Precise Time Transfer in DOCSIS Cable Access Networks

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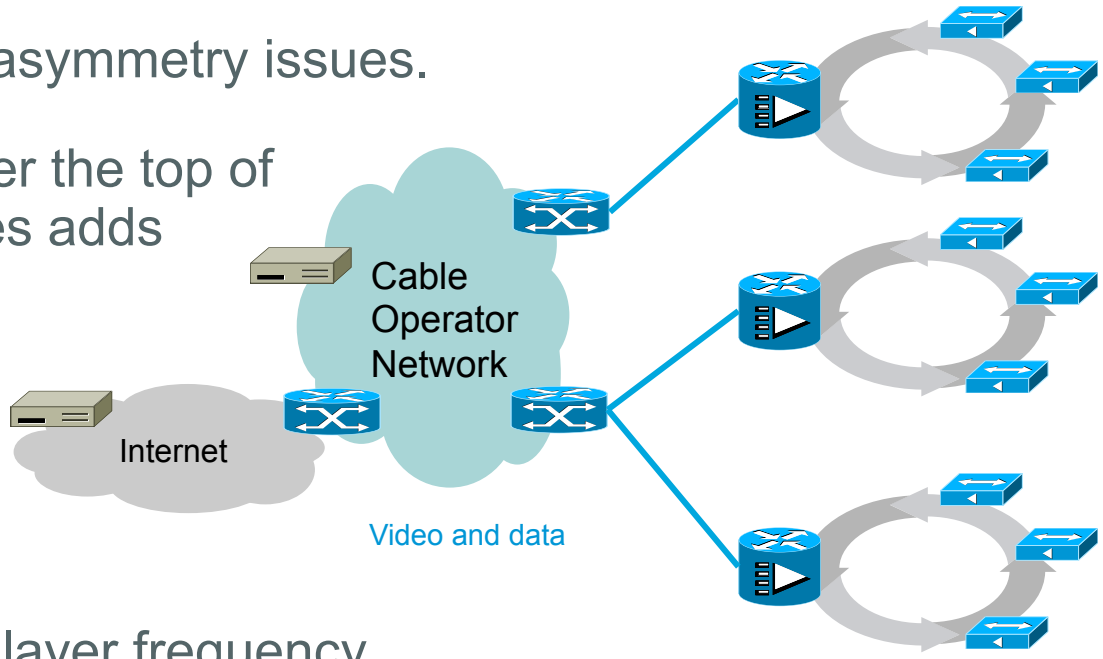
Introduction

- As DSL, GPON or EPON,
  - DOCSIS is an access link technology.
  - DOCSIS has PDV and asymmetry issues.
- Running timing protocols over the top of such access link technologies adds timing errors.



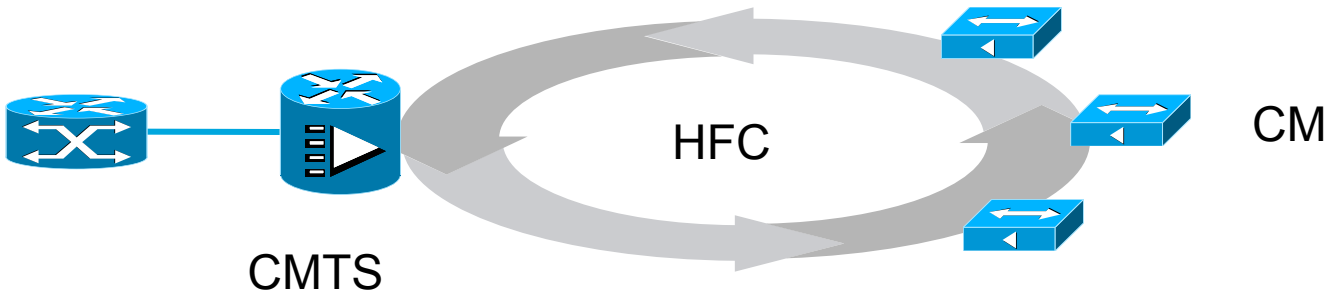
- As DSL, GPON or EPON:
  - DOCSIS supports PHY layer frequency.
  - DOCSIS needs specific technique to provide precise time synchronization : this is DOCSIS Timing Protocol proposal.

Agenda

- DOCSIS Overview
- Some DOCSIS Transmission Fundamentals
  - Boot-up / Initialization
  - Ranging process
- DOCSIS Timing Protocol
  - DTP System
  - True Ranging Offset
- DTP Use Cases

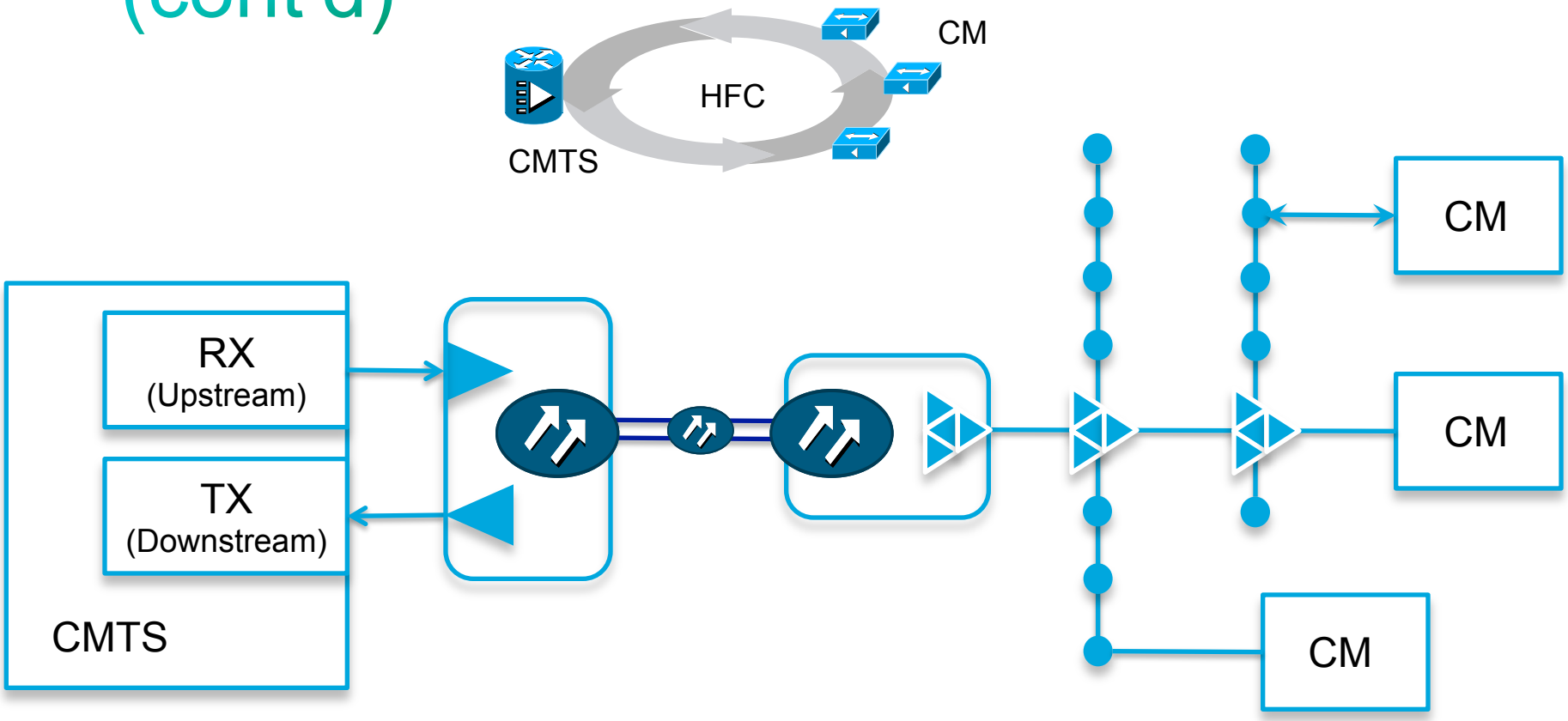
DOCSIS: Cable Access Network

- DOCSIS 1.0, 1.1, 2.0 and 3.0
- DOCSIS (CableLabs), EuroDOCSIS and International (ITU-T, J series)



CM: Cable Modem
CMTS: Cable Modem Termination System
HFC (plant): Hybrid Fiber-Coax

DOCSIS: Cable Access Network (cont'd)



HFC RF Plant: up to 160 km optical fiber, 300 meters of coaxial cable with use of fiber optic, RF distribution amplifiers and RF passive devices

Communication over the HFC

Point to multipoint
CMTS to 100's of CMs

Upstream (US)

- Shared, support multiple upstream channels, up to 6/6.4MHz width channel
- Signals: QPSK to 64QAM
- TDMA Burst

Downstream (DS)

- MPEG transmission convergence sublayer
- 6/8MHz channel width
- Signals: 64QAM or 256QAM
- TDM Continuous transmission

Communication Behavior

- All simultaneous users contend for the US and DS access.
- The CMTS transmits data to the cable modems on a first come, first served basis.
- CMs must time-shared upstream channels.
  - Request and Grant reservation scheme
- Only one modem can be active in the US at any given instant in time.
- The DOCSIS path delay is inherently asymmetrical and can contain a moderate to high amount of jitter.

MAC Management Messages

- MAC management messages are Ethernet frames with TLV payload.
  Ex: SYNC, MAP, Ranging Request/Response TLVs
- MAP (Media Access Protocol) assigns upstream transmit opportunities.
- The Request-and-Grant cycle between the CMTS and the CMs use MAP messages.
- This back-and-forth communication produces latency.
- The CM might miss a MAP, which creates jitter for over the top timing protocol.

DOCSIS Time Offset

- The CMTS provides an opportunity to transmit to a CM.
- Upstream transmission from a CM shall arrive at the appropriate time.
- The CM must transmit at the time the CMTS requested.

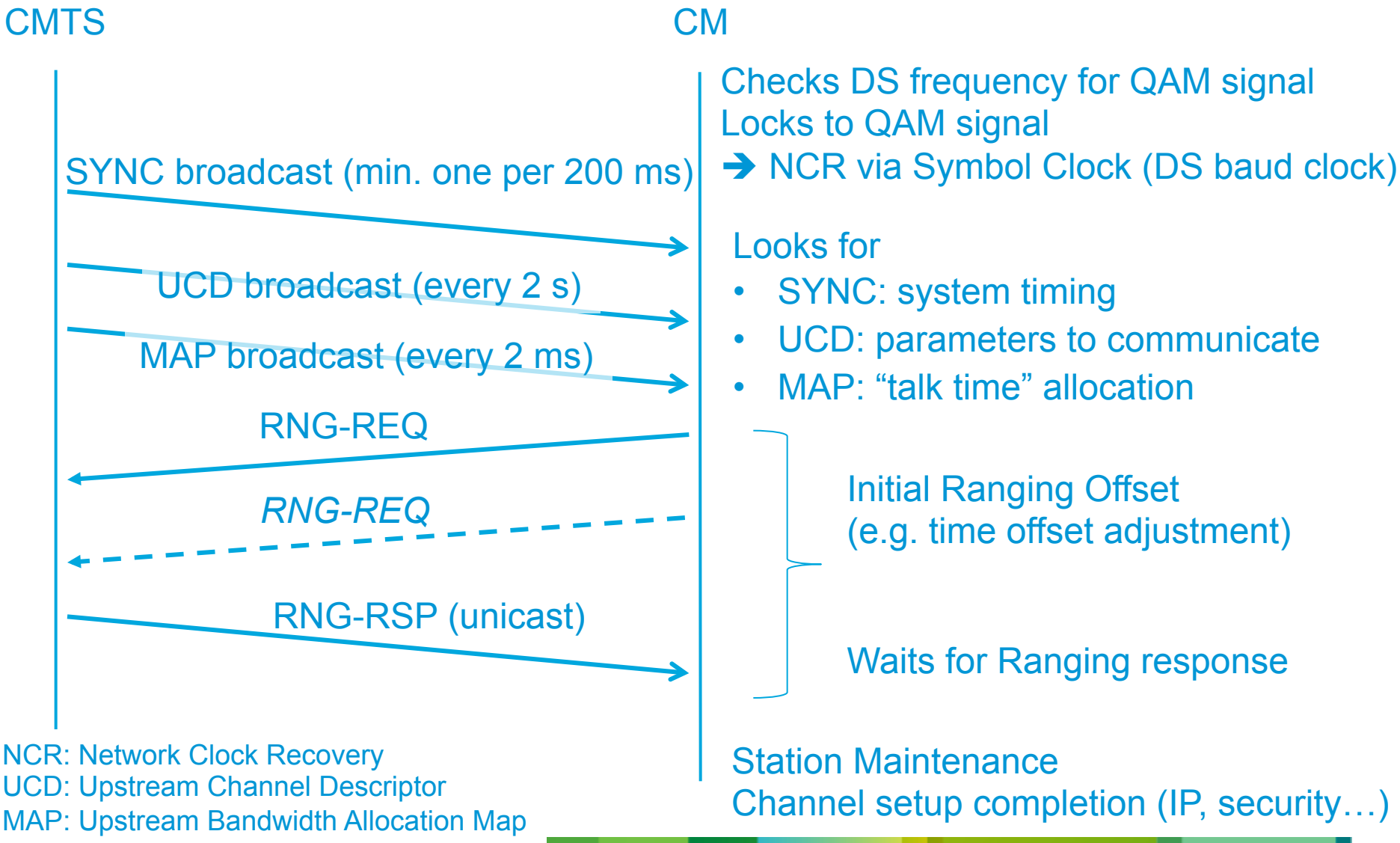
➔ Upstream transmissions shall be properly synchronized.

- The CMTS and the CM need to have an accurate idea of the correct time offset.
- The Time Offset of a CM is known as Ranging Offset.

Ranging Offset

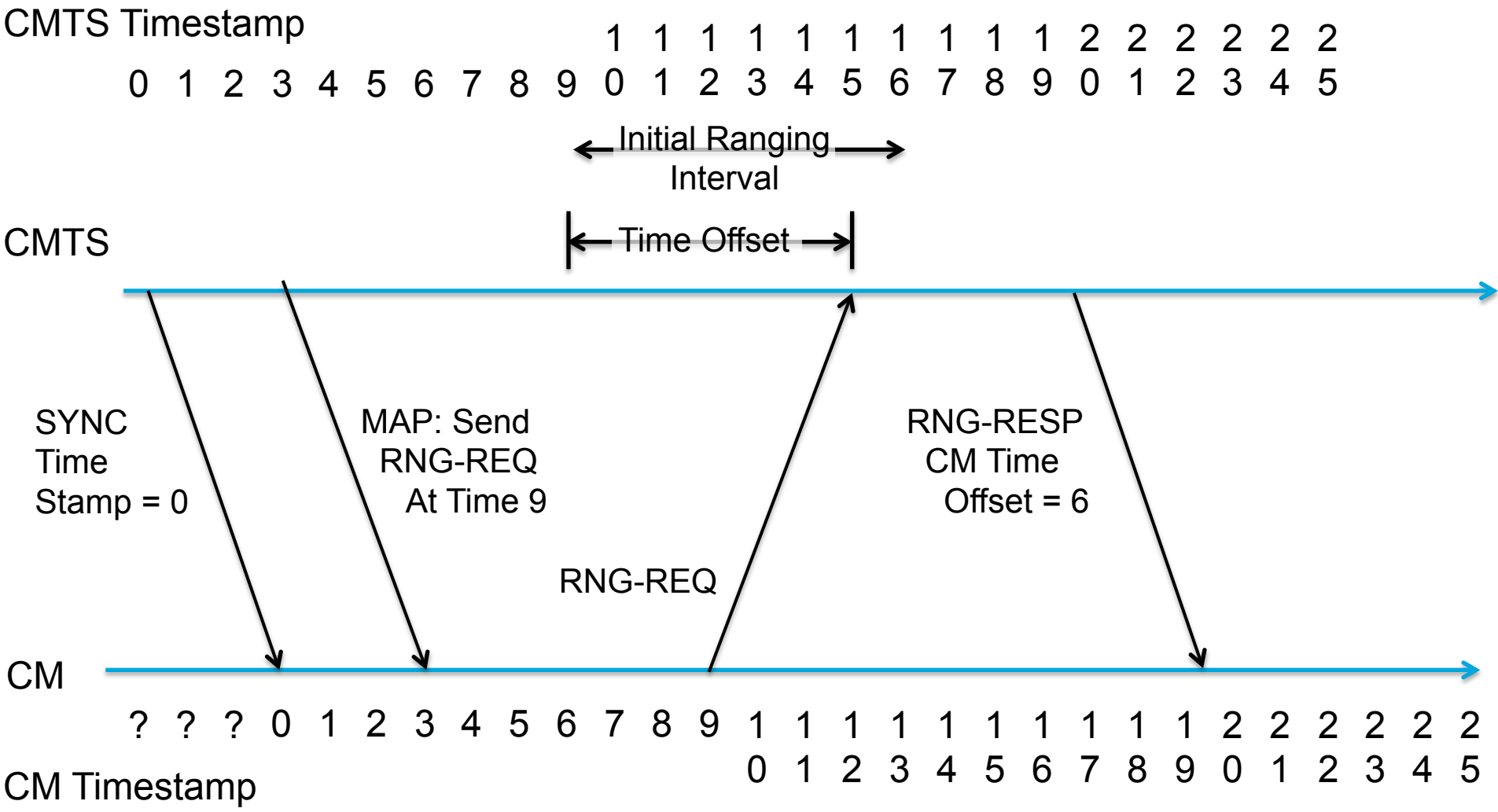
- Ranging Offset (time offset) is a value indicating the round trip delay between a CMTS and a connected CM.
- It is determined by four major factors:
  - Physical distance (HFC round trip delay)
  - Downstream modulation scheme and interleave depth
  - Upstream modulation scheme and channel width
  - Model of CM and firmware
- Initial Ranging offset happens at boot-up and shall be performed it again after any link interruption.
- A Station Maintenance Ranging (every 30 sec max) is performed after the channel is successfully established.
  - CMTS will analyze and adjust the time offset if necessary.

Channel Initialization



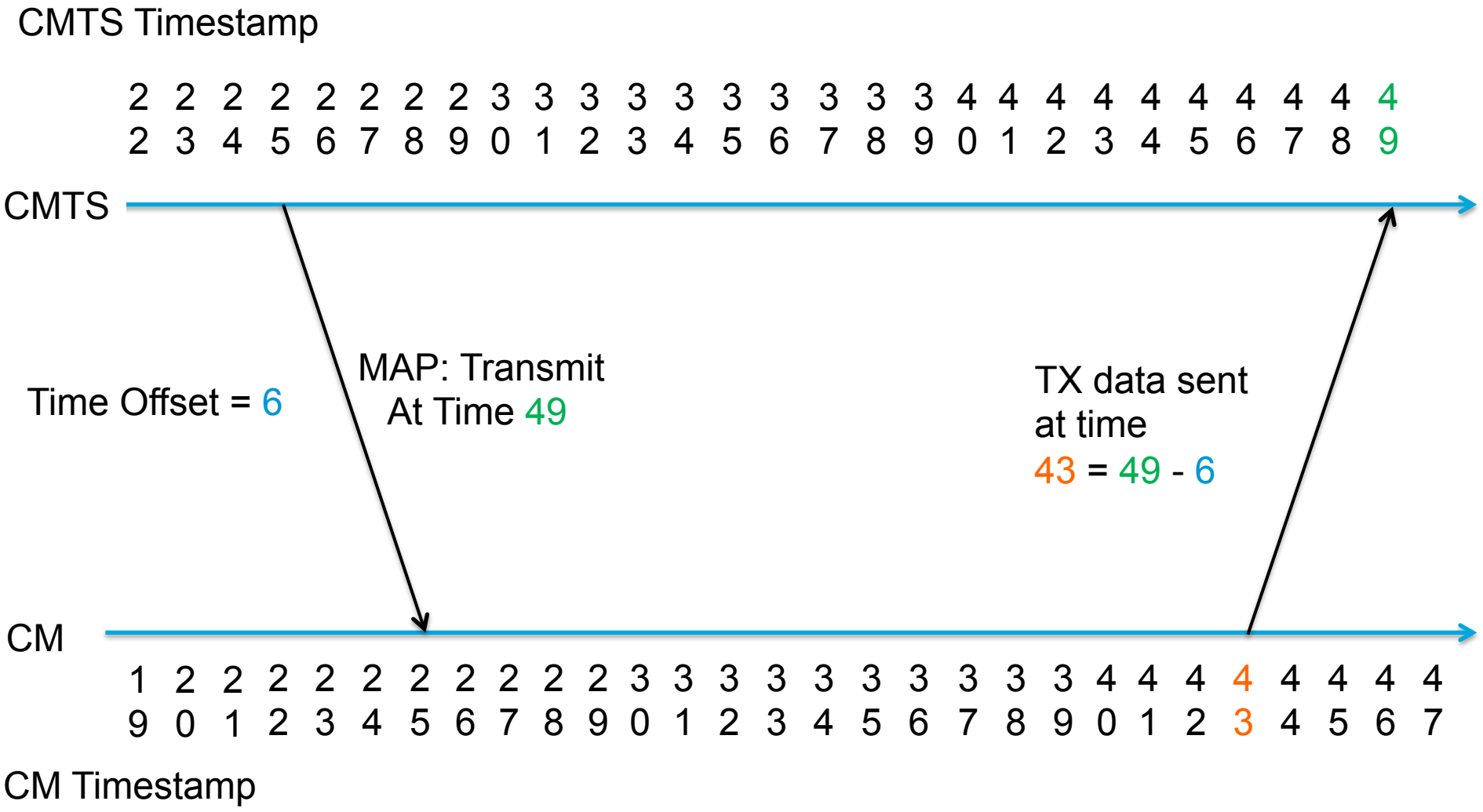
NCR: Network Clock Recovery
UCD: Upstream Channel Descriptor
MAP: Upstream Bandwidth Allocation Map

Ranging Offset in Action

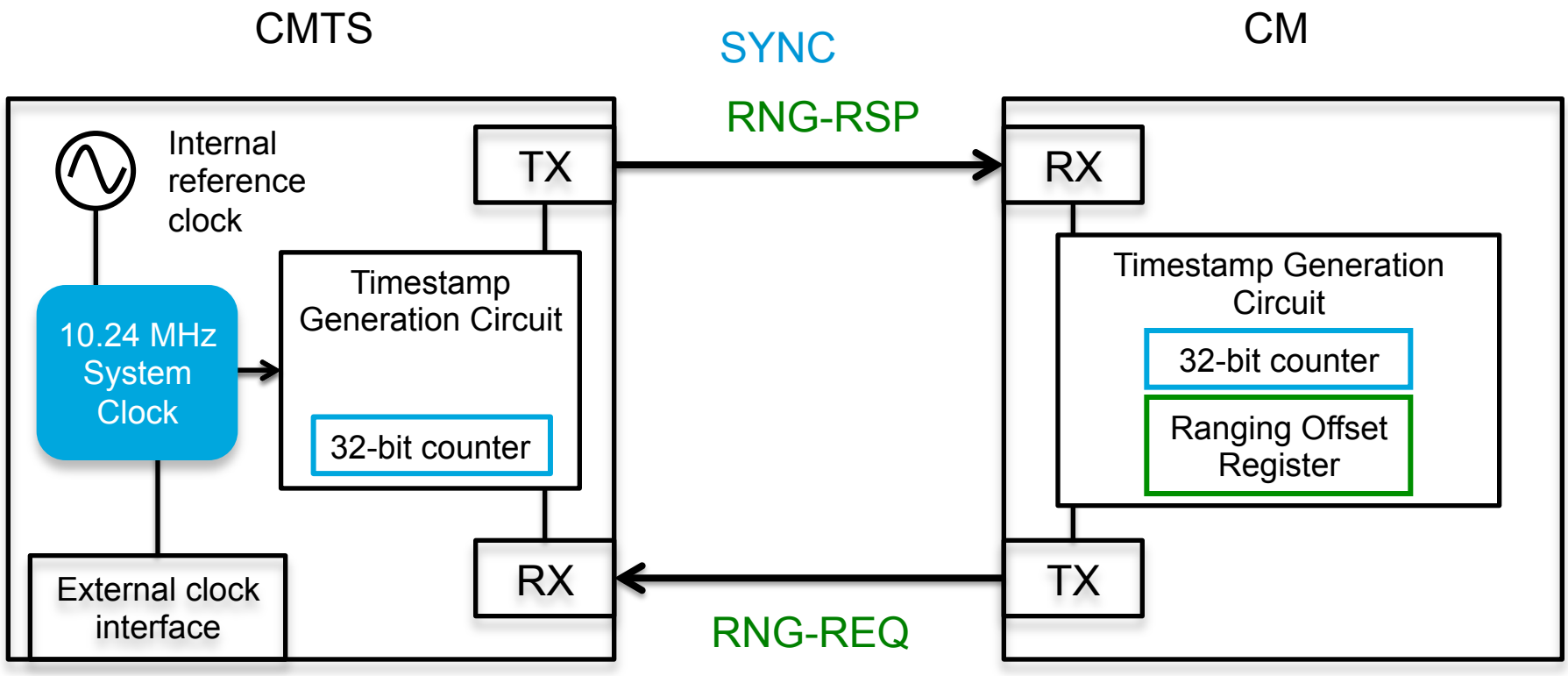


Recall: CM is frequency locked to the CMTS (QAM symbol rate)

Ranging Offset in Action (cont'd)



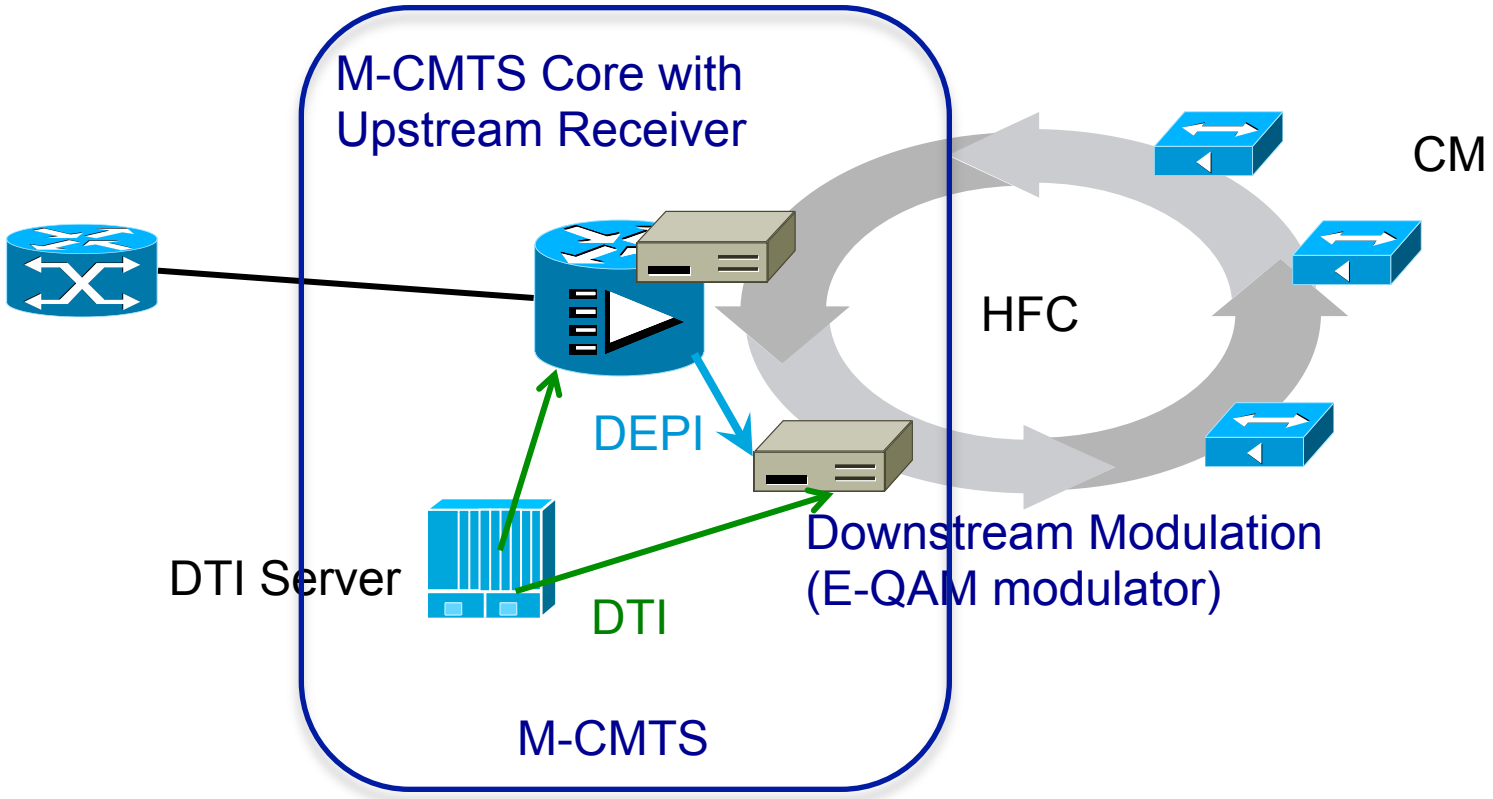
Timing counter and Ranging register



Timestamp units are (1 / 10.24 MHz) = 97.65625 ns

Register is initially set with CM known delays (e.g., DS interleaver) and updated with the Time Offset.

DOCSIS 3.0 Modular CMTS



M-CMTS: Modular Cable Modem Termination System
E-QAM: Edge QAM
DEPI: Downstream External PHY Interface
DTI: DOCSIS Timing Interface

DOCSIS Timing Protocol

- DTP is a series of extensions proposed for precise time synchronization.
- DTP synchronizes the DTP server/CMTS and DTP clients (CM).
  - Propagation delay from DTP server to DTP clients is measured.
  - Asymmetry is compensated for.
- The CM (DTP client) has a newly defined “True Ranging Offset”.
- In essence, the total round trip delay is equal to the true ranging offset of the DTP client.

True Ranging Offset (TRO)

- The TRO is defined as:

  The difference between the time the first bit of a packet is transmitted in the upstream from the DTP client (in terms of the DOCSIS timestamp),

  And the time the first bit of the packet is expected to arrive at the DTP server/CMTS.

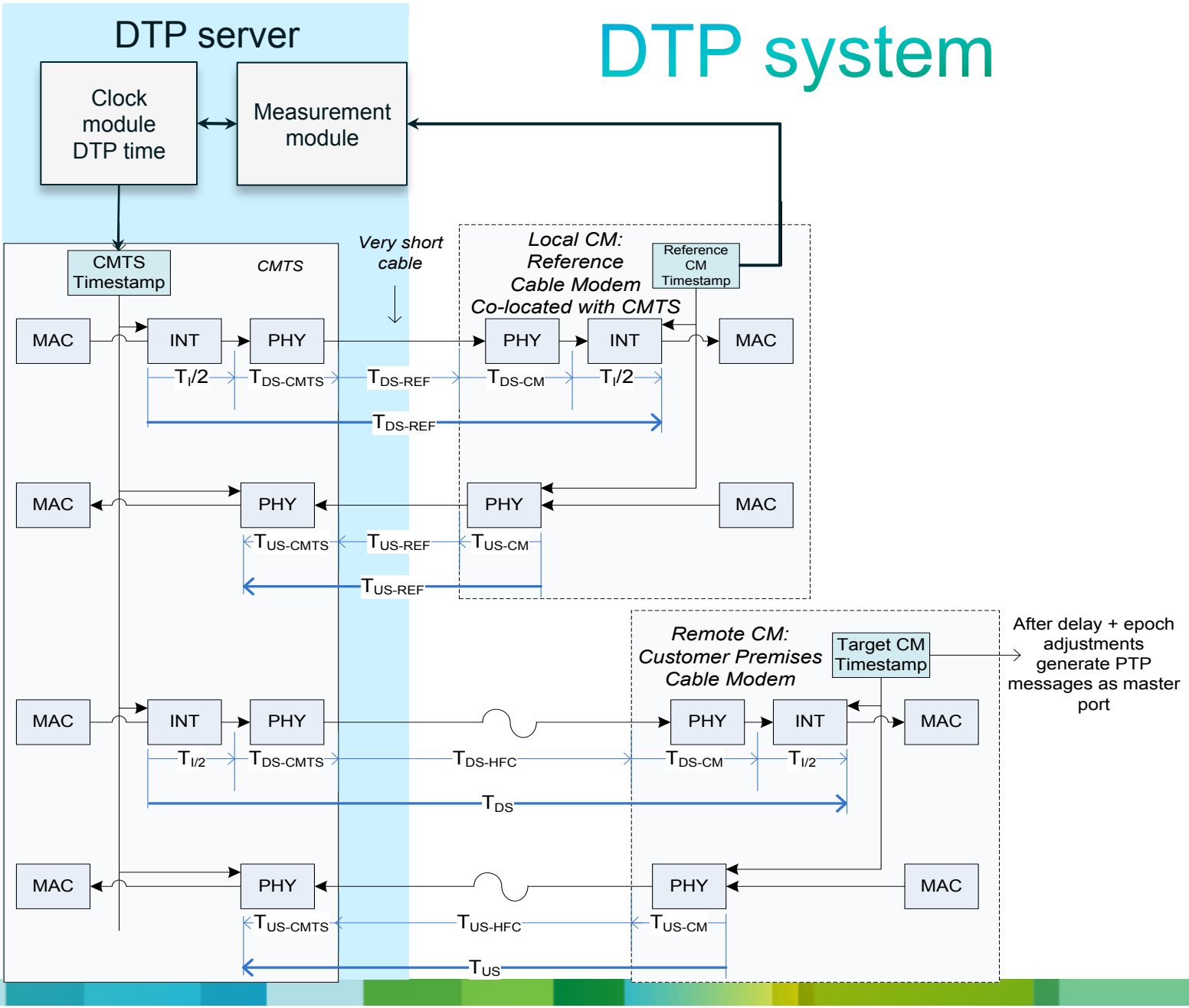
- TRO is measured in (new) hardware at the DTP client.

  Need also new hardware at the CMTS DOCSIS interface.

- Since the measurement is done when an upstream packet is transmitted, all upstream scheduling jitter is eliminated.

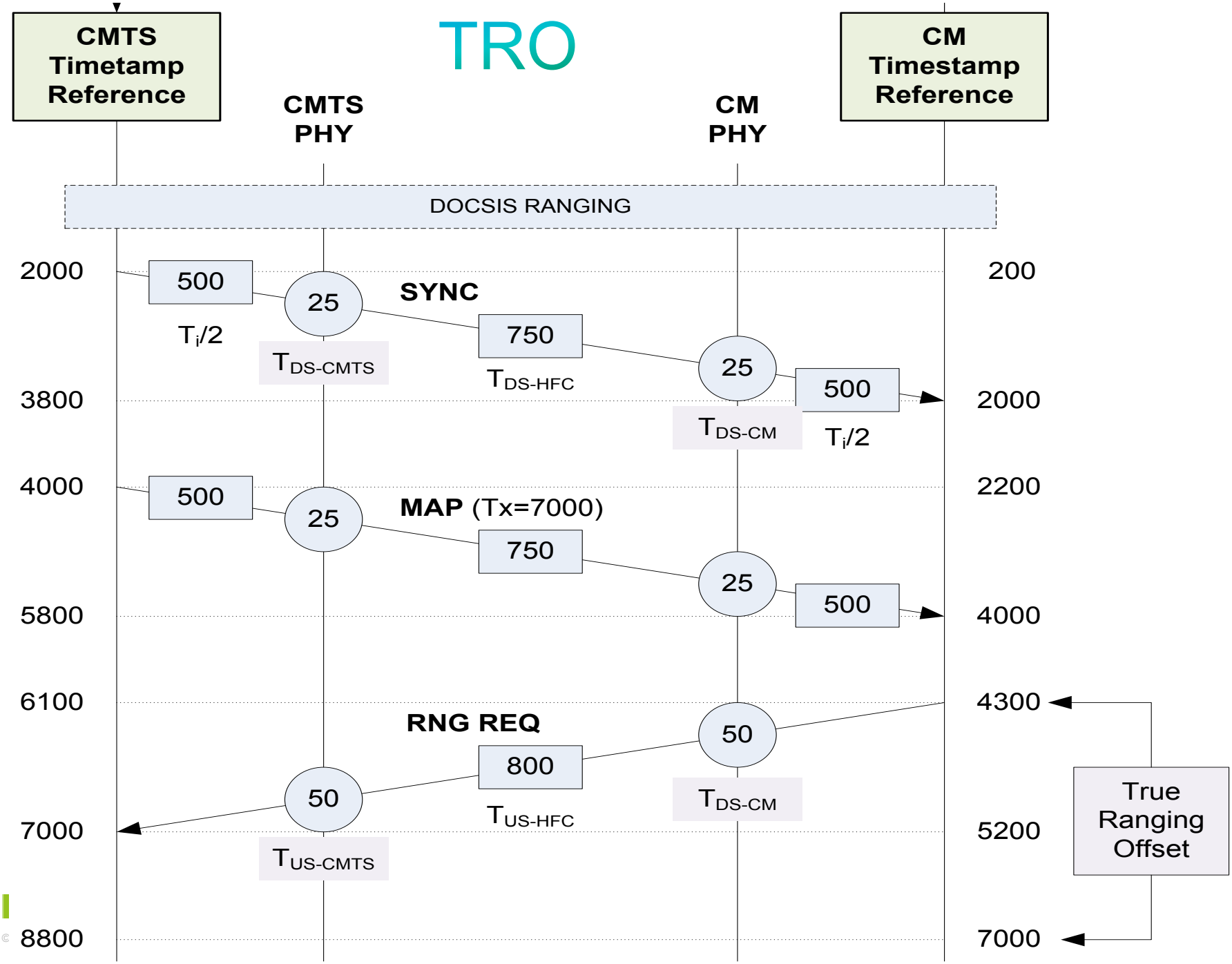
- TRO is a value that can be measured consistently across different DTP client implementations.

DTP system



DTP System Delay Definitions

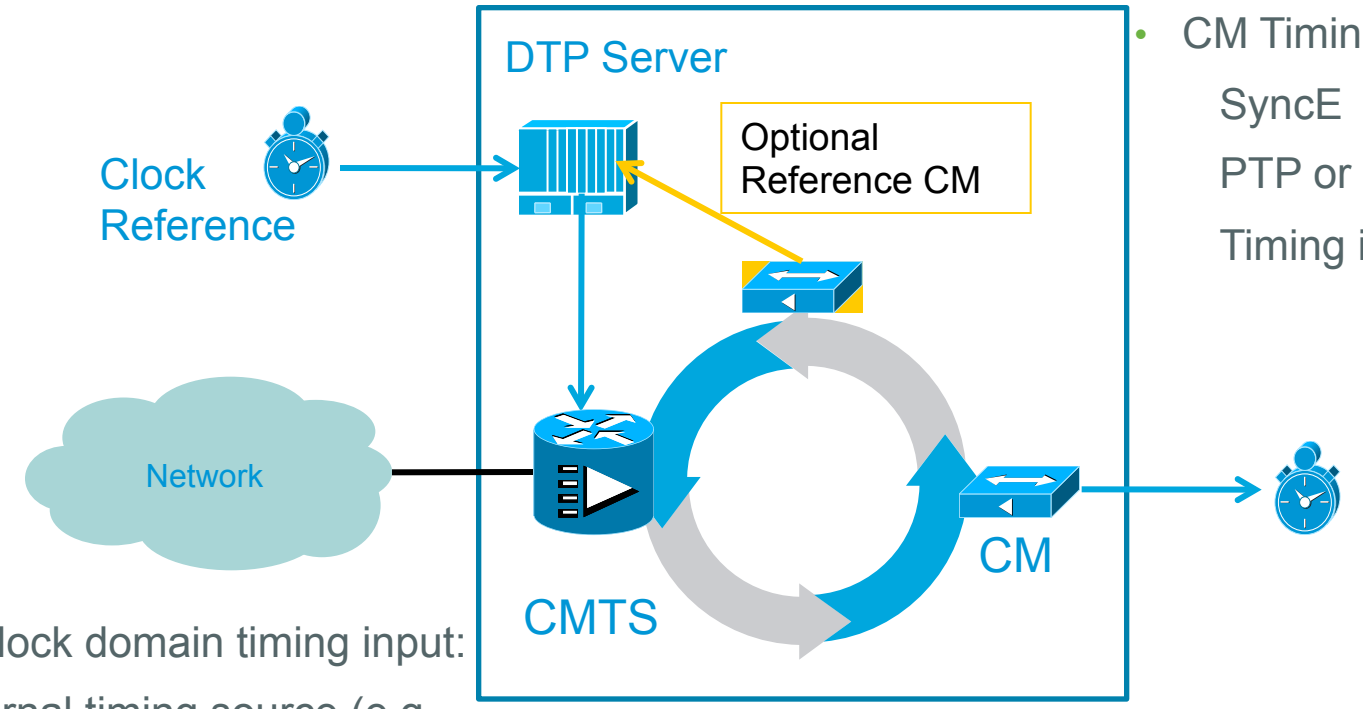
Variable	Known	Comments
Tds	No	Total downstream delay from CMTS timestamp reference point to the CM timestamp reference point. This is the ultimate value that needs to be determined.
Tus	No	Total upstream delay from the CM timestamp reference point to the CMTS timestamp reference point.
Trtt	Yes	Trtt = Tds + Tus. This is a measured value.
Ti	Yes	Total interleaver delay in the downstream path. The delay is equally shared between the CMTS and CM implementation.
Tds-cmts	Yes	Delay from CMTS timestamp reference point to CMTS output. This does not include the interleaver delay.
Tds-hfc	No	Delay of the HFC plant in the downstream.
Tds-cm	Yes	Delay from the input port of the CM to the CM timestamp reference point. This does not include the interleaver delay.
Tus-cm	Yes	Delay from the CM timestamp reference point to the CM output.
Tus-hfc	No	Delay of the HFC plant in the upstream.
Tus-cmts	Yes	Delay from the CMTS input port to the CMTS timestamp reference point. This delay should take into account the difference from where the CM timestamp was inserted into the upstream packet and the reference point used by the CMTS timestamp that the CMTS US PHY attaches to the packet.
A	Yes	An assigned variable that expresses the upstream to downstream asymmetry. This does not include the downstream interleaver delay or the upstream queuing delay or scheduler uncertainty. Asymmetry may come from differences in propagation delay at different frequencies and if there are any differences in path length between the downstream and upstream paths.


TRO
CMTS Timetamp Reference
CMTS PHY
CM PHY
CM Timestamp Reference
DOCSIS RANGING
2000
500
25
SYNC
750
25
500
200
$T_i/2$
$T_{DS-CMTS}$
T_{DS-HFC}
T_{DS-CM}
$T_i/2$
3800
2000
4000
500
25
MAP (Tx=7000)
750
25
500
2200
5800
4000
6100
RNG REQ
50
800
50
4300
T_{DS-CM}
T_{US-HFC}
True Ranging Offset
7000
$T_{US-CMTS}$
5200
8800
7000

DTP Reference CM

- To improve the accuracy the unknown propagation delays in the CMTS PHY and CM PHY can be measured.
- The DTP server measures the difference in round trip delay between the reference and the remote DTP clients.
  - This difference is the loop delay.
- The DTP server measures the one-way DS delay of the near reference CM.
  - This provides CMTS and CM delay plus half the loop delay.
  - Note: this measurement can be done by a reference DTP server remotely located.
- From this, the network DS delay for a CM is calculated.
  - Reference points are from CMTS Timestamp to CM Timestamp.

DTP Clock Domain



- CM Timing Output:
  - SyncE
  - PTP or NTP
  - Timing interface(s)

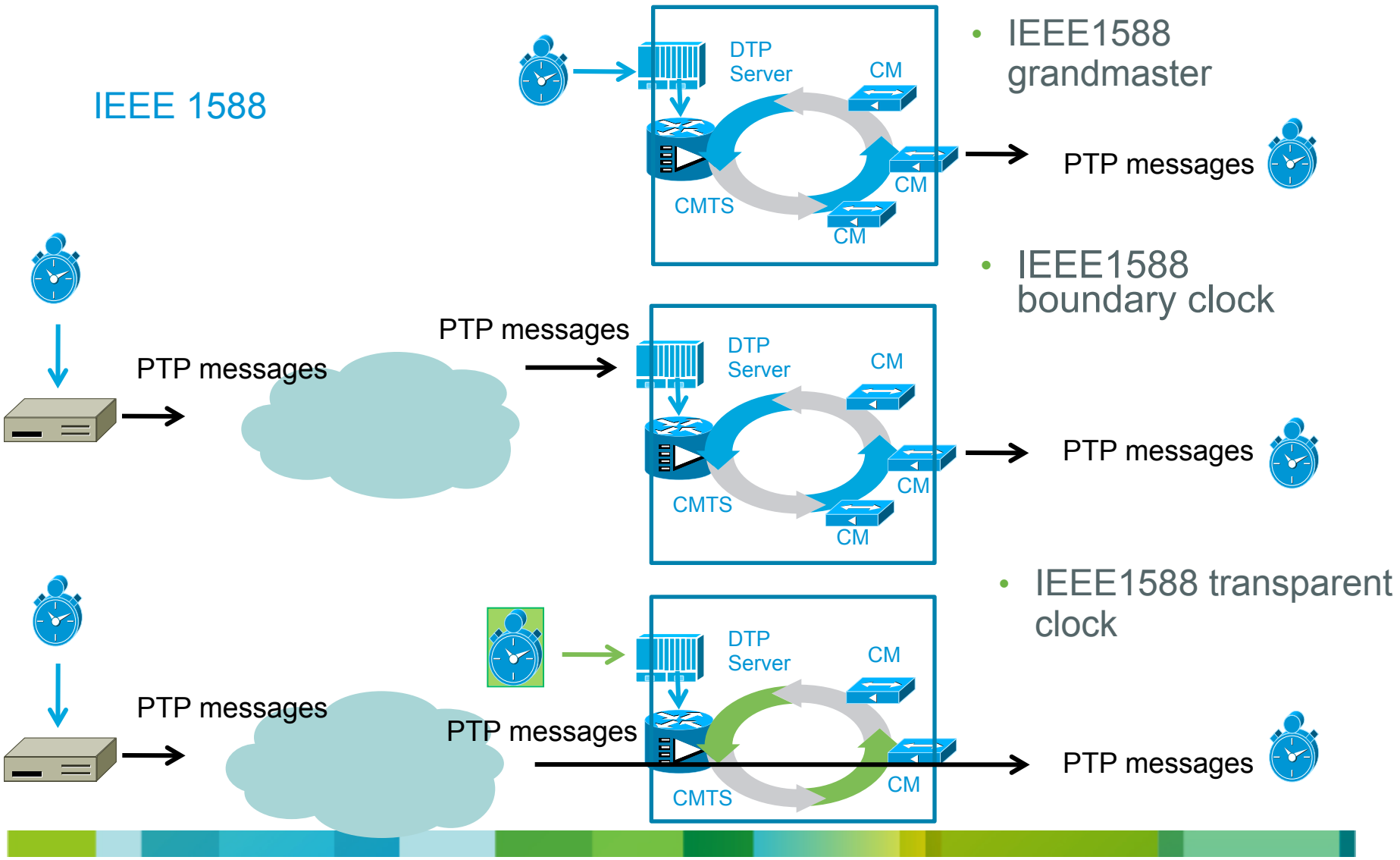
- DTP clock domain timing input:
  - External timing source (e.g., GNSS) embedded or via input interface (e.g. DTI)
  - SyncE
  - PTP (or NTP)

DTP Server is the time source of the DTP system clock.

- External DTI server
- DTI Server integrated into CMTS
- SyncE / PTP slave port in CMTS

PTP and DTP Use Cases

IEEE 1588



- IEEE1588 grandmaster
- IEEE1588 boundary clock
- IEEE1588 transparent clock

How to deliver PTPv2 from DOCSIS CM?

#	Description
1	Timing source at DTP Server/CMTS location
1a	CM acts as IEEE1588 grandmaster (or NTP server)
1b	CM acts as IEEE1588 grandmaster faking the DTP Server
1c	DTP Server acts as IEEE1588 grandmaster (or NTP Stratum 1 server) CM acts as IEEE1588 boundary clock (or NTP stratum server)
2	Timing source and IEEE1588 grandmaster (or NTP server) is upwards the DTP Server location
2a	DTP Server fakes the IEEE1588 grandmaster (or NTP Stratum 1 server)
2b	DTP Server/CMTS/CM acts as a distributed IEEE1588 boundary clock (or NTP servers)
2c	DTP Server/CMTS and CM are virtual IEEE1588 boundary clocks (or NTP servers)
2d	CMTS and CM are distributed or virtual IEEE1588 boundary clocks (or NTP servers); DTP Server is removed from timing communication path
3	CMTS/CM acts as a distributed IEEE1588 transparent clock

DTP – PTP Steps

- First, compensate for the time offset between the DOCSIS timestamp at the CM and the DOCSIS timestamp at the CMTS.
- Then, the DOCSIS timestamp at the CM is transformed into a PTP timestamp.
- The CM shall then accomplish three tasks:
  1. The least significant bits of the PTP timestamp are derived from the DOCSIS timestamp (and potentially the fractional timestamp extension).
  2. The most significant bits of the PTP timestamp are derived from a signaling message.
  3. The offset that represents the delay from the CMTS to the CM is measured, calculated, signaled and then applied to the timestamp.

Summary

- DOCSIC asymmetry and jitter introduce error into any timing protocol that might traverse the DOCSIS network.
- DTP mitigates these two factors by modifying the DOCSIS hardware design and deriving timing information directly from the DOCSIS system at the CM.
- DTP leverages and improves DOCSIS system timing, coupling:
  - Frequency: CM Ethernet clock to the DOCSIS downstream baud clock.
  - Time: CM PTP timestamp to the DOCSIS SYNC timestamp.
  - Time offset and asymmetry: measurement, signaling and ranging.
- Support of SyncE, NTP or/and PTP is implementation dependent.

Thank you.