G.8275.1] for MBH).

C.2.2 Phase Lock Time

When working in full timing support from the network, it is assumed that the "fast" locking time necessary for R-PHY operation (few minutes to achieve phase lock) can easily be fulfilled to acquire the required MBH phase accuracy.

If the phase acquisition for MBH takes longer than few minutes, then it will affect the R-PHY operational readiness.

The RPD MUST maintain a locking time similar to the locking time of its PTP master when supporting either R-PHY only or R-PHY+MBH modes.

C.2.3 Profile

The R-PHY suite of specifications define a configuration item to set the profile in [R-PHY]; in addition, there is a requirement for the RPD to support [IEEE 1588-2008] over L2 in [R-DTI]. When supporting MBH precision timing services, the RPD MUST use [G.8275.1] as the profile for both R-PHY and MBH operation.

C.2.4 SyncE

The R-PHY suite of specifications currently does not require the use of SyncE and does not have any configuration items that need to support Hybrid 1588/SyncE, as specified in Section 8 of this document.

As mentioned in Section 8, the RPD MUST support SyncE assistance for MBH.

The RPD MUST support configuration with SyncE parameters through GCP. The RPD MUST have the parameters in Table 12 configured globally and per Ethernet interface. This specification assumes that the R-PHY suite of specifications will be updated to include the configuration details for supporting SyncE on the RPD.

Table 12 - RPD SyncE Configuration Items

RPD-Level Parameters	Description	Values (Note: default values in bold)
clock mode	Configures the RPD clock operating mode between packet-based equipment clock and hybrid clock modes. Hybrid clock operating mode contains a packet-based equipment clock and a SyncE physical layer clock. An RPD reset can be required to speed the lock time for transitions between modes.	**pec** | hybrid
timing-application	Configures the application level thresholds. For the description of these options, see [R-OSSI], section entitled "ClkApplications".	**other | docsis | leakageDetection | dtpClassA | dtpClassB | mbhFrequency**
synce network type	Configures the network clock for eec option-1 or eec option-2 operation.	eec_opt1 | **eec_opt2**
synce clock source selection mode enable	Enables the G.781-based network clock source selection algorithm.	**enable** | disable
synce mode QL enabled	When enabled, includes quality level in the source selection process. When disabled, the source selection process is based on signal fail, priority, and commands.	enable | **disable**
Ethernet Interface-Level Parameters	**Description**	**Values (Note: default values in bold)**
interface sync mode	Enables synchronous mode for the interface. This affects both transmit and receive sides of the interface.	enable | **disable**
interface-source priority	Configures a priority level for the interface that is used in the selection process. Priorities reflect a preference of one synchronization source over the other. Equal synchronization source priorities reflect that no preference exists between the synchronization sources.	1 through 4, with 1 being the highest; default is 4
receive-ssm value	Configures an SSM value for the interface that is used in the selection process. If configured, this value overrides the received SSM value. Only generation 1 SSM is supported.	Option 1: QL-PRC, QL-SSU-A, QL-SSU-B, QL-EEC1,**QL-DNU** Option 2: QL-PRS, QL-STU, QL-ST2, QL-TNC, QL-ST3E, QL-EEC2, **QL-DUS**
transmit-ssm value	Configures an SSM value for the transmit interface.	Option 1: QL-PRC, QL-SSU-A, QL-SSU-B, QL-EEC1,**QL-DNU** Option 2: QL-PRS, QL-STU, QL-ST2, QL-TNC, QL-ST3E, QL-EEC2, **QL-DUS**
hold-off	Configures the hold-off timer for the interface. Hold-off time ensures that short activations of signal fail are not passed to the selection process. (This could be a global parameter.)	Configurable from 300 ms to 1800 ms; default is 600 ms
wait-to-restore	Configures the wait-to-restore timer for the interface. Wait-to-restore time ensures that a previously failed synchronization source is only again considered as available by the selection process if it is fault-free for a certain time. (This could be a global parameter.)	Configurable from 0 to 12 minutes in steps of 1 minute; default is 5 minutes

Ethernet Interface-Level Parameters	Description	Values (Note: default values in bold)
force-switch	When enabled, overrides the currently selected synchronization source by the selection of this interface, assuming this interface is enabled and not locked out. When disabled, the forced selection of this interface is removed.	enable | **disable**
manual-switch	When enabled, overrides the currently selected synchronization source, assuming this interface is enabled, not locked out, not in signal fail condition, and has a QL better than DNU in QL-enabled. When disabled, the manual switch selection of this interface is removed.	enable | **disable**
lockout	When enabled, this interface is no longer considered available by the selection process. When disabled, the interface is considered available again by the selection process.	enable | **disable**

Table 13 - RPD SyncE Status and Event Items

RPD-Level Status and Notifications	Description	Value
synce_clock_mode	Reports the current mode of the SyncE clock.	locked | acquiring | holdover | free-run
synce_clock mode_change	Reports whether the mode of the SyncE clock has changed.	active | inactive
synce_clock_failure	Reports whether there has been an equipment failure in the SyncE clock.	active | inactive
synce_clock_forced	Indicates a forced state, such as override of revertive switching.	active | inactive
synce_clock_active_reference	Indicates input reference that is in active use.	Interface number
synce_clock_active_reference_change	Indicates input reference that is in active use has changed.	active | inactive
synce_clock_reference_switch_time	Gives time of most recent reference switch.	
Ethernet Interface-Level Status	**Description**	**Value**
interface_qualified	Gives condition of input reference source.	qualified | non-qualified
interface_signal_fail	Activates in case of defects detected in the server layers.	active | inactive
received-ssm_value	Contains the received SSM value for the interface.	Option 1: QL-PRC, QL-SSU-A, QL-SSU-B, QL-EEC1, QL-DNU Option 2: QL-PRS, QL-STU, QL-ST2, QL-TNC, QL-ST3E, QL-EEC2, and QL-DUS

C.2.5 Holdover Requirements and Duration

The R-PHY suite of specifications currently do not contain any holdover requirements. Holdover requirements for the I-CMTS are addressed in Section 8.2 as well as the row “Network holdover and PTP rearrangements” in Table 6 in Section 8.4 of this document. For MBH, the RPD or the RMD can choose not to support holdover as stated in Section 8.4.1.2.

C.2.6 Phase Steps and Frequency Change Rate

The R-PHY suite of specifications requires that once the RPD is operational, it does not change its frequency with a rate that is higher than 10 ppb/s and avoids performing phase “steps.” Phase adjustment is done only through frequency changes.

In order to maintain DOCSIS network performance, the RPD MUST maintain the same restriction defined in [R-PHY] for MBH time adjustments. Because of this restriction, it can take longer to make phase corrections needed for MBH, as it is bound to the DOCSIS frequency and phase change restrictions.

C.2.7 Precision Timing Frequency and Phase Budget

When supporting MBH precision timing services, the RPD MUST meet the phase and frequency accuracies as defined in Table 6 in Section 8 for its R-PHY operation.

C.2.8 RPD "Soft Reset" Support

The R-PHY suite of specifications requires the RPD to support a "soft reset" in which it becomes operational with sufficiently accurate frequency and phase in less than 1 minute. This requirement assumes that, during the soft reset, the RPD is placed in holdover and that the RPD clock will not drift significantly within the soft reset process. The RPD is assumed to go operational even before it relocks to the GM after the soft reset.

When supporting MBH, the RPD clock might drift during the soft reset process over the limits required for MBH. Because the RPD goes operational even before it relocks to the GM, the phase accuracy when going operational might not be accurate for MBH. In addition, after the RPD is operational, phase changes are limited, as specified in Section C.2.6; therefore, the ability to converge quickly to the phase requirements of MBH can be limited.

In a case of soft reset, the RPD MUST maintain its quick recovery as in non-MBH R-PHY cases.

In a case of soft reset, the RPD MUST adhere to the frequency and phase change limitation specified in Section C.2.6 when trying to converge to MBH phase and frequency thresholds.

The RPD SHOULD use SyncE to maintain its holdover frequency. Therefore, the RPD SHOULD NOT reset SyncE as part of the soft reset.

C.2.9 BC Functionality

In order to reduce the amount of fibers connected to the RPDs, a required topology for RPDs could be the use of daisy chaining or ring deployments.

For the case of full network support, each Ethernet hop needs to be able to function as a T-BC. This necessity might impose significant challenges on the RPD switch.

The use of BC on RPDs is for further study.

C.2.10 Other RPD Global Configurations

Other RPD global configurations are listed below:

- RPD Timing Application (R-PHY-only, MBH-Frequency, MBH-Phase)
- RPD Clock mode – PTP versus Hybrid PTP/SyncE
- RPD DTP support capabilities
- RPD DTP support enable

C.3 Partial Timing Support for Phase Synchronization on RPD

Not covered in this version of the specification.

C.4 Physical Layer Timing Support for Frequency Synchronization on RPD

Section 7 describes the requirements for supporting full timing support for frequency synchronization, which requires the use of SyncE as the frequency source for the RPD.

DOCSIS technology couples timestamp and symbol clock together. Because the RPD already uses PTP to align its frequency and phase for R-PHY operation, the RPD cannot provide downstream a SyncE-traceable clock, unless the input SyncE and PTP were already traceable to the same source. Therefore, if both SyncE and PTP inputs are present, the RPD uses PTP for frequency and phase.

Note: It is recommended that the source of SyncE within a network is generated from same source as the PTP domain (e.g., GPS or PRTC).

For both R-PHY and MBH scenarios, the RPD MUST generate the downstream DOCSIS frequency and timestamp traceable to the PTP clock domain. The RPD MAY use SyncE to assist the PTP clock (e.g., holdover, fast-lock). The RPD MUST carry Announce clockClass and convert to SyncE ESMC messages downstream for the CM, as specified in Section 8.5.

Because R-PHY and MBH have different frequency accuracy requirements, the RPD MUST adhere to the MBH frequency accuracy requirements (in [G.8261.1], case 3 (16 ppb)) for R-PHY as well, and use the phase accuracy requirements specified in [R-DTI].

For the RPD case, it is highly recommended to place an EdgeGM in the CIN, which will convert SyncE to PTP using the [G.8275.2] profile. To support the R-PHY timing requirements, there are a few scenarios for placing the EdgeGM in the CIN network and providing accurate phase to the Core and RPD.

C.4.1 EdgeGM Placed in the CIN

Figure 40 shows a deployment scenario in which the EdgeGM is placed in the CIN. The EdgeGM is locked in frequency to SyncE and acts as a 1588 master clock for both the Core and RPD.

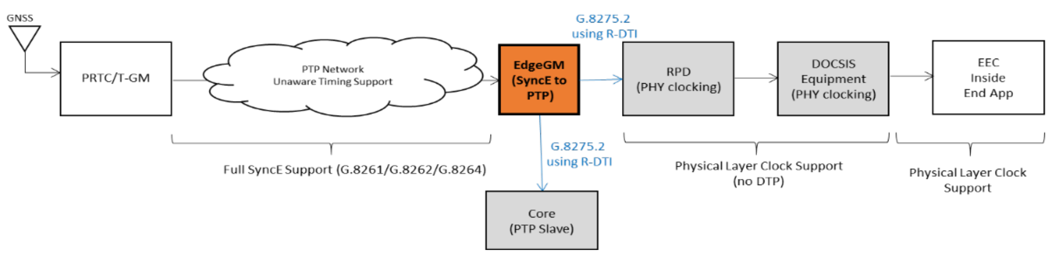

Figure 40 - EdgeGM in the CIN

C.4.2 CMTS Core Acting as an EdgeGM

Figure 41 shows a deployment scenario in which the CMTS Core is acting as the EdgeGM for the RPDs. The Core is locked in frequency to SyncE and uses an arbitrary time of day while acting as a 1588 master clock for the RPD.

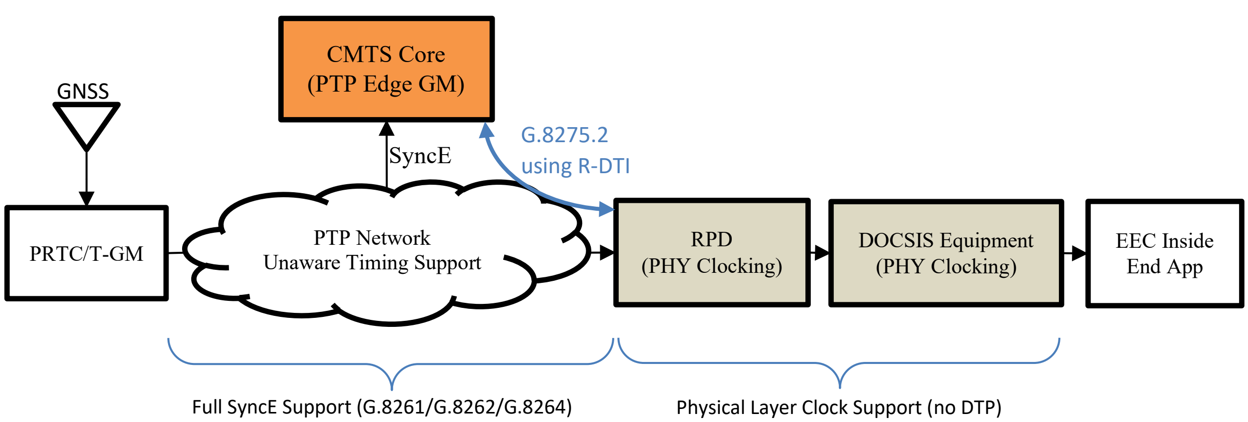

Figure 41 - CMTS Core as the EdgeGM

The CMTS Core MAY support acting as an EdgeGM for the RPDs.

C.5 Partial Timing Support for Frequency Synchronization on RPD

Not covered in this version of the specification.

C.6 DTP Support on RPD

The RPD does not usually communicate directly with the CM; all MAC Management Messages (MMMs) are transmitted only between the CMTS Core and the CM. Therefore, there is an advantage of having the CMTS Core act as the DTP node communicating with the CM.

The RPD MUST advertise its DTP capabilities via GCP after startup.

The RPD MUST support being configured with DTP support.

The RPD MUST send the CMTS Core its DTP parameters (*t-cmts-ds-i*, *t-cmts-ds-o*, *t-cmts-ds-p*, *t-cmts-us-o*, *t-cmts-us-p*) as a response to a GCP read from the CMTS Core.

The CMTS Core MUST be configured with HFC DTP parameters for each of its RPDs (*t-hfc-ds-o*, *t-hfc-us-o*).

The CMTS Core MUST support reading the RPD's DTP parameters via a GCP read.

The CMTS Core MUST support DTP as specified in Section 6 of this specification.

The CMTS Core MUST use the DTP parameters when communicating to a DTP CM based on the RPD and HFC parameters that connect to this CM.

Annex D DOCSIS TLV Encoding for Synchronization Support (Normative)

This section defines the DOCSIS TLV encodings for the various synchronization functionalities.

DOCSIS TLV encodings are specified in Annex C of [MULPIv3.1] including the DTP related encodings. This section defines the DOCSIS TLV encodings added in addition to the TLVs defined in [MULPIv3.1], in order to support the various synchronization functionalities described in this specification.

D.1 Registration-Request/Response-Specific Encodings

The encodings defined in this section are for CM capabilities and are not found in the configuration file, but are included in the Registration Request, and Registration Response as defined below.

D.1.1 DOCSIS Sync Capabilities

This TLV specifies the sync capabilities of the CM. These capabilities are exchanged as part of the registration process in addition to the standard DOCSIS capabilities using TLV 5 as specified in [MULPIv3.1].

Type	Length	Value
98	N	Composite

D.1.1.1 DOCSIS Sync TE Class Type

This parameter indicates the DOCSIS Time Error class type supported in the CM as defined in Section 8.4.2.6. The CM MUST include this TLV in the Registration Request message. The CMTS MUST return this TLV to the CM with the value as the CM included in the Registration Request message.

Type	Length	Value
98.1	1	0 = DOCSIS TE support is unknown 1 = DOCSIS TE Class A supported 2 = DOCSIS TE Class B supported 3 – 255 = Reserved

D.1.1.2 PTP Clock Support

This value is used by the CM to indicate the support for PTP clock functionality. The CM MUST include this capability. To disable PTP operation for the CM, the CMTS overrides the reported capability with a value of 0. To enable PTP Master clock operation, the CMTS confirms the reported value with a value of 1. The CMTS MUST NOT configure the CM to PTP clock Mode if the CM does not support it.

Type	Length	Value
98.2	1	0 = PTP clock functionality is not supported 1 = PTP clock functionality is supported 2 – 255 = Reserved

D.1.1.3 PTP IPv6 Support

This value is used by the CM to indicate support for PTP over IPv6. The CM MUST indicate support for PTP over IPv6. The CMTS MUST return this TLV to the CM with the value as the CM included in the Registration Request message.

Type	Length	Value
98.3	1	0 = PTP over IPv6 is not supported 1 = PTP over IPv6 is supported 2 – 255 = Reserved

D.1.1.4 PTP Profile Support

This value is used by the CM to indicate which PTP profile are supported. The bits are set to 1 to indicate that support for the specific profile. When G.8275.2 and G.8265.1 are marked as supported, the CM MUST support PTP over IPv4. The support for PTP over IPv6 for these profiles is advertised via TLV 98.3. The CM MUST include this capability. To configure a specific profile for the CM, the CMTS MUST set the bit representing the desired profile while unsetting all the other bits. The CMTS MUST NOT configure the CM to a profile mode the CM does not support.

Type	Length	Value
98.4	2	bit #0: IEEE-1588 Default profile bit #1: ITU-T G.8265.1 bit #2: ITU-T G.8275.1 bit #3: ITU-T G.8275.2 bit #4-15: Reserved

D.1.1.5 PTP Max Number of Clock Slaves Support

This value is used by the CM to indicate the maximum number of clock slaves it can support. The CMTS responds with the maximum number of slaves the CM needs to limit. The CMTS MUST return a value of 0 in case no limit is required or incase the CM reported a value of 0. The CM MUST include this TLV in the Registration Request message. The CMTS MUST NOT configure the CM to a number of slaves that is greater than the maximum number it supports.

Type	Length	Value
98.5	1	0 = maximum number of slaves is unknown 1-255 = maximum number of slaves supported

D.1.1.6 SyncE Support on Ethernet CMCI Ports

This value is used by the CM to indicate the support for SyncE on the CM’s Ethernet CMCI ports. The CM MUST include this capability. To disable SyncE operation for the CM, the CMTS overrides the reported capability with a value of 0. To enable SyncE operation, the CMTS MUST confirm the reported value with a value of 1. The CMTS MUST NOT configure the CM to SyncE if the CM does not support it.

Type	Length	Value
98.6	1	0 = SyncE functionality is not supported 1 = SyncE functionality is supported 2 – 255 = Reserved

D.1.1.7 1PPS Support

This value is used by the CM to indicate the support for a 1PPS output. This TLV is for capability reporting only. The CM MUST include this TLV in the Registration Request message. The CMTS MUST return this TLV to the CM with the value as the CM included in the Registration Request message.

Type	Length	Value
98.7	1	0 = 1PPS output is not supported 1 = 1PPS output is supported 2 – 255 = Reserved

D.1.2 DOCSIS CM System Information

This TLV specifies the System Information of the CM. This information is advertised by the CM as part of the registration request-response process in addition to the standard DOCSIS capabilities using TLV 5 as specified in [MULPIv3.1]. This TLV is for reporting purposes only. The CMTS is not required to include this TLV in the Registration Response message.

Type	Length	Value
99	N	Composite

D.1.2.1 CM HW Version Number

This parameter indicates hardware version number of the CM and is identical to the value as reported in <Hardware version> field in MIB object sysDescr. The CM MUST include this capability.

Type	Length	Value
99.1	0-255	A string representing the HW version currently running on of the CM

D.1.2.2 CM SW Version Number

This parameter indicates Software version number of the CM and is identical to the value as reported in <Software version> field in MIB object sysDescr. The CM MUST include this capability.

Type	Length	Value
99.2	0-255	A string representing the SW version currently running on of the CM

D.1.2.3 CM Boot ROM Version

This parameter indicates Boot ROM version of the CM and is identical to the value as reported in <Boot ROM Version> field in MIB object sysDescr. The CM MUST include this capability.

Type	Length	Value
99.3	0-255	A string representing the Boot ROM version currently running on of the CM

D.1.2.4 CM Model Number

This parameter indicates Model Number of the CM and is identical to the value as reported in <Model Number> field in MIB object sysDescr. The CM MUST include this capability.

Type	Length	Value
99.4	0-255	A string representing the CM Model Number

D.1.2.5 CM Vendor Name

This parameter indicates Vendor Name of the CM and is identical to the value as reported in <Vendor Name> field in MIB object sysDescr. The CM MUST include this capability.

Type	Length	Value
99.5	0-255	A string representing the CM Vendor Name

D.1.3 Sync DSID Assignments

This TLV specifies the DSID assignments to support PTP and SyncE capabilities. The CMTS assigns these DSIDs in the Registration Response message.

Type	Length	Value
100	N	Composite

D.1.3.1 PTP DSID Configuration

This TLV defines the DSID that carries the PTP announce messages from the CMTS to the CM's special PTP port. This TLV is presented in the Registration Response message by the CMTS. The CMTS decides PTP DSID based on internal configuration or by other criteria. The CMTS MUST include this TLV in the Registration Response message only if the PTP Master Clock Enable TLV (TLV 101.1) indicates a value of 1 (enable).

Type	Length	Value
100.1	3	1-10485755= PTP DSID

D.1.3.2 SyncE DSID Configuration

This TLV defines the DSID that carries the SyncE SSM messages from the CMTS to the CM's. This TLV is presented in the Registration Response message by the CMTS. The CMTS decides SyncE DSID based on internal configuration or by other criteria. The CMTS MUST include this TLV in the Registration Response message only if the SyncE Clock Enable TLV (TLV 101.4) indicates a value of 1 (enable).

Type	Length	Value
100.2	3	1-1048575 = SyncE DSID

D.2 Configuration File and Registration Settings

The TLVs in the following section are included in the CM configuration file and are intended to be forwarded by the CM to the CMTS in the Registration Request message.

D.2.1 DOCSIS Sync Configurations

The following TLVs specify the DOCSIS sync configuration for the CM. If these TLVs are present in a CM configuration file and the CM supports PTP, the CM MUST include it in the Registration Request message. The CMTS MUST NOT include this TLV in the Registration Response. The CMTS configures DOCSIS Sync in the Registration Response using the DOCSIS Sync capability TLVs (see section D.1.1).

Type	Length	Value
101	N	Composite

D.2.1.1 PTP Master Clock Enable

The PTP Configuration TLV defines CM configuration file encoding which specifies the provisioned PTP mode for a CM. The configuration file can specify whether PTP is enabled or disabled. This TLV can be present in CM configuration file and in Registration Request message. If this TLV is present in a CM configuration file, the CM MUST include it in the Registration Request message. The CMTS uses the information received in this TLV to set the CM's PTP Clock Support via TLV 98.2.

If this TLV is not present in the CM configuration file, the CMTS decides CM's PTP Mode based on other criteria.

Type	Length	Value
101.1	1	0 = reserved 1 = PTP enabled 2 = PTP disabled 3-255: Reserved

D.2.1.2 PTP Profile Configuration

This TLV defines the PTP profile to be used by the CM. This TLV can be present in CM Configuration file and in Registration Request message. If this TLV is present in a CM configuration file, the CM MUST include it in the Registration Request message. The CMTS uses the information received in this TLV to set the CM's PTP Profile Support via TLV 98.4.

If this TLV is not present in the CM configuration file, the CMTS decides CM's PTP profile based on other criteria.

Type	Length	Value
101.2	1	0 = IEEE-1588 Default profile 1 = ITU-T G.8265.1 2 = ITU-T G.8275.1 3 = ITU-T G.8275.2 4-255: Reserved

D.2.1.3 PTP Max Number of Clock Slaves Configuration

This TLV defines the maximum number of slaves clocks the CM needs to support and limit. This TLV can be present in CM configuration file and in Registration Request message. If this TLV is present in a CM configuration file, the CM MUST include it in the Registration Request message. The CMTS uses the information received in this TLV to set the CM's PTP Max Number of Clock Slaves Support via TLV 98.5.

If this TLV is not present in the CM Configuration file, the CMTS decides CM's PTP Max Number of Clock Slaves Support based on other criteria.

Type	Length	Value
101.3	1	0 = maximum number of slaves is not defined 1-255 = maximum number of slaves

D.2.1.4 SyncE Clock Enable

The SyncE Configuration TLV defines CM configuration file encoding which specifies the provisioned SyncE mode for a CM. The configuration file can specify whether SyncE is enabled or disabled. This TLV can be present in CM configuration file and in Registration Request message. If this TLV is present in a CM configuration file, the CM MUST include it in the Registration Request message. The CMTS uses the information received in this TLV to set the CM's SyncE Support via TLV 98.6.

If this TLV is not present in the CM configuration file, the CMTS decides CM's SyncE Mode based on other criteria.

Type	Length	Value
101.4	1	0 = reserved 1 = SyncE enabled 2 = SyncE disabled 3-255: Reserved

D.2.2 PTP Address Configurations

The following TLVs specify the PTP address configurations for the CM. If these TLVs are present in a CM configuration file and the CM supports PTP, the CM MUST include it in the Registration Request message. If this TLV is not present in the CM configuration file, the CMTS decides PTP addresses based on other criteria. The CMTS MUST include the PTP Address Configuration TLV in the Registration Response.

Type	Length	Value
102	N	Composite

D.2.2.1 PTP Source IP Address Configuration

This TLV defines the source IP address that carries the PTP messages from the CM master port. This TLV can be present in CM configuration file and in Registration Request message. If this TLV is present in a CM configuration file, the CM MUST include it in the Registration Request message.

If this TLV is not present in the CM configuration file, the CMTS decides the CM's PTP source IP address based on other criteria. The CMTS MUST include this TLV in the Registration Response only if the PTP Profile Configuration (TLV 101.2) indicates a value of 3 (ITU-T G.8275.2).

Type	Length	Value
102.1	4 (IPv4) or 16 (IPv6)	PTP source IP address

D.2.2.2 CMTS PTP IP Address Configuration

This TLV defines the CMTS core special PTP port IP address that should be reached for PTP signaling messages. This TLV can be present in CM configuration file and in Registration Request message. If this TLV is present in a CM configuration file, the CM MUST include it in the Registration Request message.

If this TLV is not present in the CM configuration file, the CMTS decides PTP CMTS IP address based on other criteria. The CMTS MUST include this TLV in the Registration Response only if the PTP Profile Configuration (TLV 101.2) indicates a value of 3 (ITU-T G.8275.2).

Type	Length	Value
102.2	4 (IPv4) or 16 (IPv6)	CMTS Core PTP IP address

D.2.2.3 PTP Destination Multicast MAC Address Configuration

This TLV defines the destination multicast address that carries the PTP messages when profile G.8275.1 is used between the CM PTP master port and its connected slave clocks. This TLV can be present in CM configuration file and in Registration Request message. If this TLV is present in a CM configuration file, the CM MUST include it in the Registration Request message.

If this TLV is not present in the CM configuration file, the CMTS decides PTP multicast MAC address based on other criteria. The CMTS MUST include this TLV in the Registration Response only if the PTP Profile Configuration (TLV 101.2) indicates a value of 2 (ITU-T G.8275.1).

Type	Length	Value
102.3	6	PTP destination multicast MAC address

D.3 MIB Attributes

The MIB attributes in this section are not intended to be forwarded by the CM to the CMTS in the Registration Request message.

In general, the configuration file specific setting for the sync operation will be included as SNMP MIB objects as defined in section C.1.2.5 (SNMP MIB Object) of [MULPIv3.1].

Table 14 lists the SNMP MIB attributes that can be set by the configuration file. The SNMP MIB objects definition is listed in Appendix VI.

Table 14 - SNMP MIB Attributes

Object Name	Object Type	OID	Comments
docsCmSyncPtpPortDomain	Unsigned32		
docsCmSyncPtpPortDscp	Unsigned32		DSCP value for PTP packets
docsCmSyncPtpPortCos	Unsigned32		CoS value for PTP packets
docsCmSyncPtpPortLogSyncInterval	Integer32		Maximum supported Sync message interval per slave
docsCmSyncPtpPortLogDelayReqInterval	Integer32		Maximum supported Delay Request message interval per slave
docsCmSyncPtpPortLogAnnounceInterval	Integer32		Maximum supported announce message interval per slave
docsCmSyncPtpPortAnnounceIntervalTimeout	Unsigned32		Announce message receipt timeout (from CMTS)
docsCmSyncPtpPortGrantDuration	Unsigned32		Maximum supported grant duration per slave
docsCmSyncSynceTransmitSsmValue	Unsigned32		SyncE transmitted SSM value

In the defined SYNC MIB structure, a PTP clock can contain multiple PTP ports that can be separately configured/read. Since the CM PTP clock supports two PTP ports: one PTP master port for communicating with the PTP slave clock on the LAN side, and one “special” slave PTP port for receiving announce information from the CMTS.

The CM MUST use PTP port number of 0 for the master PTP port and PTP port number of 1 for the “special” slave PTP port.

Appendix I Partial Timing Support for Phase Synchronization (Informative)

This section is intended to be a placeholder for the methods and requirements to provide partial timing support for phase synchronization, to be finalized as a normative section in a later version of this document. This scenario supports phase distribution to the end application mobile base station, in which there are nodes that are not PTP aware between the DOCSIS network and the PRTC, or in which T-BC-P node is placed close to the DOCSIS network. This scenario also supports frequency synchronization distribution to the end application.

I.1 Architecture, Use Cases

The first network architecture for a partial timing support deployment is shown in Figure 42. The timing flow starts from a PRTC (with embedded or external T-GM) that is synchronized to GNSS. The PRTC transfers timing information to a T-BC-P Edge equipment clock using the [G.8275.2] PTP profile. The T-BC-P Edge can optionally support a GNSS input, which can be useful for asymmetry correction; such T-BC-P with GNSS input is also known as T-BC-A. The T-BC-P Edge is modeled using [G.8273.4] as a reference. The T-BC-P Edge removes some of the network error introduced, then transfers the timing to the PTP-to-DOCIS IWF (e.g., I-CMTS or RPD) using the [G.8275.2] PTP profile. The timing flow is then converted by the IWF to the DOCSIS PTP profile and transferred with the support of DTP to the CM. The combined PTP-to-DOCSIS IWF and DOCSIS-to-PTP IWF can be modeled as a single [G.8273.4] equipment clock with an additional constant time error (cTE) allocation. The DOCSIS-to-PTP IWF (i.e., CM) then transfers the timing information directly to the end application (e.g., base station) using [G.8275.2].

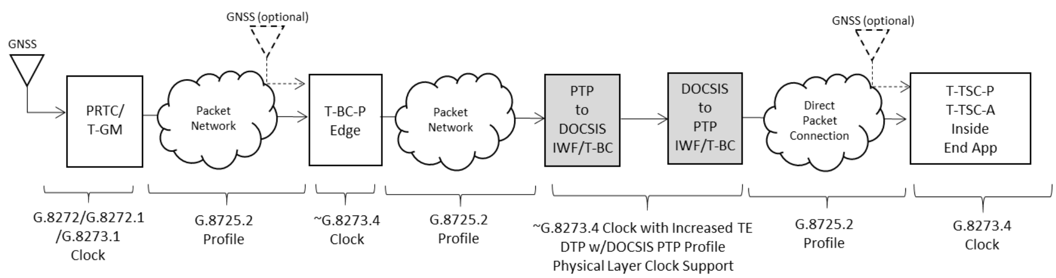

Figure 42 - Partial Timing Support Deployment, Scenario 1

The second network architecture for a partial timing support deployment is shown in Figure 43. The timing flow starts from a PRTC (with embedded or external T-GM) that is synchronized to GNSS. The PRTC transfers timing information to the PTP-to-DOCIS IWF (e.g., I-CMTS or RPD/RMD) using the [G.8275.2] PTP profile. The timing flow is then converted by the IWF to the DOCSIS PTP profile and transferred with the support of DTP to the CM. The combined PTP-to-DOCSIS IWF and DOCSIS-to-PTP IWF can be modeled as a single [G.8273.4] equipment clock with an additional cTE allocation. The CM IWF then transfers the timing information directly, or over a single L2 switch node, to the end application (e.g., base station) using [G.8275.2].

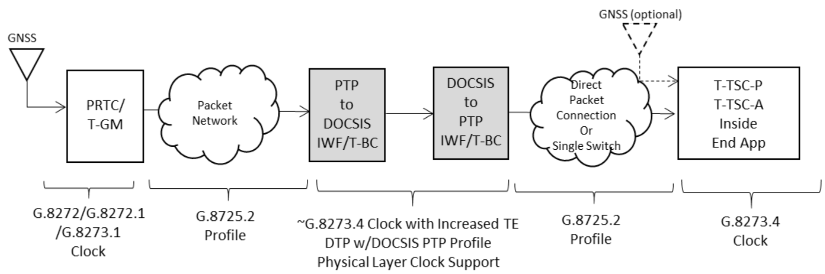

Figure 43 - Partial Timing Support Deployment, Scenario 2

I.2 Protection/Holdover

The partial timing support for phase deployment can support protection and/or holdover. Protection is the availability of multiple timing sources, and holdover is the ability to maintain phase alignment with limited or slow degradation when no timing sources are available. Two example protection scenarios are shown in Figure 44 and Figure 45.

In Figure 44, the T-BC-P Edge is connected to two independent PRTC sources. The T-BC-P Edge would select one PRTC as the best source to use. If that selected PRTC were to fail, then the T-BC-P Edge could select the other as a backup. In Figure 44, the PTP-to-DOCSIS IWF has only one source of timing from the T-BC-P Edge, and if this connection were to fail, then holdover would be used until the timing connection is restored.

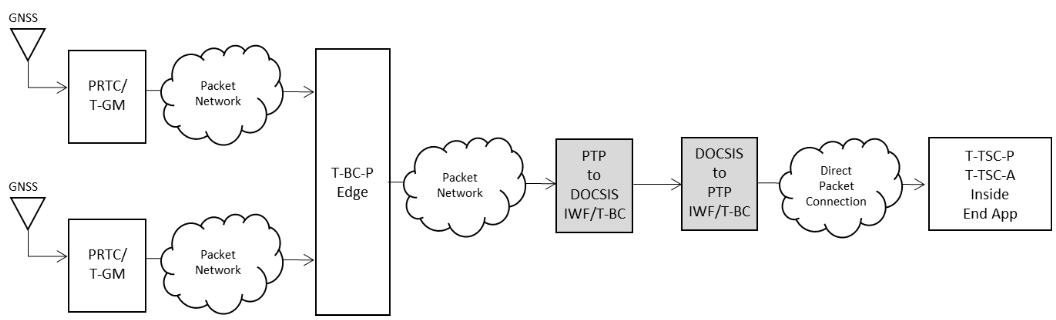

Figure 44 - PTP Deployment with Protection Available at T-BC-P Edge

In Figure 45, the PTP-to-DOCSIS IWF is connected to two independent PRTC-traceable timing sources. The PTP-to-DOCSIS IWF would select one T-GM as the best source to use. If that selected T-GM were to fail, then the PTP-to-DOCSIS IWF could select the other as a backup. The PTP-to-DOCSIS IWF would follow the [G.8275.2] profile operation to prefer (select) a T-GM that is traceable to the PRTC rather than a T-GM that is not traceable to a PRTC (e.g., one that is in holdover).

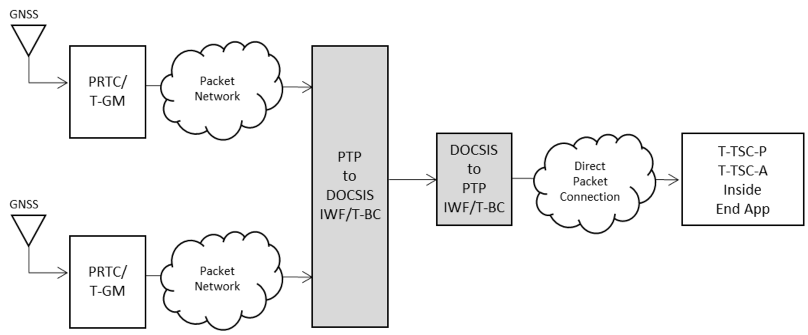

Figure 45 - PTP Deployment with Protection Available at PTP-to-DOCSIS IWF

In either of these scenarios, there might be transitional periods when a PTP clock is switching between its active/primary synchronization source and a standby/backup synchronization source, during which holdover is required in the PTP clock. During this failover period, there might be synchronization performance requirements for the end application that still need to be met.

Likewise, there might be scenarios in which no alternate source of traceable synchronization is available for the end application even though some synchronization performance requirements can apply.

In order to ensure that after failure of PRTC/T-GM traceability to the end application, the synchronization performance degradation is limited and time synchronization performance requirements are still met, the operator can plan its deployment to have holdover capability at one or more places.

The design of the synchronization in the network can be such that the holdover capability is located in one or more of the following locations:

- an upstream switch/router or edge equipment (e.g., T-BC-P Edge);
- the I-CMTS, RPD, or RMD (PTP-to-DOCSIS IWF/T-BC);
- the T-TSC embedded inside the end application; or
- the end application clock itself.

The holdover capability required for the network can depend on the target performance of the end application, as well as on the length of the expected outage of an available PRTC/T-GM or the duration of the lack of visibility of the PRTC/T-GM by the end application.

I.3 ITU-T Partial Timing Support Budget

I.3.1 Network Noise Accumulation

A partially aware network can comprise multiple network segments of non-participating switches/routers and participating equipment boundary clocks before the timing reaches the end application (see Figure 46 for an example). The network operator can build a variety of combinations and scenarios using the approach documented in [G.8271.2], Appendix IV, "Noise Accumulation Model in Partially Aware Networks."

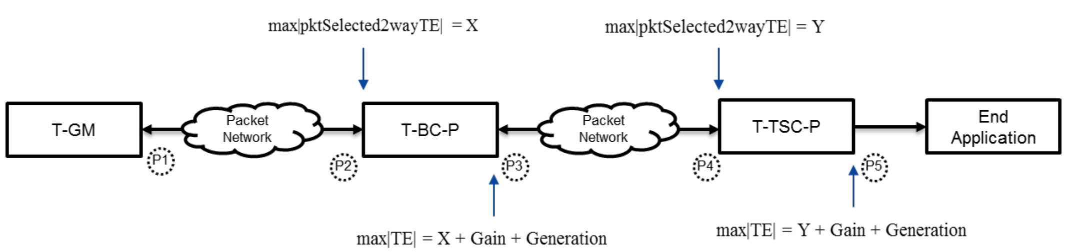

Figure 46 - Example Network Showing Noise Accumulation Model

I.4 Partial Timing Support Budget When Deploying a DOCSIS Network

Not covered in this version of the specification (network limits to be determined).

I.5 Profile Requirements on DOCSIS Components

Not covered in this version of the specification, although it will parallel Section 8.5.

I.6 Performance of DOCSIS Timing Equipment

Not covered in this version of the specification.

I.7 PTP and SyncE Control Plane over DOCSIS

Not covered in this version of the specification, although it will parallel Section 6.7.3.

Appendix II Partial Timing Support for Frequency Synchronization (Informative)

Not covered in this version of the specification.

Appendix III LTE Air Interface Synchronization Details (Informative)

In this section, detailed background on mobile synchronization requirements [SCTE 2017] is provided.

III.1 LTE FDD

Frequency synchronization in LTE FDD is required (1) to enable a local reference within the radio cell between the radio and its connected devices and (2) to have all devices connected to the same 4G network use the same heart beat when transmitting and receiving. Without frequency synchronization, user equipment would need time to resynchronize to the new radio cell, resulting in a temporary loss of connection during handover.

III.2 LTE TDD

With the expected U.S. deployment in the 3.5 GHz spectrum, the popularity of TDD has grown. LTE TDD is also prevalent in Europe. TDD, however, requires tight time synchronization.

In LTE TDD, uplink (UL) and downlink (DL) transmissions occur at the same frequency but are separated in time. The eNBs have to inform all user equipment (UE) devices in the cell whether they should be listening or transmitting. The 3GPP defines seven TDD subframe configurations so that the UE devices know which subframe is for transmit or receive, although most small cells today support subframe configurations 1 and/or 2 only. The TDD frame structure for subframe configuration 1 is shown in Figure 47. A special subframe denoted as the “S” subframe is defined to include a partial UL and a partial DL subframe, with a “guard period” sandwiched in the middle to facilitate switching between the UL and DL transmissions.

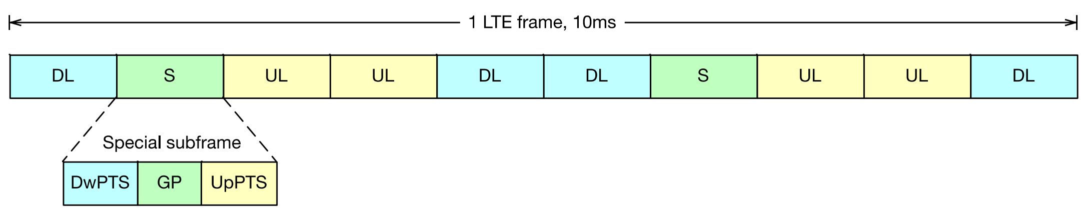

Figure 47 - Frame Structure for TDD Subframe Configuration 1

To ensure maximum spectrum reuse, the eNBs operate in the same frequency. Additionally, to minimize interference, a cluster of eNBs are configured to use the same subframe configurations so that they are either transmitting or receiving at the same time. Consequently, the adjacent eNBs need to be synchronized almost perfectly to avoid an UL transmission interfering with a DL transmission in the neighboring cell. The 3GPP has specified in TS 36.133 that the neighboring eNBs need to be phase-aligned to within 3 µs, which corresponds to ±1.5 µs of time error between the grandmaster and the end application (eNB) used in this specification.

III.3 Heterogeneous Networks and Dense Deployments

Small-cell deployments are intended to address the ever-increasing mobile demands in both indoor and outdoor scenarios. For outdoor deployments, small cells are deployed in the same coverage area as the macrocells to fill in the capacity gaps. It is preferable to deploy small cells in different spectrum from the macrocells, but it is not always possible because of limited spectrum availability. In co-channel or in-band deployments, small cells operate on the same frequency as the macrocells to maximize spectrum utilization. Such networks are called heterogeneous networks, or HetNets. The small cells in the HetNets experience inter-cell interference because the macrocells transmit at significantly higher power levels.

As a large percentage of mobile traffic is consumed indoors, operators need to deploy ultra-dense small cells to fulfill the capacity needs. These co-channel eNBs situated in close proximity cause interference to one another, particularly at the overlapping cell edges.

The operators need to implement interference management techniques to address the interference issues unique to small cell deployments.

Traditional LTE includes simple physical (PHY) layer techniques such as heavy coding or OFDM's built-in cyclic prefix to combat interference. However, the techniques have all been designed for single cell operation. In the case of HetNets and ultra-dense deployments, these methods are not enough.

To address this, a number of LTE-A interference management techniques have been developed. The next two sections look at eICIC and CoMP in particular.

Ultimately, although these techniques improve small cell system capacity, they pose stringent requirements on both synchronization and latency.

III.4 ICIC, eICIC

Suppose two neighboring eNBs are operating on the same frequency. The UEs situated in the overlapping coverage area will experience high interference. This is because although the eNBs transmit to the UEs situated at the cell center with low power, they have to transmit at higher power to the UEs at the cell edge in order to reach them with a good enough SINR (signal-to-interference-plus-noise ratio). This situation is depicted in the left side of Figure 48.

With ICIC (inter-cell interference coordination), rather than transmitting blindly to the edge UEs with high power that would cause severe interference at the UEs, the two eNBs exchange information about the portions of the frequency spectrum they plan to use to transmit with high power. In this way, the interference posed on each UE's data channel (PHY downlink shared channel, or PDSCH) is reduced. The right side of Figure 48 shows an example situation: although eNBs A and B operate on the same frequency resource f1, A transmits in resource f3 with high power, and B transmits in resource f2 with high power. This technique is, in essence, a way for the eNBs to partition the spectrum so that they do not transmit with high power in the same OFDM subcarriers. The ICIC technique was developed in LTE Rel-8.

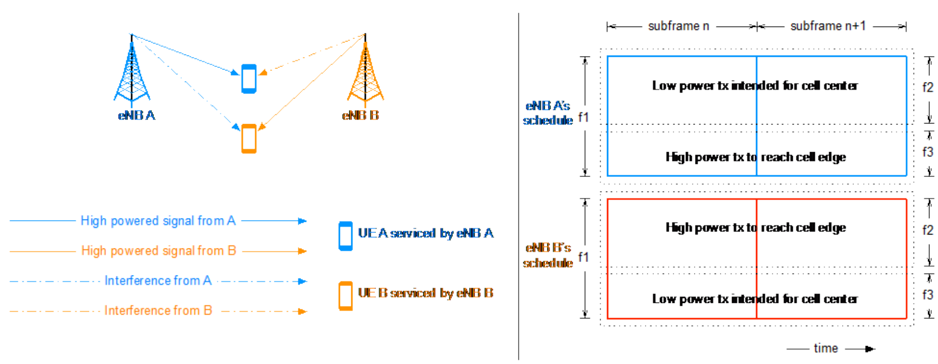

Figure 48 - Interference in Overlapping Cells (Left) and Frequency Domain Inter-Cell Coordination (Right)

Although frequency partitioning works well for data channels, it does not solve the interference issue on the control channel. In each LTE subframe, the first 1 to 3 OFDM symbol(s) includes a broadcast control channel, i.e., the PHY downlink control channel (PDCCH), that includes subframe format indication and how the subframe is being scheduled to each UE, illustrated in Figure 49. This channel needs to be received correctly in order for the UEs to decode the rest of the subframe.

To mitigate interference on the control channel, LTE Rel-10 defines the eICIC (enhanced ICIC) with the concept of the "almost blank subframe (ABS)." ABS is essentially subframe muting, and is shown in the left side of Figure 49. One of the eNBs provides information on which subframes it will mute in the near future to the other eNB. The negotiation between the two eNBs involves message exchanges and takes place on the X2, which is a point-to-point logical interface between two eNBs.

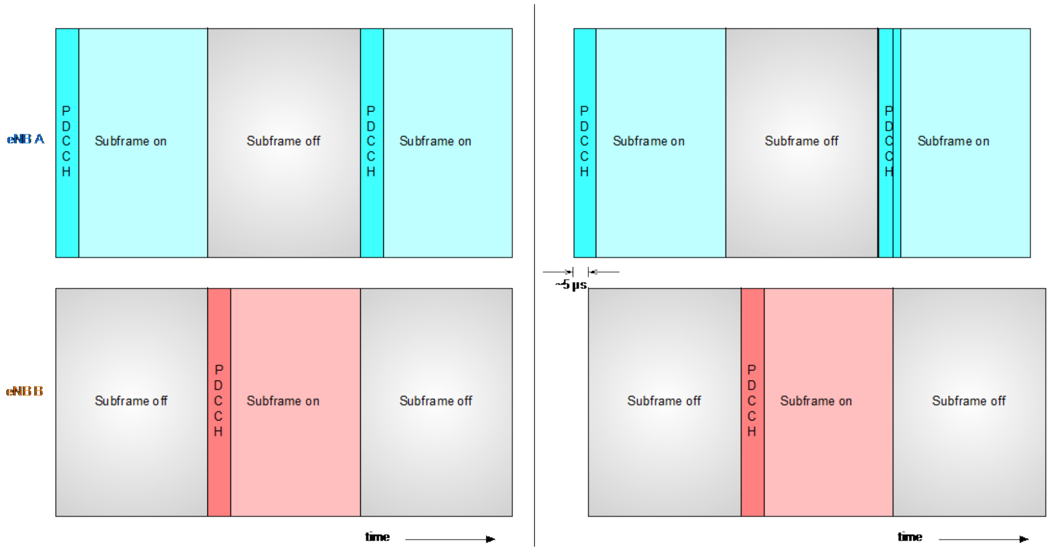

Figure 49 - ABS with Perfect Phase Sync (Left) and Without Perfect Phase Sync (Right)

ABS works when the two eNBs are in perfect phase synchronization. It is therefore critical for the clocks of the participating eNBs to be phase aligned so that the subframes of the overlay eNBs do not overlap when one cell transitions its transmission to “on” while the other transitions to “off.” Otherwise, the PDCCH of one of the eNBs will experience severe interference, as shown on the right side of Figure 49. The 3GPP does not formally define this phase sync limit, but various eNB vendors have quoted that the participating eNBs generally need to be phase aligned within 5 µs, about the size of the cyclic prefix for the first LTE subframe symbol, in order for the technique to result in substantial performance gain.

III.5 CoMP

Although eICIC improves the interference level experienced by UEs at the cell edges, the UE’s throughput is limited to what can be achieved in a single cell because of the frequency and time partitioning of the spectrum and airtime. Coordinated multipoint (CoMP), featured in LTE Rel-11, enables multiple eNBs to simultaneously serve the UEs residing at the cell edge, analogous to a MIMO system, to increase the signal level and thereby achieve better edge UE throughput. Furthermore, whereas eICIC works on a semi-static time frame, which is not suited to fast-changing channel conditions, CoMP allows eNBs in the coordinating set to negotiate resources dynamically.

The 3GPP defines several types of CoMP: coordinated scheduling (CS), which includes beamforming, and joint processing, which includes dynamic point selection and joint transmission.

CS is, in essence, a dynamic version of ICIC, but it has frequency resource partitioning occurring dynamically at every subframe. The left side of Figure 50 shows a snapshot of signal versus interference in subframe n after two eNBs have coordinated their scheduling. When eNBs A and B operate on the same frequency resource f1, it is possible through CoMP signaling to optimize the bandwidth usage. In this example, eNB A transmits in resource f3 to reach its edge UE A, while eNB B transmits in resource f2 to reach its edge UE B at subframe n, indicated in the figure. The right side of Figure 50 shows that the spectrum resources are partitioned and that the scheduling of frequency resources can adapt dynamically on a subframe-by-subframe time scale.

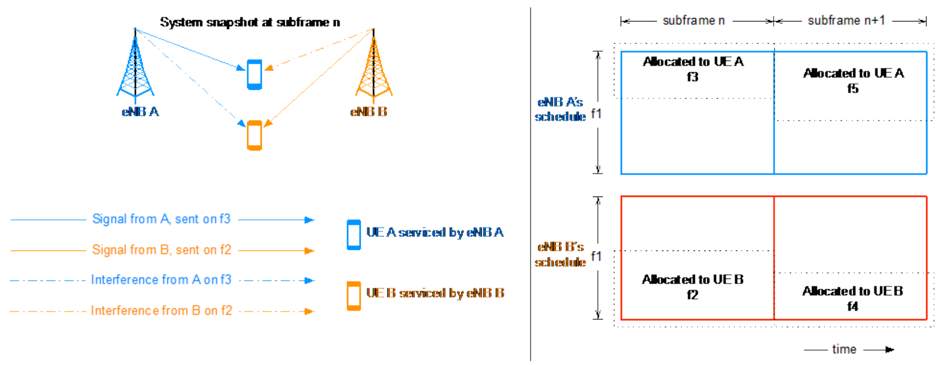

Figure 50 - Coordinated Scheduling:
Snapshot of Signal vs. Interference for Subframe N (Left),
and Subframe Scheduling After Negotiation (Right)

For CS, the data are only available at the UE's serving cell. In this example, eNB A serves as the master eNB for UE A, and eNB B serves as the master eNB for UE B. Scheduling and beamforming decisions are based on the channel state information (CSI) shared between the eNBs in the coordinating set.

With joint processing, user data are available at multiple eNBs. Dynamic point selection, shown in Figure 51, is one type of joint processing. It is similar to CS in that only a single eNB transmits to an edge UE at a given time. The difference is that with dynamic point selection, any eNB can serve an edge UE, not only the master eNB as with CS.

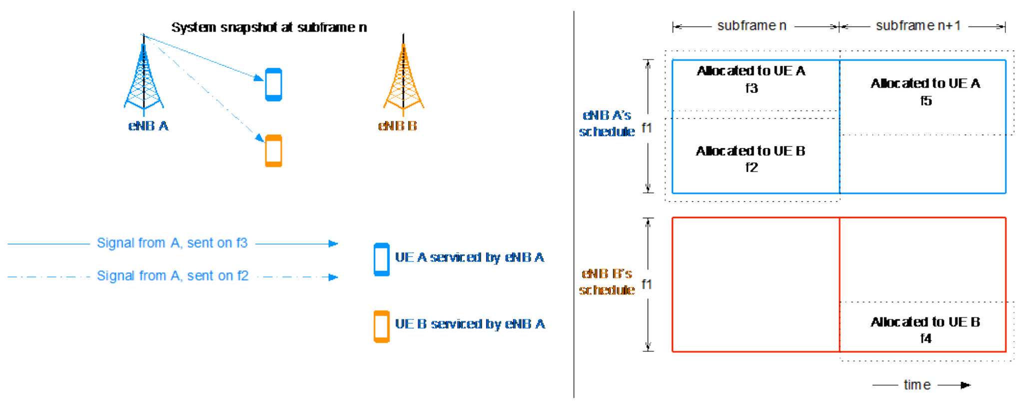

Figure 51 - Dynamic Point Selection:
Snapshot of Signal vs. Interference for Subframe N (Left),
and Subframe Scheduling After Negotiation (Right)

With joint transmission, multiple eNBs can send the same data simultaneously to the edge UE at the same time and on the same frequency resource. This technique improves the received power level at the UE, thereby improving the throughput.

A CoMP resource coordinator (RC) coordinates the schedules among multiple eNBs. It can reside in the eNBs in a distributed fashion, or be close to the evolved packet core (EPC) in a centralized fashion. Figure 52 gives a high level view of how CoMP works when a resource coordinator (RC) is located centrally. Referring to the steps in Figure 52: the UE in CoMP mode measures the CSI from all eNBs it can hear and sends CSI feedback to its master eNB (step 1). The eNBs forward the CSI from the CoMP UEs to the Resource Coordinator (RC, step 2). The RC performs scheduling functions (step 3), and the scheduling information is then conveyed back to each eNB (step 4). If the CSI is delayed on the X2 interface, then the performance gain for the CoMP UE will degrade.

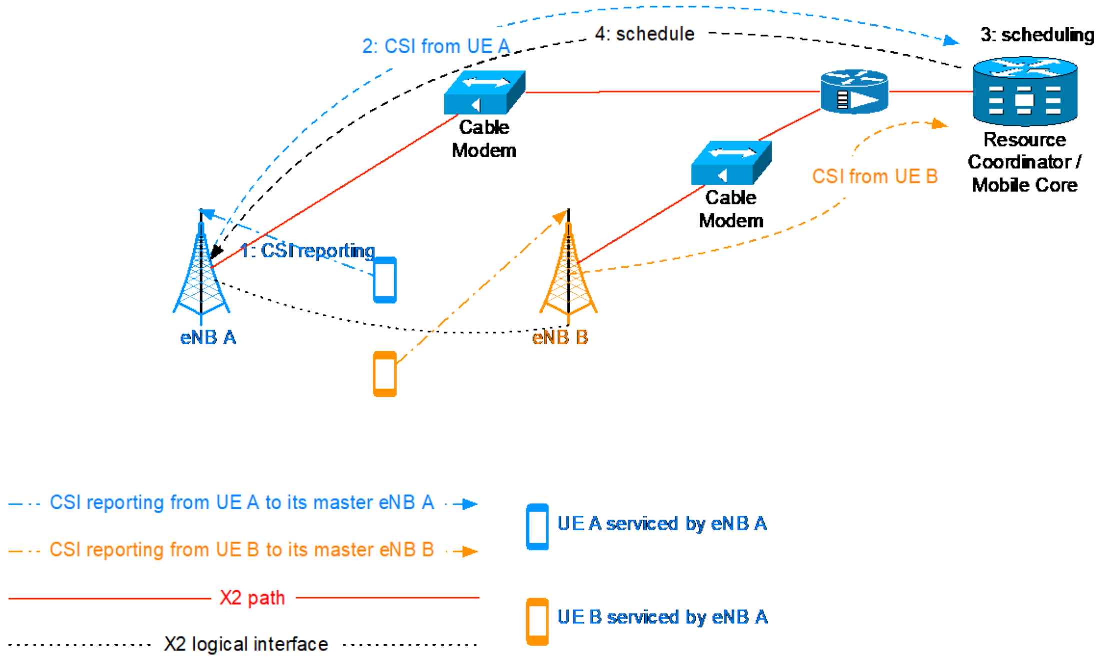

Figure 52 - Example CoMP operations

Therefore, to support inter-eNB CoMP, the clocks of the neighboring eNBs need to be time and phase synchronized to align the radio frames transmitted from different eNBs to the UE. The UE performance degrades with less accurate time and phase synchronization, and the amount of degradation depends on the CoMP technique.

In addition to the phase synchronization requirement, clearly, the CSI needs be sent expeditiously in order for the information to stay relevant and allow the cells to coordinate scheduling according to the dynamically varying channel conditions. This need leads to a set of latency requirements (and possible solutions), which is covered by the authors in [BWR WP].

III.6 eMBMS / MBSFN

Another LTE feature is the evolved Multimedia Broadcast Multicast Services (eMBMS), commonly used for mobile broadcasts of live sporting events. It is supported in LTE over the MBMS Single Frequency Network (MBSFN), which allows multiple eNBs to transmit identical waveforms at the same time and on the same frequency resource. The UE combines the multiple waveforms as multipath components of a single eNB. So, the synchronization requirement is driven by the OFDM cyclic prefix in order to avoid inter-symbol interference.

This technique requires an accuracy of ±10 µs to avoid inter-cell interference.

Appendix IV Transport Mechanisms for PTP Control Plane Messages (Informative)

This section discusses the several approaches to transporting Precision Time Protocol (PTP) and Synchronous Ethernet (SyncE) control plane messages. See Section 6.7.3 for the requirements for transporting PTP and SyncE control plane messages.

The Special PTP ports use DTP for synchronization and PTP for the control plane. DTP runs on DOCSIS MAC management messages. Different ITU-T recommendations use different PTP transport mechanisms.

- [G.8275.1] uses [IEEE 1588-2008], Annex F, "Transport of PTP over IEEE802.3/Ethernet for the transport layer."
- [G.8275.2] uses [IEEE 1588-2008], Annex D, "Transport of PTP over User Datagram Protocol over Internet Protocol Version 4," and Annex E, "Transport of PTP over User Datagram Protocol over Internet Protocol Version 6."

However, as noted in Section 8.5.2.1, the PTP control plane can be transferred through a DOCSIS-specific alternate mechanism, different from those defined in [IEEE 1588-2008] Annex D, E, or F. There are two sets of candidate solutions.

- **Unicast over DOCSIS.** The CMTS is required to send unicast packets that carry the PTP Announce contents to the CM, and CM is required to detect the packets and recover the PTP Announce contents before forwarding them to the Special PTP port. The unicast packets can use one of the following three formats.
    - PTP Announce message ([IEEE 1588-2008], section 13.5) is written into the User Data field of the packet-based unicast DOCSIS MAC frame ([MULPIv3.1], section 6.2.2, “Packet-Based MAC Frames”).
    - PTP Announce message ([IEEE 1588-2008], section 13.5) is first assembled into a UDP packet ([IEEE 1588-2008] Annex D or E) and then written into the User Data field of the packet-based unicast DOCSIS MAC frame ([MULPIv3.1], section 6.2.2, “Packet-Based MAC Frames”).
    - A unicast DOCSIS MAC Management Message (MMM) is used to carry the content of PTP Announce message. This format will require definition of a new DOCSIS MMM or new TLVs for an existing DOCSIS MMM. Given that DTP is performed at a rate of about 1 packet every 10 seconds, it is not suitable to carry the PTP Announce under [G.8275.1], which requires the rate to be 8 packets per second. Under [G.8275.2], however, the packet rate can be negotiated, so DTP might be used only under [G.8275.2].
- **Multicast over DOCSIS.** The CMTS is required to send multicast packets that carry the PTP Announce contents to the CM, and CM is required to detect the packets and recover the PTP Announce contents before forwarding them to the Special PTP port. The multicast packets can use one of the following formats.
    - PTP Announce message ([IEEE 1588-2008], section 13.5) is written into the User Data field of the packet-based multicast DOCSIS MAC frame ([MULPIv3.1], section 6.2.2, "Packet-Based MAC Frames"). DOCSIS multicast addresses are defined in [MULPIv3.1], Annex A.1.1, "General MAC Addresses."
    - IP multicast over DOCSIS can also be used.
    - A multicast (or broadcast) DOCSIS MMM is used to carry the content of PTP Announce message. This format will require definition of a new DOCSIS MMM or new TLVs for an existing DOCSIS MMM.

Appendix V ITU-T Suite of Recommendations (Informative)

This appendix lists the timing recommendations for synchronization developed by ITU-T as of June 2017. All published ITU-T recommendations can be downloaded from http://www.itu.int/rec/T-REC-G/e.

ITU-T recommendations addressing the basics and Network Requirements for frequency

1. ITU-T Recommendation G.8261, Timing and synchronization aspects in packet networks *(includes network requirements for SyncE).*
2. ITU-T Recommendation G.8261.1, Packet delay variation network limits applicable to packet-based methods (Frequency synchronization).

ITU-T recommendations addressing Clocks Requirements for frequency

1. ITU-T Recommendation G.811, Timing characteristics of primary reference clocks
2. ITU-T Recommendation G.811.1, Timing characteristics of enhanced primary reference clocks
3. ITU-T Recommendation G.812, Timing requirements of slave clocks suitable for use as node clocks in synchronization networks
4. ITU-T Recommendation G.813, Timing characteristics of SDH equipment slave clocks
5. ITU-T Recommendation G.8262, Timing characteristics of a synchronous Ethernet equipment slave clock
6. ITU-T Recommendation G.8262.1, Timing characteristics of an enhanced synchronous equipment slave clock (this recommendation is being developed)
7. ITU-T Recommendation G.8263, Timing characteristics of packet-based equipment clocks
8. ITU-T Recommendation G.8266, Timing characteristics of telecom grandmaster clocks for frequency synchronization

ITU-T recommendations addressing methods and architecture for frequency

1. ITU-T Recommendation G.8264, Distribution of timing information through packet networks
2. ITU-T Recommendation G.8265, Architecture and requirements for packet-based frequency delivery

ITU-T recommendation addressing profile for frequency

1. ITU-T Recommendation G.8265.1, Precision time protocol telecom profile for frequency synchronization

ITU-T recommendations addressing Primary Reference Clock requirements that can be used in networks for frequency and time/phase

1. ITU T Recommendation G.8272, Timing characteristics of primary reference time clocks. *The current recommendation addresses Clock Class A. Clock class B is in development.*
2. ITU T Recommendation G.8272.1, Timing characteristics of enhanced primary reference time clocks. *The current recommendation addresses Clock Class A. Clock class B is in development.*

ITU-T recommendations addressing Definitions/Terminology for frequency and time/phase

1. ITU-T Recommendation G.810, Definitions and terminology for synchronization networks
2. ITU-T Recommendation G.8260, Definitions and terminology for synchronization in packet networks

ITU-T recommendations addressing the basics and Network Requirements for time/phase

1. ITU T Recommendation G.8271, Time and phase synchronization aspects of telecommunication networks
2. ITU T Recommendation G.8271.1, Network limits for time synchronization in packet networks
   This recommendation is used for full time support (FTS) for accuracy levels of 4, 5, and 6 as defined in ITU-T G.8271.
3. ITU T Recommendation G.8271.2, Network limits for time synchronization in packet networks with partial timing support from the network
   This recommendation is used for assisted partial time support (APTS) and for partial time support (PTS) for accuracy level of 4 as defined in ITU-T G.8271.

ITU-T recommendations addressing Clocks Requirements for time/phase for FTS

1. ITU T Recommendation G.8273, Framework of phase and time clocks
2. ITU T Recommendation G.8273.1, Timing characteristics of telecom grandmaster clocks for time synchronization
   (this recommendation is being developed)
3. ITU T Recommendation G.8273.2, Timing characteristics of telecom boundary clocks and telecom time slave clocks
4. ITU T Recommendation G.8273.3, Timing characteristics of telecom transparent clocks

ITU-T recommendations addressing Clocks Requirements for time/phase for APTS/PTS

1. ITU T Recommendation G.8273.4, Timing characteristics of partial timing support telecom boundary clocks and telecom time slave clocks
   (this recommendation is being developed)

ITU-T recommendations addressing architecture for time/phase

1. ITU T Recommendation G.8275, Architecture and requirements for packet-based time and phase distribution

ITU-T recommendations addressing profile for time/phase for FTS

1. ITU-T Recommendation G.8275.1, Precision time protocol telecom profile for phase/time synchronization with full timing support from the network

ITU-T recommendations addressing profile for time/phase for APTS/PTS

1. ITU-T Recommendation G.8275.2, Precision time protocol telecom profile for time/phase synchronization with partial timing support from the network

ITU-T recommendations addressing Synchronization Layer functions

1. ITU-T Recommendation G.781, Synchronization layer functions
2. ITU-T Recommendation G.781.1, Synchronization layer functions for time and frequency transport
   (this recommendation is being developed)

ITU-T recommendations addressing Interfaces

1. ITU-T Recommendation G.703, Physical/electrical characteristics of hierarchical digital interfaces

The following ITU-T supplements related to synchronization are being developed.

1. TR-GNSS, Technical Report on Considerations on the Use of GNSS as a Primary Time Reference in Telecommunications
2. G.Suppl.SyncOAM, Supplement on Synchronization OAM requirement
3. G.Supp.sim, Supplement on Simulations of Transport of Time over Packet Networks

Appendix VI Synchronization-Related SNMP MIB Object (Informative)

The text below is for informational purpose only. The MIB file will be published at a later date. At that time, the text below will be replaced by a reference and link to the MIB file.

```
DOCS-CM-SYNC-MIB DEFINITIONS ::= BEGIN
  IMPORTS
    MODULE-IDENTITY,
    OBJECT-TYPE,
    Unsigned32,
    Counter64,
    Integer32,
    TimeTicks
        FROM SNMPv2-SMI         -- RFC 2578
    TruthValue,
    TimeStamp,
    DateAndTime,
    TEXTUAL-CONVENTION
        FROM SNMPv2-TC
    OBJECT-GROUP,
    MODULE-COMPLIANCE
        FROM SNMPv2-CONF
    SnmpAdminString
        FROM SNMP-FRAMEWORK-MIB -- RFC 3411
    IfDirection
        FROM DOCS-IF3-MIB
    clabProjDocsis
        FROM CLAB-DEF-MIB
    docsCmSyncRpdDevInfoUniqueId
        FROM DOCS-RPHY-MIB;
    InetAddressType,
    InetAddress
        FROM INET-ADDRESS-MIB

docsCmSyncMib MODULE-IDENTITY
    LAST-UPDATED    "xxx" -- TBD, 2020
    ORGANIZATION    "Cable Television Laboratories, Inc"
    CONTACT-INFO
        "
         Postal: Cable Television Laboratories, Inc.
         400 Centennial Parkway
         Louisville, Colorado 80027-1266
         U.S.A.
         Phone: +1 303-661-9100
         Fax: +1 303-661-9199
         E-mail: mibs@cablelabs.com"
    DESCRIPTION
        "This MIB module contains the status and reporting objects
         for the CM Sync (DTP, SyncE and PTP) management.
         Copyright 2017-2021 Cable Television Laboratories, Inc.
         All rights reserved."
    REVISION "XX" -- TBD, 2020
    DESCRIPTION
        "Initial version, created by xxx."
::= { clabProjDocsis XX }


-- ---------------------------------------------------------
-- Textual Conventions
-- ---------------------------------------------------------
```

```
-- ---------------------------------------------------------------------
-- Main Groups
-- ---------------------------------------------------------------------
docsCmSyncNotifications        OBJECT IDENTIFIER ::= { docsCmSyncMib 0}
docsCmSyncObjects              OBJECT IDENTIFIER ::= { docsCmSyncMib 1}
docsCmSyncConformance          OBJECT IDENTIFIER ::= { docsCmSyncMib 2}

docsCmSyncPtpMibObjects        OBJECT IDENTIFIER ::= { docsCmSyncObjects 1}
docsCmSyncSynceMibObjects      OBJECT IDENTIFIER ::= { docsCmSyncSynceObjects 2}
docsCmSyncDtpMibObjects        OBJECT IDENTIFIER ::= { docsCmSyncDtpObjects 3}


docsCmSyncCompliances          OBJECT IDENTIFIER ::= { docsCmSyncConformance 1 }
docsCmSyncGroups               OBJECT IDENTIFIER ::= { docsCmSyncConformance 2 }


-- ---------------------------------------------------------------------
-- Notification Objects
-- ---------------------------------------------------------------------

-- ---------------------------------------------------------------------
-- PTP Group Objects
-- ---------------------------------------------------------------------

-- ---------------------------------------------------------------------
-- Default DataSet Group
-- ---------------------------------------------------------------------

docsCmSyncPtpDefaultDataSet    OBJECT IDENTIFIER ::= {docsCmSyncPtpMibObjects 1}

docsCmSyncPtpDefaultDataSetTwoStepFlag OBJECT-TYPE
    SYNTAX      TruthValue
    MAX-ACCESS  read-only
    STATUS      current
    DESCRIPTION
        "This attribute specifies whether the Two Step process is
         used (i.e., the clock is a two-step clock)."
    ::= {docsCmSyncPtpDefaultDataSet 1}

docsCmSyncPtpDefaultDataSetClockIdentity OBJECT-TYPE
    SYNTAX      OCTET STRING(SIZE(8))
    MAX-ACCESS  read-only
    STATUS      current
    DESCRIPTION
        "This attribute specifies the default Dataset clock identity."
    ::= {docsCmSyncPtpDefaultDataSet 2}

docsCmSyncPtpDefaultDataSetPriority1 OBJECT-TYPE
    SYNTAX      Unsigned32
    MAX-ACCESS  read-only
    STATUS      current
    DESCRIPTION
        "This attribute specifies the default Dataset clock Priority1.
         Lower values take precedence."
    ::= {docsCmSyncPtpDefaultDataSet 3}

docsCmSyncPtpDefaultDataSetPriority2 OBJECT-TYPE
    SYNTAX      Unsigned32
    MAX-ACCESS  read-only
    STATUS      current
    DESCRIPTION
        "This attribute specifies the default Dataset clock Priority2.
```

```
         Lower values take precedence."
     ::= {docsCmSyncPtpDefaultDataSet 4}

docsCmSyncPtpDefaultDataSetSlaveOnly OBJECT-TYPE
    SYNTAX      TruthValue
    MAX-ACCESS  read-only
    STATUS      current
    DESCRIPTION
        "This attribute specifies whether the SlaveOnly flag is set."
    ::= {docsCmSyncPtpDefaultDataSet 5}

docsCmSyncPtpDefaultDataSetQualityClass OBJECT-TYPE
    SYNTAX      Unsigned32(0..255)
    MAX-ACCESS  read-only
    STATUS      current
    DESCRIPTION
        "This attribute of an ordinary or boundary clock denotes the traceability
         of the time or frequency distributed by the grandmaster clock.
         See section 7.6.2.4 in [IEEE 1588]."
    ::= {docsCmSyncPtpDefaultDataSet 6}

docsCmSyncPtpDefaultDataSetQualityAccuracy OBJECT-TYPE
    SYNTAX      Unsigned32
    MAX-ACCESS  read-only
    STATUS      current
    DESCRIPTION
        "This attribute characterizes a clock for the purpose of the best master
         clock (BMC) algorithm. See section 7.6.2.5 in [IEEE 1588]."
    ::= {docsCmSyncPtpDefaultDataSet 7}

docsCmSyncPtpDefaultDataSetQualityOffset OBJECT-TYPE
    SYNTAX      Unsigned32(0..65535)
    MAX-ACCESS  read-only
    STATUS      current
    DESCRIPTION
        "This attribute is the offset, scaled, logarithmic representation of
         the clock variance. See Section 7.6.3.5 in [IEEE 1588]."
    ::= {docsCmSyncPtpDefaultDataSet 8}

-- ---------------------------------------------------------------------
-- Current DataSet Group
-- ---------------------------------------------------------------------
docsCmSyncPtpCurrentDataSet OBJECT IDENTIFIER ::= {docsCmSyncPtpMibObjects 2}

docsCmSyncPtpCurrentDataSetStepsRemoved OBJECT-TYPE
    SYNTAX      Unsigned32
    UNITS       "steps"
    MAX-ACCESS  read-only
    STATUS      current
    DESCRIPTION
        "This attribute is the number of communication paths traversed between the
         local clock and the grandmaster clock. The initialization value is 0."
    ::= {docsCmSyncPtpCurrentDataSet 1}

docsCmSyncPtpCurrentDataSetOffsetFromMaster OBJECT-TYPE
    SYNTAX      Integer32
    UNITS       "Nanoseconds"
    MAX-ACCESS  read-only
    STATUS      current
    DESCRIPTION
        "This attribute is an implementation-specific representation of the current
         value of the time difference between a master and a slave as computed by
         the slave."
```

```
     ::= {docsCmSyncPtpCurrentDataSet 2}

docsCmSyncPtpCurrentDataSetMeanPathDelay OBJECT-TYPE
    SYNTAX      Unsigned32
    UNITS       "Nanoseconds"
    MAX-ACCESS  read-only
    STATUS      current
    DESCRIPTION
        "This attribute is an implementation-specific representation of the current
         value of the mean propagation time between a master and slave clock as
         computed by the slave. Zero means that the path delay is unavailable."
    ::= {docsCmSyncPtpCurrentDataSet 3}

-- ---------------------------------------------------------------------
-- Parent DataSet Group
-- ---------------------------------------------------------------------

docsCmSyncPtpParentDataSet OBJECT IDENTIFIER ::= {docsCmSyncPtpMibObjects 3}

docsCmSyncPtpParentDataSetParentClockId OBJECT-TYPE
    SYNTAX      OCTET STRING(SIZE(8))
    MAX-ACCESS  read-only
    STATUS      current
    DESCRIPTION
        "This attribute is the clock identifier of the clock port on the master that
         issues the Sync messages used in synchronizing this clock."
    ::= {docsCmSyncPtpParentDataSet 1}

docsCmSyncPtpParentDataSetParentPortNumber OBJECT-TYPE
    SYNTAX      Unsigned32
    MAX-ACCESS  read-only
    STATUS      current
    DESCRIPTION
        "This attribute is the port number of the clock port on the master that issues
         the Sync messages used in synchronizing this clock."
    ::= {docsCmSyncPtpParentDataSet 2}

docsCmSyncPtpParentDataSetParentStats OBJECT-TYPE
    SYNTAX      TruthValue
    MAX-ACCESS  read-only
    STATUS      current
    DESCRIPTION
        "This attribute is set to True if the clock has a port in the slave state and
         the clock has computed statistically valid estimates of the ClockOffset
         Scaled Log Variance and the Clock PhaseChangeRate. If either the ClockOffset
         Scaled Log Variance or the Clock PhaseChangeRate is not computed, then the
         core needs set the value of ParentStats to false."
    ::= {docsCmSyncPtpParentDataSet 3}

docsCmSyncPtpParentDataSetClockOffset OBJECT-TYPE
    SYNTAX      Integer32
    UNITS       "Nanoseconds"
    MAX-ACCESS  read-only
    STATUS      current
    DESCRIPTION
        "This attribute represents the value of the observed Parent Offset Scaled Log
         Variance, which is an estimate of the parent clock's PTP variance as observed
         by the slave clock. The computation of this value is optional, but if not
         computed, the value of parentStats is FALSE. The initialization value of
         ClockOffset is 0xFFFF."
    ::= {docsCmSyncPtpParentDataSet 4}

docsCmSyncPtpParentDataSetPhaseChangeRate OBJECT-TYPE
```

```
    SYNTAX      Integer32
    UNITS       "Nanoseconds"
    MAX-ACCESS  read-only
    STATUS      current
    DESCRIPTION
        "This attribute represents the value of Phase Change Rate, which is an
         Estimate of the parent clock's phase change rate as observed by the slave
         clock. If the estimate exceeds the capacity of its data type, this value is
         set to 0x7FFF FFFF. A positive sign indicates that the parent clock's phase
         change rate is greater than the rate of the slave clock. The computation of
         this value is optional, but if not computed, the value of parentStats is
         FALSE."
    ::= {docsCmSyncPtpParentDataSet 5}

docsCmSyncPtpParentDataSetGmClockIdentity OBJECT-TYPE
    SYNTAX      OCTET STRING(SIZE(8))
    MAX-ACCESS  read-only
    STATUS      current
    DESCRIPTION
        "This attribute represents the clock Identity of the grandmaster clock."
    ::= {docsCmSyncPtpParentDataSet 6}

docsCmSyncPtpParentDataSetGmPriority1 OBJECT-TYPE
    SYNTAX      Unsigned32
    MAX-ACCESS  read-only
    STATUS      current
    DESCRIPTION
        "This attribute represents the priority1 of the grandmaster clock.
         Lower values take precedence."
    ::= {docsCmSyncPtpParentDataSet 7}

docsCmSyncPtpParentDataSetGmPriority2 OBJECT-TYPE
    SYNTAX      Unsigned32
    MAX-ACCESS  read-only
    STATUS      current
    DESCRIPTION
        "This attribute represents the priority2 of the grandmaster clock. Lower
         values take precedence."
    ::= {docsCmSyncPtpParentDataSet 8}

docsCmSyncPtpParentDataSetGmQualityClass OBJECT-TYPE
    SYNTAX      Unsigned32
    MAX-ACCESS  read-only
    STATUS      current
    DESCRIPTION
        "This attribute is the clock class for the grandmaster clock. The clock class
         attribute of an ordinary or boundary clock denotes the
         traceability of the time or frequency distributed by the
         grandmaster clock. See section 7.6.2.4 in [IEEE 1588]."
    ::= {docsCmSyncPtpParentDataSet 9}

docsCmSyncPtpParentDataSetGmQualityAccuracy OBJECT-TYPE
    SYNTAX      Unsigned32
    MAX-ACCESS  read-only
    STATUS      current
    DESCRIPTION
        "This attribute characterizes the grandmaster clock for the purpose of the
         best master clock (BMC) algorithm. See section 7.6.2.5 in [IEEE 1588]."
    ::= {docsCmSyncPtpParentDataSet 10}

docsCmSyncPtpParentDataSetGmQualityOffset  OBJECT-TYPE
    SYNTAX      Unsigned32
    MAX-ACCESS  read-only
```

```
    STATUS      current
    DESCRIPTION
        "This attribute represents the offset, scaled, logarithmic representation of
         the grandmaster clock variance. See Section 7.6.3.5 in [IEEE 1588]."
    ::= {docsCmSyncPtpParentDataSet 11}

-- ------------------------------------------------------------------
-- Time Properties Group
-- ------------------------------------------------------------------
docsCmSyncPtpTimeProperties OBJECT IDENTIFIER ::= {docsCmSyncPtpMibObjects 4}

docsCmSyncPtpTimePropertiesCurrentUtcOffsetValid OBJECT-TYPE
    SYNTAX        TruthValue
    MAX-ACCESS    read-only
    STATUS        current
    DESCRIPTION
        "This attribute represents the value of currentUtcOffsetValid is TRUE if the
         currentUtcOffset is known to be correct."
    ::= {docsCmSyncPtpTimeProperties 1}

docsCmSyncPtpTimePropertiesCurrentUtcOffset OBJECT-TYPE
    SYNTAX        Integer32
    UNITS         "Seconds"
    MAX-ACCESS    read-only
    STATUS        current
    DESCRIPTION
        "This attribute represents the offset between International Atomic Time (TAI)
         and Universal Coordinated Time (UTC)."
    ::= {docsCmSyncPtpTimeProperties 2}

docsCmSyncPtpTimePropertiesLeap59 OBJECT-TYPE
    SYNTAX        TruthValue
    MAX-ACCESS    read-only
    STATUS        current
    DESCRIPTION
        "This attribute represents whether or not there are 59 seconds
         in the last minute of the current UTC day for PTP systems
         whose epoch is the PTP epoch,; a TRUE value for Leap59 indicates
         that the last minute of the current UTC day contains 59 seconds."
    ::= {docsCmSyncPtpTimeProperties 3}

docsCmSyncPtpTimePropertiesLeap61 OBJECT-TYPE
    SYNTAX        TruthValue
    MAX-ACCESS    read-only
    STATUS        current
    DESCRIPTION
        "This attribute represents whether or not there are 61 seconds in the last
         minute of the current UTC day for PTP systems whose epoch is the PTP epoch;
         a TRUE value for Leap61 indicates that the last minute of the current UTC day
         contains 61 seconds."
    ::= {docsCmSyncPtpTimeProperties 4 }

docsCmSyncPtpTimePropertiesTimeTraceable OBJECT-TYPE
    SYNTAX        TruthValue
    MAX-ACCESS    read-only
    STATUS        current
    DESCRIPTION
        "This attribute represents whether the timescale and the value of
         currentUtcOffset are traceable to a primary reference. TimeTraceable is TRUE
         if the timescale and the value of currentUtcOffset are traceable to a primary
         reference; otherwise, the value is FALSE."
    ::= {docsCmSyncPtpTimeProperties 5 }
```

```
docsCmSyncPtpTimePropertiesFreqTraceable OBJECT-TYPE
    SYNTAX        TruthValue
    MAX-ACCESS    read-only
    STATUS        current
    DESCRIPTION
        "This attribute represents whether the frequency determining the timescale is
         traceable to a primary reference. The value of FrequencyTraceable is TRUE if
         the frequency determining the timescale is traceable to a primary reference;
         otherwise, the value is FALSE."
    DEFVAL { true }
    ::= {docsCmSyncPtpTimeProperties 6}

docsCmSyncPtpTimePropertiesPtpTimescale OBJECT-TYPE
    SYNTAX        TruthValue
    MAX-ACCESS    read-only
    STATUS        current
    DESCRIPTION
        "This attribute is always true for grandmaster clocks with a clock timescale
         of PTP."
    ::= {docsCmSyncPtpTimeProperties 7}

docsCmSyncPtpTimePropertiesTimeSource OBJECT-TYPE
    SYNTAX        Unsigned32 (0..255)
    MAX-ACCESS    read-only
    STATUS        current
    DESCRIPTION
        "This attribute represents the source of time used by the grandmaster clock.
         See Table 7 in [IEEE 1588]. If the time source of the grandmaster clock is
         unknown, the core needs set the TimeSource value to INTERNAL_OSCILLATOR
         (0xA0)."
    ::= {docsCmSyncPtpTimeProperties 8}

-- ---------------------------------------------------------------------
-- Port Data Set Table
-- ---------------------------------------------------------------------

docsCmSyncPtpPortDataSetTable OBJECT-TYPE
    SYNTAX        SEQUENCE OF DocsCmSyncPtpPortDataSetEntry
    MAX-ACCESS    not-accessible
    STATUS        current
    DESCRIPTION
        "See section 8.2.5 in [IEEE 1588] for details of the 1588 port dataset."
    ::={docsCmSyncPtpMibObjects 5}

docsCmSyncPtpPortDataSetEntry OBJECT-TYPE
    SYNTAX        DocsCmSyncPtpPortDataSetEntry
    MAX-ACCESS    not-accessible
    STATUS        current
    DESCRIPTION
        "The conceptual row of docsCmSyncPtpPortDataSetTable."
    INDEX        {docsCmSyncPtpPortDataSetPortNumber}
    ::= {docsCmSyncPtpPortDataSetTable 1}

DocsCmSyncPtpPortDataSetEntry ::= SEQUENCE
    {
    docsCmSyncPtpPortDataSetPortNumber       Unsigned32,
    docsCmSyncPtpPortDataSetPortState        Unsigned32,
    docsCmSyncPtpPortDataSetMeanPathDelay    Integer32
    }

docsCmSyncPtpPortDataSetPortNumber OBJECT-TYPE
    SYNTAX        Unsigned32 (0..65535)
    MAX-ACCESS    not-accessible
```

```
    STATUS        current
    DESCRIPTION
        "This key attribute is the port number of the local clock port.
         Port numbers 0 and 65,535 are reserved and cannot be used for real clock
         ports. See [IEEE 1588] for more information. When a PTP clock has N ports,
         the core needs set the port number to a value in the interval 1..N."
    ::= {docsCmSyncPtpPortDataSetEntry 1}

docsCmSyncPtpPortDataSetPortState OBJECT-TYPE
    SYNTAX        Unsigned32 (0..255)
    MAX-ACCESS    read-only
    STATUS        current
    DESCRIPTION
        "This attribute is the state of this PTP clock port. See Table 8 in
         [IEEE 1588]."
    ::= {docsCmSyncPtpPortDataSetEntry 2}

docsCmSyncPtpPortDataSetMeanPathDelay OBJECT-TYPE
    SYNTAX        Integer32
    MAX-ACCESS    read-only
    STATUS        current
    DESCRIPTION
        "This attribute is an implementation-specific representation of the current
         value of the mean propagation time between a master and slave clock as
         computed by the slave. Zero means that the path delay is unavailable."
    ::= {docsCmSyncPtpPortDataSetEntry 3}

-- ---------------------------------------------------------------------
-- Clock Status Group
-- ---------------------------------------------------------------------

docsCmSyncPtpClockStatus OBJECT IDENTIFIER ::= {docsCmSyncPtpMibObjects 6}

docsCmSyncPtpClockStatusPacketsSent OBJECT-TYPE
    SYNTAX            Counter64
    UNITS             "Packets"
    MAX-ACCESS        read-only
    STATUS            current
    DESCRIPTION
        "This attribute represents the number of PTP packets sent for this clock."
    ::= {docsCmSyncPtpClockStatus 1 }

docsCmSyncPtpClockStatusPacketsReceived OBJECT-TYPE
    SYNTAX            Counter64
    UNITS             "Packets"
    MAX-ACCESS        read-only
    STATUS            current
    DESCRIPTION
        "This attribute represents the number of PTP packets received for this clock."
    ::= {docsCmSyncPtpClockStatus 2 }

docsCmSyncPtpClockStatusPacketsDropped OBJECT-TYPE
    SYNTAX            Counter64
    UNITS             "Packets"
    MAX-ACCESS        read-only
    STATUS            current
    DESCRIPTION
        "This attribute represents the number of PTP packets dropped for this clock."
    ::= {docsCmSyncPtpClockStatus 3 }

docsCmSyncPtpClockStatusProfileId OBJECT-TYPE
    SYNTAX            OCTET STRING (SIZE (6))
    MAX-ACCESS        read-only
```

```
    STATUS            current
    DESCRIPTION
        "This attribute represents the profile used by the clock."
    ::= {docsCmSyncPtpClockStatus 4 }

docsCmSyncPtpClockStatusVersionNumber OBJECT-TYPE
    SYNTAX            Unsigned32
    MAX-ACCESS        read-only
    STATUS            current
    DESCRIPTION
        "This attribute represents the PTP version number. IEEE 1588-2008 &
         IEEE 1588-2019 use version number 2."
    ::= {docsCmSyncPtpClockStatus 5 }

docsCmSyncPtpClockStatusMinorVersionNumber OBJECT-TYPE
    SYNTAX            Unsigned32
    MAX-ACCESS        read-only
    STATUS            current
    DESCRIPTION
        "This attribute represents the PTP minor version number. IEEE 1588-2008 uses a
         minor version number of 0, while & IEEE 1588-2019 use a minor version number
         of 1."
    ::= {docsCmSyncPtpClockStatus 6 }

docsCmSyncPtpClockStatusMaxSlaves OBJECT-TYPE
    SYNTAX            Unsigned32
    MAX-ACCESS        read-only
    STATUS            current
    DESCRIPTION
        "This attribute represents the maximum number of slaves supported on a master
         clock port."
    ::= {docsCmSyncPtpClockStatus 7 }



-- ------------------------------------------------------------
-- Port Status Table
-- ------------------------------------------------------------

docsCmSyncPtpPortStatusTable OBJECT-TYPE
    SYNTAX         SEQUENCE OF DocsCmSyncPtpPtpPortStatusEntry
    MAX-ACCESS     not-accessible
    STATUS         current
    DESCRIPTION
        "PtpStatus is an instantiation of the abstract class
         PtpPortStatus and inherits those common attributes"
    ::={docsCmSyncPtpMibObjects 7 }

docsCmSyncPtpPortStatusEntry OBJECT-TYPE
    SYNTAX        DocsCmSyncPtpPortStatusEntry
    MAX-ACCESS    not-accessible
    STATUS        current
    DESCRIPTION
        "The conceptual row of docsCmSyncPtpPortStatusTable."
    INDEX         {docsCmSyncPtpPortStatusPortNumber }
    ::= {docsCmSyncPtpPortStatusTable 1}

DocsCmSyncPtpPortStatusEntry ::= SEQUENCE
    {
    docsCmSyncPtpPortStatusPortNumber                 Unsigned32,
    docsCmSyncPtpPortStatusPacketsSent                Counter64,
    docsCmSyncPtpPortStatusPacketsReceived            Counter64,
```

```
    docsCmSyncPtpPortStatusPacketsDropped             Counter64,
    docsCmSyncPtpPortStatusCounterDiscontinuityTime   DateAndTime
    }

docsCmSyncPtpPortStatusPortNumber OBJECT-TYPE
    SYNTAX        Unsigned32 (0..65535)
    MAX-ACCESS    not-accessible
    STATUS        current
    DESCRIPTION
        "This key attribute is the port number of the local clock port. Port 0 needs
         to be used for the master port and port 1 needs be used for the special slave
         PTP port"
    ::= {docsCmSyncPtpPortStatusEntry 1 }

docsCmSyncPtpPortStatusPacketsSent OBJECT-TYPE
    SYNTAX        Counter64
    UNITS        "Packets"
    MAX-ACCESS    read-only
    STATUS        current
    DESCRIPTION
        "This attribute represents the number of PTP packets
         sent for this clock port."
    ::= {docsCmSyncPtpPortStatusEntry 2 }

docsCmSyncPtpPortStatusPacketsReceived OBJECT-TYPE
    SYNTAX        Counter64
    UNITS        "Packets"
    MAX-ACCESS    read-only
    STATUS        current
    DESCRIPTION
        "This attribute represents the number of PTP packets
         received for this clock port."
    ::= {docsCmSyncPtpPortStatusEntry 3 }

docsCmSyncPtpPortStatusPacketsDropped OBJECT-TYPE
    SYNTAX        Counter64
    UNITS        "Packets"
    MAX-ACCESS    read-only
    STATUS        current
    DESCRIPTION
        "This attribute represents the number of PTP packets
         dropped for this clock port."
    ::= {docsCmSyncPtpPortStatusEntry 4 }


docsCmSyncPtpPortStatusCounterDiscontinuityTime OBJECT-TYPE
    SYNTAX        DateAndTime
    MAX-ACCESS    read-only
    STATUS        current
    DESCRIPTION
        "This attribute reports the date and time at which any
         one or more of the counters in this group were created or
         last reset to zero. If the CM does not acquire time of day
         it can report an initial CounterDiscontinuityTime of Jan 1 1970."
    ::= {docsCmSyncPtpPortStatusEntry 45}

-- ---------------------------------------------------------------------
-- PortAssociatesClockStatusTable
-- ---------------------------------------------------------------------

docsCmSyncPtpPortAssociatesClockStatusTable OBJECT-TYPE
    SYNTAX            SEQUENCE OF DocsCmSyncPtpPortAssociatesClockStatusEntry
    MAX-ACCESS        not-accessible
```

```
    STATUS            current
    DESCRIPTION
        "This table contains Port Associates Clock Status attributes. For a master
         port this lists slave clocks that are connected. For a slave/special port
         this lists the master clock for the announce messages."
    ::={docsCmSyncPtpMibObjects 8 }

docsCmSyncPtpPortAssociatesClockStatusEntry OBJECT-TYPE
    SYNTAX        DocsCmSyncPtpPortAssociatesClockStatusEntry
    MAX-ACCESS    not-accessible
    STATUS        current
    DESCRIPTION
        "The conceptual row of docsCmSyncPtpPortAssociatesClockStatusTable."
    INDEX       {docsCmSyncPtpPortStatusPortNumber }
    ::= {docsCmSyncPtpPortAssociatesClockStatusTable 1}

DocsCmSyncPtpPortAssociatesClockStatusEntry ::= SEQUENCE
    {
    docsCmSyncPtpPortAssociatesClockStatusPacketsSent               Counter64,
    docsCmSyncPtpPortAssociatesClockStatusPacketsReceived           Counter64,
    docsCmSyncPtpPortAssociatesClockStatusPacketsDropped            Counter64,
    docsCmSyncPtpPorAssociatesClockStatusClockId                    OCTET STRING,
    docsCmSyncPtpPortAssociatesClockStatusClockPortNumber           Unsigned32,
    docsCmSyncPtpPortAssociatesClockStatusClockPortNumber           Unsigned32,
    docsCmSyncPtpPortAssociatesClockStatusIsConnected               TruthValue,
    docsCmSyncPtpPortAssociatesClockStatusLogSyncInterval           Unsigned32,
    docsCmSyncPtpPortAssociatesClockStatusLogDelayReqInterval       Unsigned32,
    docsCmSyncPtpPortAssociatesClockStatusLogAnnounceInterval       Unsigned32,
    docsCmSyncPtpPortAssociatesClockStatusGrantDuration             Unsigned32,
    docsCmSyncPtpPortAssociatesClockStatusAddrType                  InetAddressType,
    docsCmSyncPtpPortAssociatesClockStatusInetAddr                  InetAddress,
    docsCmSyncPtpPortAssociatesClockStatusCounterDiscontinuityTime DateAndTime
    }

docsCmSyncPtpPortAssociatesClockStatusPacketsSent OBJECT-TYPE
    SYNTAX           Counter64
    UNITS            "Packets"
    MAX-ACCESS       read-only
    STATUS           current
    DESCRIPTION
        "This attribute represents the number of PTP packets
         sent to this Associate for this clock port."
    ::= {docsCmSyncPtpPortAssociatesClockStatusEntry 1 }

docsCmSyncPtpPortAssociatesClockStatusPacketsReceived OBJECT-TYPE
    SYNTAX           Counter64
    UNITS            "Packets"
    MAX-ACCESS       read-only
    STATUS           current
    DESCRIPTION
        "This attribute represents the number of PTP packets
         received from this Associate for this clock port."
    ::= {docsCmSyncPtpPortAssociatesClockStatusEntry 3 }

docsCmSyncPtpPortAssociatesClockStatusPacketsDropped OBJECT-TYPE
    SYNTAX           Counter64
    UNITS            "Packets"
    MAX-ACCESS       read-only
    STATUS           current
    DESCRIPTION
        "This attribute represents the number of PTP packets
         dropped from this Associate for this clock port."
    ::= {docsCmSyncPtpPortAssociatesClockStatusEntry 4 }
```

```
docsCmSyncPtpPortAssociatesClockStatusClockId OBJECT-TYPE
    SYNTAX           OCTET STRING(SIZE(8))
    MAX-ACCESS       read-only
    STATUS           current
    DESCRIPTION
        "This attribute specifies the clock identifier of this Associates clock."
    ::= {docsCmSyncPtpPortAssociatesClockStatusEntry 4 }

docsCmSyncPtpPortAssociatesClockStatusClockPortNumber OBJECT-TYPE
    SYNTAX           Unsigned32 (0..65535)
    MAX-ACCESS       read-only
    STATUS           current
    DESCRIPTION
        "This attribute specifies Associates clock's port number."
    ::= {docsCmSyncPtpPortAssociatesClockStatusEntry 5 }

docsCmSyncPtpPortAssociatesClockStatusIsConnected OBJECT-TYPE
    SYNTAX           TruthValue
    MAX-ACCESS       read-only
    STATUS           current
    DESCRIPTION
        "This attribute is set to TRUE if a signaling session with the Associates
         is successfully established."
    ::= {docsCmSyncPtpPortAssociatesClockStatusEntry 6 }

docsCmSyncPtpPortAssociatesClockStatusLogSyncInterval OBJECT-TYPE
    SYNTAX Integer32 (-7..7)
    MAX-ACCESS   read-only
    STATUS current
    DESCRIPTION
        "PTP sync message interval."
    ::= { docsCmSyncPtpPortAssociatesClockStatusEntry 7}

docsCmSyncPtpPortAssociatesClockStatusLogDelayReqInterval OBJECT-TYPE
    SYNTAX Integer32 (-7..7)
    MAX-ACCESS   read-only
    STATUS current
    DESCRIPTION
        "PTP delay request message interval."
    ::= { docsCmSyncPtpPortAssociatesClockStatusEntry 8}

docsCmSyncPtpPortAssociatesClockStatusLogAnnounceInterval OBJECT-TYPE
    SYNTAX Integer32 (-7..7)
    MAX-ACCESS   read-only
    STATUS current
    DESCRIPTION
        "PTP announce message interval."
    ::= { docsCmSyncPtpPortAssociatesClockStatusEntry 8}

docsCmSyncPtpPortAssociatesClockStatusGrantDuration OBJECT-TYPE
    SYNTAX Unsigned32
    MAX-ACCESS   read-only
    STATUS current
    DESCRIPTION
        "The grant duration requested for Unicast Negotiation."
    ::= { c}

docsCmSyncPtpPortAssociatesClockStatusAddrType OBJECT-TYPE
    SYNTAX InetAddressType
    MAX-ACCESS   read-only
    STATUS current
    DESCRIPTION
```

```
        "Type of the associated PTP Clock address."
    ::= { docsCmSyncPtpPortAssociatesClockStatusEntry 10}

docsCmSyncPtpPortAssociatesClockStatusInetAddr OBJECT-TYPE
    SYNTAX InetAddress
    MAX-ACCESS   read-only
    STATUS current
    DESCRIPTION
        "Associates Clock address."
    ::= { docsCmSyncPtpPortAssociatesClockStatusEntry 10}

docsCmSyncPtpPortAssociatesClockStatusCounterDiscontinuityTime OBJECT-TYPE
    SYNTAX           DateAndTime
    MAX-ACCESS       read-only
    STATUS           current
    DESCRIPTION
        "This attribute reports the date and time at which any
         one or more of the counters in this group were created or
         last reset to zero. If the RPD does not acquire time of day
         it can report an initial CounterDiscontinuityTime of Jan 1 1970."
    ::= {docsCmSyncPtpPortAssociatesClockStatusEntry 11 }


-- ---------------------------------------------------------------------
-- PTP port configuration table
-- ---------------------------------------------------------------------

docsCmSyncPtpPortTable OBJECT-TYPE
    SYNTAX            SEQUENCE OF DocsCmSyncPtpPortEntry
    MAX-ACCESS        not-accessible
    STATUS            current
    DESCRIPTION
        "This table contains PTP Port configuration attributes."
    ::={docsCmSyncPtpMibObjects 9 }

docsCmSyncPtpPortEntry OBJECT-TYPE
    SYNTAX        DocsCmSyncPtpPortEntry
    MAX-ACCESS    not-accessible
    STATUS        current
    DESCRIPTION
        "The conceptual row of docsCmSyncPtpTable."
    INDEX         {docsCmSyncPtpPortPortNumber }
    ::= {docsCmSyncPtpPortTable 1}

DocsCmSyncPtpPortEntry ::= SEQUENCE
    {
    docsCmSyncPtpPortDomain                  Unsigned32,
    docsCmSyncPtpPortDscp                    Unsigned32,
    docsCmSyncPtpPortCos                     Unsigned32,
    docsCmSyncPtpPortLogSyncInterval         Integer32,
    docsCmSyncPtpPortLogDelayReqInterval     Integer32,
    docsCmSyncPtpPortLogAnnounceInterval     Integer32,
    docsCmSyncPtpPortAnnounceIntervalTimeout Unsigned32,
    docsCmSyncPtpPortGrantDuration           Unsigned32,
    docsCmSyncPtpPortAdminState              TruthValue
    }

docsCmSyncPtpPortNumber OBJECT-TYPE
    SYNTAX        Unsigned32 (0..65535)
    MAX-ACCESS    not-accessible
    STATUS        current
    DESCRIPTION
        "This key attribute is the port number of the local clock port. Port 0 needs
```

```
         To be used for the master port and port 1 needs be used for the special slave
         PTP port."
    ::= {docsCmSyncPtpPortEntry 1 }

docsCmSyncPtpPortDomain OBJECT-TYPE
    SYNTAX           Unsigned32 (0..255)
    MAX-ACCESS       read-create
    STATUS           current
    DESCRIPTION
        "This attribute specifies PTP port domain."
    ::= {docsCmSyncPtpPortEntry 2 }

docsCmSyncPtpPortDscp OBJECT-TYPE
    SYNTAX           Unsigned32 (0..255)
    MAX-ACCESS       read-create
    STATUS           current
    DESCRIPTION
        "This attribute specifies PTP port DSCP value."
    ::= {docsCmSyncPtpPortEntry 3 }

docsCmSyncPtpPortCos OBJECT-TYPE
    SYNTAX           Unsigned32 (0..7)
    MAX-ACCESS       read-create
    STATUS           current
    DESCRIPTION
        "This attribute specifies PTP port COS."
    ::= {docsCmSyncPtpPortEntry 4 }

docsCmSyncPtpPortLogSyncInterval OBJECT-TYPE
    SYNTAX Integer32 (-7..7)
    MAX-ACCESS   read-create
    STATUS current
    DESCRIPTION
        "PTP sync message interval. For a master port this value represents the
         maximum sync interval allowed per slave."
    DEFVAL { -5 }
    ::= { docsCmSyncPtpPortEntry 5}

docsCmSyncPtpPortLogDelayReqInterval OBJECT-TYPE
    SYNTAX Integer32 (-7..7)
    MAX-ACCESS   read-only
    STATUS current
    DESCRIPTION
        "PTP delay request message interval. For a master port this value represents
         the maximum delay request interval allowed per slave."
    DEFVAL { -5 }
    ::= { docsCmSyncPtpPortEntry 5}

docsCmSyncPtpPortLogAnnounceInterval OBJECT-TYPE
    SYNTAX Integer32 (-7..7)
    MAX-ACCESS   read-create
    STATUS current
    DESCRIPTION
        "PTP announce message interval. For a master port this value represents the
         maximum sync interval allowed per slave."
    DEFVAL { -1 }
    ::= { docsCmSyncPtpPortEntry 7}

docsCmSyncPtpPortAnnounceIntervalTimeout OBJECT-TYPE
    SYNTAX Unsigned32 (2..255)
    MAX-ACCESS   read-create
    STATUS current
    DESCRIPTION
```

```
        "The announce interval timeout. For a master port this value is ignored."
    DEFVAL { 3 }
    ::= { { docsCmSyncPtpPortEntry 8}

docsCmSyncPtpPortGrantDuration OBJECT-TYPE
    SYNTAX Unsigned32
    UNITS (seconds)
    MAX-ACCESS   read-create
    STATUS current
    DESCRIPTION
        "The grant duration requested for Unicast Negotiation. For a master port this
         value represents the maximum grant duration allowed per slave."
    DEFVAL { 300 }

    ::= { { docsCmSyncPtpPortEntry 9}

docsCmSyncPtpPortAdminState OBJECT-TYPE
    SYNTAX TruthValue
    MAX-ACCESS   read-create
    STATUS current
    DESCRIPTION
        "True means the PTP port is enabled. False means the PTP port is disabled."
    DEFVAL { 1 }
    ::= { docsCmSyncPtpPortEntry 7}



-- ---------------------------------------------------------------------
-- SyncE Group Objects
-- ---------------------------------------------------------------------
docsCmSyncSyncE OBJECT IDENTIFIER ::= {docsCmSyncMibObjects 2}

docsCmSyncSynceType OBJECT-TYPE
    SYNTAX            INTEGER
{
eec-1 (1),
eec-2 (2),
e-eec (3)
}
    MAX-ACCESS        read-only
    STATUS            current
    DESCRIPTION
        "This attribute represents the EEC type of this SyncE clock."
    ::= {docsCmSyncSynce 1 }

docsCmSyncSynceTransmitSsmValue OBJECT-TYPE
    SYNTAX            unsigned32
    MAX-ACCESS        read-write
    STATUS            current
    DESCRIPTION
        "This attribute represents the transmitted SSM value."
    ::= {docsCmSyncSyncE 2 }

docsCmSyncSynceReceivedSsmValue OBJECT-TYPE
    SYNTAX            unsigned32
    MAX-ACCESS        read-only
    STATUS            current
    DESCRIPTION
        "This attribute represents the Received SSM value."
    ::= {docsCmSyncSyncE 3 }

docsCmSyncSyncEPacketsSent OBJECT-TYPE
    SYNTAX            Counter64
```

```
    UNITS             "Packets"
    MAX-ACCESS        read-only
    STATUS            current
    DESCRIPTION
        "This attribute represents the number of ESMC packets sent for this clock."
    ::= { docsCmSyncSyncE 4 }

docsCmSyncSyncePacketsReceived OBJECT-TYPE
    SYNTAX            Counter64
    UNITS             "Packets"
    MAX-ACCESS        read-only
    STATUS            current
    DESCRIPTION
        "This attribute represents the number of ESMC packets received for this
         clock."
    ::= {docsCmSyncSyncE 5 }

docsCmSyncSyncePacketsDropped OBJECT-TYPE
    SYNTAX            Counter64
    UNITS             "Packets"
    MAX-ACCESS        read-only
    STATUS            current
    DESCRIPTION
        "This attribute represents the number of ESMC packets dropped for this clock."
    ::= {docsCmSyncSyncE 6 }



-- ---------------------------------------------------------------------
-- DTP Group Objects
-- ---------------------------------------------------------------------
docsCmSyncDtp OBJECT IDENTIFIER ::= {docsCmSyncMibObjects 3}

docsCmSyncDtpMode OBJECT-TYPE
    SYNTAX            INTEGER
{
not-used (0),
slave (1),
master (2)
}
    MAX-ACCESS        read-only
    STATUS            current
    DESCRIPTION
        "This attribute represents the DTP mode configured for the CM."
    ::= {docsCmSyncDtp 1 }

docsCmSyncDtpTro OBJECT-TYPE
    SYNTAX            unsigned32
    MAX-ACCESS        read-only
    STATUS            current
    DESCRIPTION
        "This attribute represents the computed True Ranging Offset."
    ::= {docsCmSyncDtp 2 }

docsCmSyncDtpTimingAdjust OBJECT-TYPE
    SYNTAX            unsigned32
    MAX-ACCESS        read-only
    STATUS            current
    DESCRIPTION
        "This attribute represents the timing adjust value used by The CM."
    ::= {docsCmSyncDtp 3 }

docsCmSyncDtpPacketsSent OBJECT-TYPE
```

```
    SYNTAX            Counter64
    UNITS             "Packets"
    MAX-ACCESS        read-only
    STATUS            current
    DESCRIPTION
        "This attribute represents the number of DTP packets sent from this CM."
    ::= { docsCmSyncDtp 4 }

docsCmSyncDtpPacketsReceived OBJECT-TYPE
    SYNTAX            Counter64
    UNITS             "Packets"
    MAX-ACCESS        read-only
    STATUS            current
    DESCRIPTION
        "This attribute represents the number of DTP packets received on this CM."
    ::= {docsCmSyncDtp 5 }

docsCmSyncSyncePacketsDropped OBJECT-TYPE
    SYNTAX            Counter64
    UNITS             "Packets"
    MAX-ACCESS        read-only
    STATUS            current
    DESCRIPTION
        "This attribute represents the number of DTP packets dropped on this CM."
    ::= {docsCmSyncDtp 6 }



-- ---------------------------------------------------------
-- Conformance definitions
-- ---------------------------------------------------------

docsCmSyncCompliance MODULE-COMPLIANCE
    STATUS current
    DESCRIPTION
        "The compliance statement for CM Sync features."

MODULE -- docsCmSyncMib

-- conditionally mandatory groups

GROUP docsCmSyncPtpGroup
    DESCRIPTION
        "Group of objects applicable to PTP."

GROUP docsCmSyncSynceGroup
    DESCRIPTION
        "Group of objects applicable to SyncE."

GROUP docsCmSyncDtpGroup
    DESCRIPTION
        "Group of objects applicable to DTP."


-- conditionally optional groups


::= { docsCmSyncCompliances 1}

docsCmSyncDeprecatedCompliance MODULE-COMPLIANCE
   STATUS      deprecated
   DESCRIPTION
        "The compliance statement for deprecated sync objects."
```

```
MODULE -- this MODULE
GROUP docsCmSyncDeprecatedGroup
DESCRIPTION
    "This group contains sync objects which are deprecated
     from the MIB as of the current release."
::= { docsCmSyncCompliances 2 }
```

Appendix VII Acknowledgements (Informative)

On behalf of the cable industry and our member companies, CableLabs thanks the following individuals and their companies for contributing to the development this specification.

Contributor	Company Affiliation
Jennifer Andreoli-Fang	CableLabs
John T. Chapman, Elias Chavarria Reyes, Zheng Lu	Cisco
Greg Cyr, Yair Neugeboren, Chris Zettinger	CommScope
Greg Armstrong, Silvana Rodrigues	IDT
Peter Meyer, Lee Cosart	Microchip
Pedro Antao	NOS
Bruno Cornaglia, Alvaro Simon	Vodafone

CableLabs also thanks the following individuals and their companies for contributing to the development of the technology and participating in the Mobile Xhaul team.

Contributor	Company Affiliation
Victor Hou, Niki Pantelias	Broadcom
Volker Leisse, Peter Percosan	CableLabs
Troy Bergstrom, Tim Frost	Calnex Solutions
Lakhbir Singh	Charter Communications
Barak Hermesh	Intel
Tilco van Dijk	Liberty Global
Satish Mudugere	MaxLinear
Bill Powell	Nokia
David Spencer	Qulsar
Arif Ahsan	Sercomm
Robert Grimm	Vodafone

Jennifer Andreoli-Fang, CableLabs

Appendix VIII Revision History

The following Engineering Change was incorporated into CM-SP-SYNC-I02-210407.

ECN Identifier	Accepted Date	Title of EC	Author
SYNC-N-21.2152-3	3/18/2021	SYNC Updates for I02	Andreoli-Fang

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