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DOCSIS® Time Protocol Proof of Concept Phase II Results

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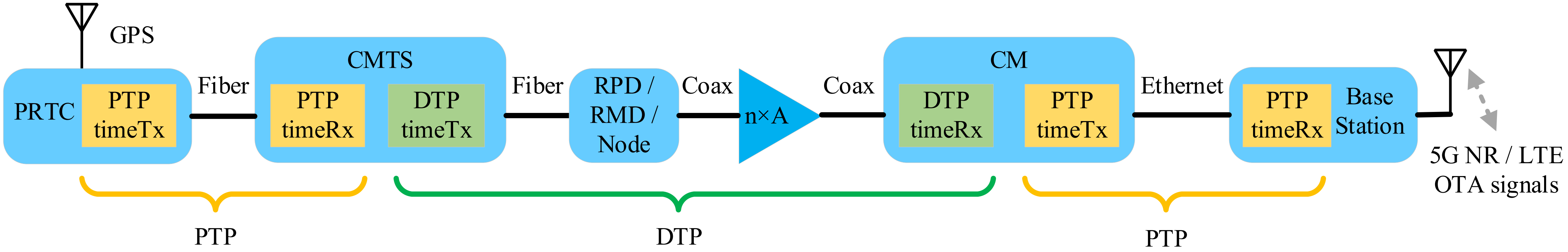
What is DTP?

DTP (DOCSIS Time Protocol) is a time protocol that provides a high-accuracy synchronization for a DOCSIS network

- HFC as mobile Xhaul
- DTP over HFC meets 3GPP synchronization requirement: 1.5 μs for base stations (BS)



PRTC: Primary Reference Time Clock
PTP: Precision Time Protocol
GPS: Global Positioning System

NR: New Radio
LTE: Long-Term Evolution
OTA: over-the-air

A: amplifier
CM: cable modem
CMTS: cable modem termination system

HFC: hybrid fiber coaxial
RPD: remote PHY device
RMD: remote MAC-PHY device

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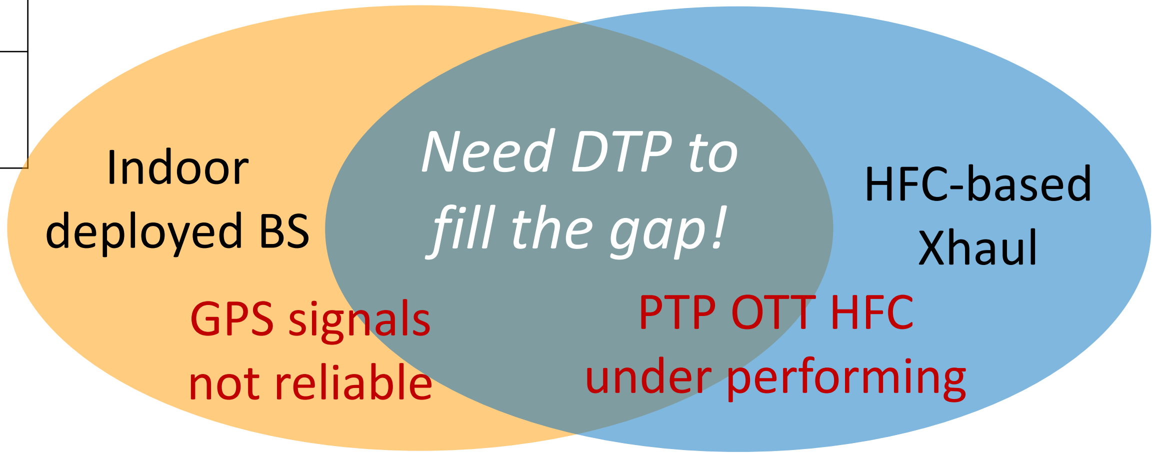
Where is DTP needed?

Timing sources	Accuracy	Applications
Network Time Protocol (NTP)	tens of ms	Not usable for BS
Precision Time Protocol (PTP, a.k.a, IEEE 1588)	< 1.5 µs	Widely supported by LTE/NR BS, performs poorly on HFC
Global Positioning System (GPS)	a few ns	For outdoor BS
DOCSIS Time Protocol (DTP)	< 1.5 µs	***Fills the gap!***

- Outdoor BS synchronization relies on GPS
- GPS signal unreliable for indoor or urban canyon
- Small-cell or femtocell deployed indoor cannot rely on GPS

PTP over-the-top (OTT) on the HFC network performs poorly
- PTP is "data traffic" on HFC
- Time error in the order of milliseconds. Time error fluctuates by a few milliseconds due to DOCSIS traffic and queuing

DTP is specifically designed for HFC
- As a "control message"
- Promising timing source on HFC



The gap is both a challenge and an opportunity for MSOs!

How does DTP work?

Timestamp synchronizations

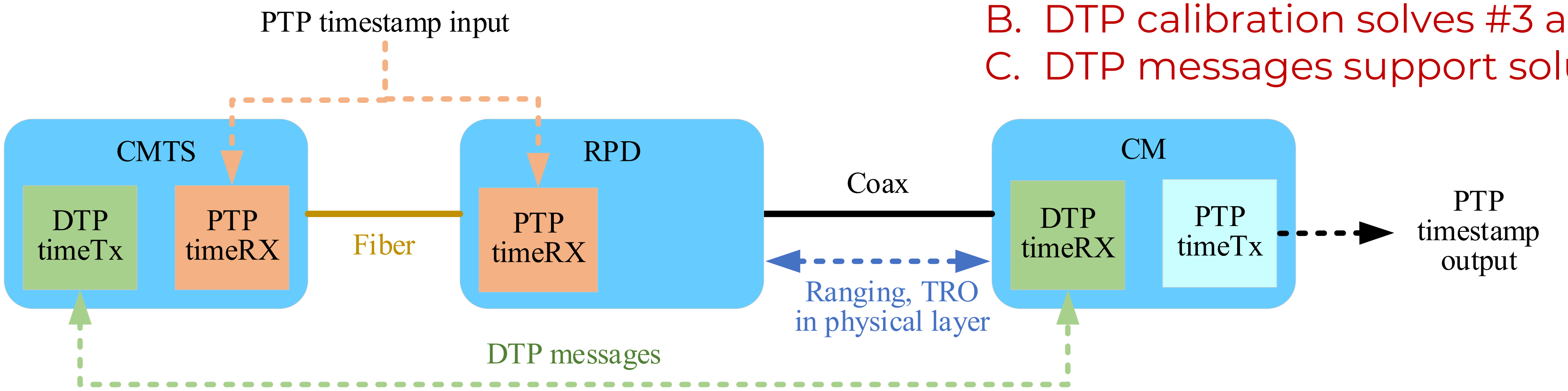
- PTP timestamp inputs -> local timestamp in CMTS and RPD
- RPD local timestamp -> DOCSIS 3.1 timestamp
- DOCSIS 3.1 timestamp -> local timestamp in CM
- CM local timestamp -> PTP timestamp output to BS

Challenges:

1. DOCSIS 3.1 timestamp is delayed in the downstream
   - Ranging measures round-trip delay in real time, which is called true ranging offset (TRO)
   - Assuming delays in DS and US are the same (symmetrical), DTP uses TRO/2 to compensate for the DS delay
2. Asymmetrical delay in the cable plant
3. Timestamp mapping time errors inside devices

Solutions:

A. Ranging solves the symmetrical part of #1
B. DTP calibration solves #3 and part of #2
C. DTP messages support solutions A and B



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DTP History and Status

- 2011 — Invented
- 4/2020 — Incorporated in the DOCSIS SYNC Specification, updated in 4/2021 and 7/2022
- 2020 — First CMTS, RPD and CM devices are available
- 8/2020 — CableLabs, Charter, Cisco and Hitron started the proof-of-concept (PoC) testing
- 12/2021 — DTP validation of 3GPP requirement under various HFC operational conditions. Requires the CableLabs developed AWS DTP calibration database
  - DTP calibration is needed for field deployment. The calibration method is defined.
  - CableLabs/Kyrio team established the Network Timing Lab to conduct the DTP calibration testing.
- Now — Commercial development is continuing in the industry
  - Multiple CMTS/RPD/RMD vendors, and multiple CM and CM chipset vendors developed or are developing products that support DTP

Key deliverables of the DTP PoC project

- DTP PoC phase 1 testing
  - An SCTE Cable-Tec Expo 2021 paper
  - A CableLabs Technical Report
- DTP PoC phase 2 testing
  - A CableLabs Technical Report
- DTP calibration and DTP cloud database
  - Designed a three-step DTP calibration procedure
  - Developed the database hosted on AWS to distribute the calibration data
  - Kyrio/CableLabs established the Network Timing Lab to conduct the calibration testing
  - An SCTE Cable-Tec Expo 2021 paper
- Updating the DOCSIS SYNC Specification
  - Added comprehensive descriptions of the three-steps DTP calibration procedure
  - Defined the interface between the cloud database and CMTS
  - Numerous other updates based on DTP PoC testing observations

DTP PoC

Phase I: September 2020 to July 2021

- Evaluate R-PHY DTP time error (TE) by closed- and open-loop settings.
- Evaluate the TE of an LTE signal in the air transmitted by an eNode B (eNB) that is synced by DTP/PTP.
- Test the impact of true ranging offset (TRO) and DTP time adjustment.
- Compare the measured TE of the above scenarios with the DTP TE budget.

Phase II: August 2021 to December 2021

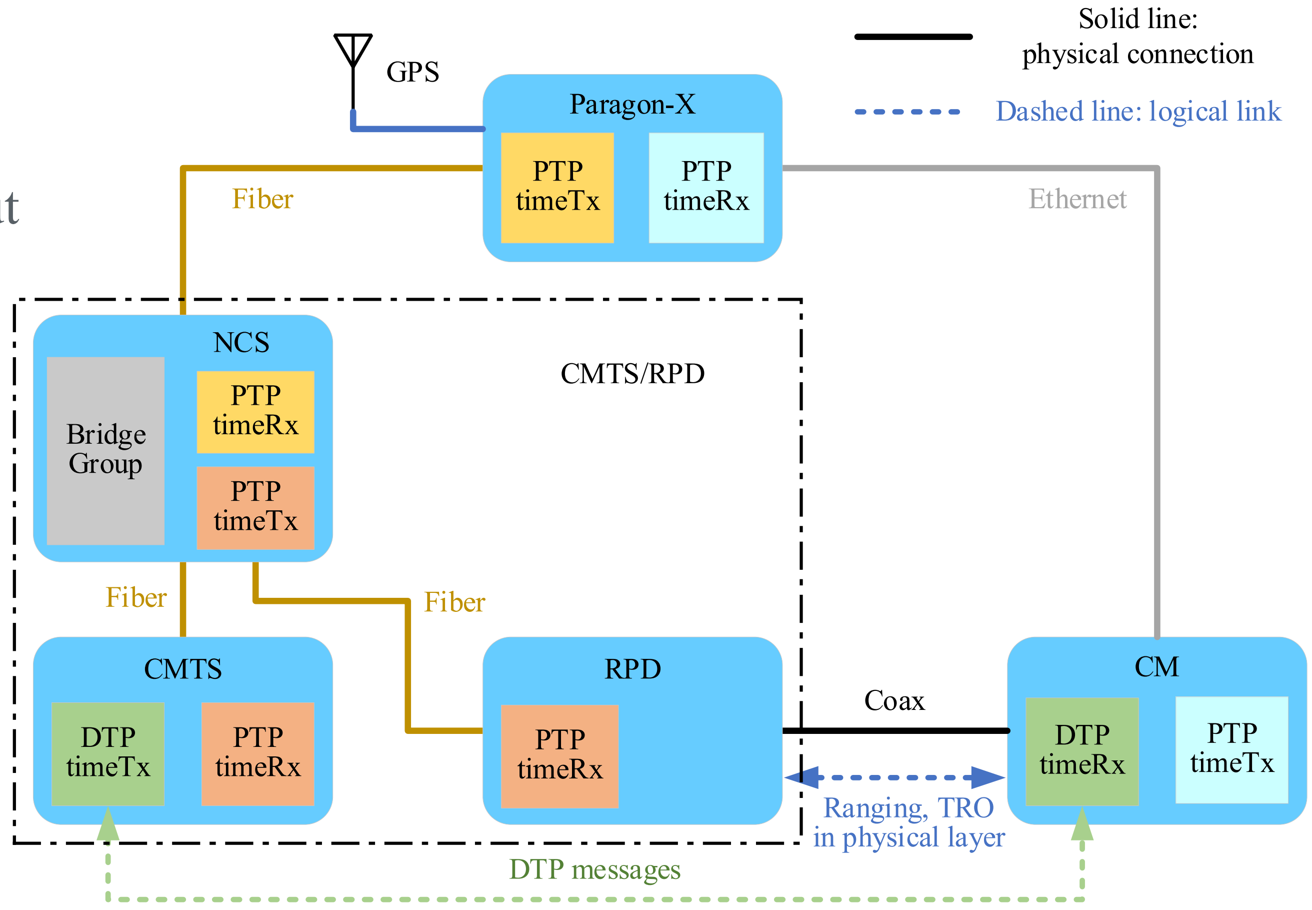
- Compare DTP vs. PTP over the top through the DOCSIS network in the absence of the DTP protocol.
- Re-evaluate DTP/PTP performance by adding traffic load into the DOCSIS network.
- Re-evaluate DTP with more sophisticated network configurations, such as adding amplifiers, adjusting cable and fiber length; and changing modulation, interleaver, cyclic prefix (CP), and upstream frame size in the HFC network.
- Set up a network timing lab at CableLabs/Kyrio, determine procedures and methodologies for performing calibration tests, and develop a cloud database that distributes calibration data to operational CMTSs.

Test Plan

Parameters		Baseline test value	Comparative test values	Extreme values (optional test)
DS load impact on PTP over the top		0	25%, 50%	75%, 100%
US load impact on PTP over the top		0	25%, 50%	75%, 100%
DS load impact on DTP		0	25%, 50%	75%, 100%
US load impact on DTP		0	25%, 50%	75%, 100%
Fiber length (NCS to RPD)		90 m	5 m, 25 km	
Coax length (RPD to CM)		3 m	244 m (800 ft) 591 m (1938 ft) 835 m (2738 ft)	
Number of amplifiers		0	1, 2, 3, 4, 5	
CM configs (US)	Frame size	$K = 6$	$K = 18$	
	OFDMA modulation	256-QAM	64-QAM	1024-QAM
	Cyclic prefix	6: 256 samples	4: 192 samples	
CMTS configs (DS)	Interleaver	2	1	16
	Modulation	4096-QAM	1024-QAM, 256-QAM	
	Cyclic prefix	256 samples (1.25 µs)	512 samples (2.5 µs)	192, 768 and 1024 samples

Lab Configuration

- The Paragon-X measures PTP time error (TE) between the input of the CMTS/RPD and the output of the CM
- Distributed Access Architecture (DAA)
  - Integrated CMTS (I-CMTS): Cisco cBR-8
  - Remote-PHY device (RPD): Cisco SmartPHY 120
- CM: Hitron ODIN1112
- Cisco Network Convergence System (NCS)
  - Switch that connects other devices
  - Includes a boundary clock



Observations

- **Observation 1**: DTP will work. The default test case met the DTP time error budget.
- **Observation 2**: PTP over-the-top of HFC network does not meet the 3GPP requirement. The dynamic time error (TE) is on the order of milliseconds with or without traffic load. The constant TE changes with different levels of downstream and upstream load by multiple milliseconds.
- **Observation 3**: DTP performance is not impacted by traffic load in either the downstream (DS) or the upstream (US).
- **Observation 4**: Fiber length in the DAA-RPD architecture does not impact DTP.
- **Observation 5**: Cable length does not impact DTP. Vector Network Analyzer (VNA) measurements indicate that coaxial cable does not introduce any asymmetrical delay. The additional round-trip delay from cable length is symmetrical and the corresponding TE is well compensated by TRO, which is verified in the DTP measurements.

Observations

- **Observation 6**: Amplifiers introduce an asymmetrical delay in the HFC plant and additional TE to DTP. The additional TE varies with amplifier make and model. The QDAX amplifier has an additional TE of 36-40 ns that is accurately characterized by the VNA. Such additional TE from each QDAX amplifier is on average 54 ns measured in the DTP testbed. *(Requires MSO attention!)*
- **Observation 7**: HFC upstream network configurations of frame size, modulation scheme and cyclic prefix do not impact DTP performance.
- **Observation 8**: HFC downstream interleaver and modulation scheme do not impact DTP performance.
- **Observation 9**: The downstream cyclic prefix significantly impacts DTP. Every 1.25 µs CP length reduces constant TE by approximately 80 µs. As of August 2022, this issue is being investigated by the CM vendor and chipset vendor.
- **Observation 10:** The NCS class B boundary clock TE is between -8 and 1 ns, which is smaller than the 20-ns TE budget defined in the SYNC spec.
- **Observation 11:** The US OFDMA channel frequency does impact DTP depending on the group delay variation over frequency. *(Requires MSO attention!)*

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Suggestions for MSOs

- DTP calibration
  - A three-step DTP calibration procedure is required to guarantee DTP performance.
  - The calibration test needs to be done for each pair of CMTS/RPD/RMD and CM devices.
- Asymmetrical delay from amplifiers
  - Each amplifier may introduce 36 – 40 ns additional TE.
  - If a large number of amplifiers is used, the TE from other network elements will need to be reduced in order to meet the entire TE budget. Two possible solutions are:
    - Use a higher class of CMTS or CM with better quality and smaller TE; or
    - Reduce the number of cascading boundary clocks used in the DTP network.
- Upstream frequency selection to reduce asymmetrical delay
  - The upstream channel frequency may impact DTP depending on the number of diplexers, amplifiers and filters that changes the group delay over frequency.
  - Use the portion of the channel closest to the center of the upstream band in order to stay clear of the expected delay variation/increase at the band edges.

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Thank You!

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