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2021 Fall Technical Forum
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Wireline Access Network

DOCSIS Time Protocol Proof of Concept

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Agenda

Introduction: background of DOCSIS Time Protocol (DTP)

DTP Proof-of-Concept (PoC) test plan

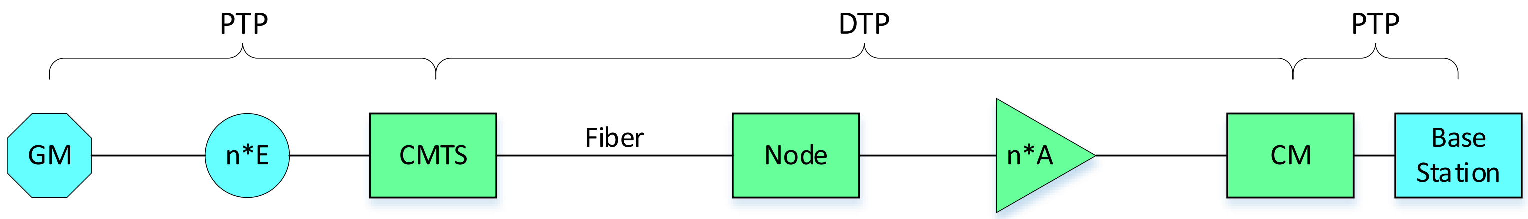
DTP performance: test method, setup and results

LTE timing performance using DTP in the backhaul: test method, setup and results

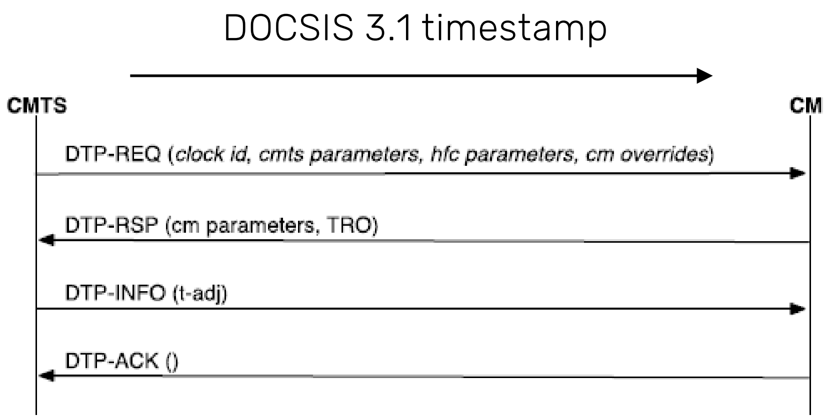
Conclusion and future work

What is DTP?

- DTP (DOCSIS Time Protocol) is a time protocol that provides a high-accuracy synchronization signal for a DOCSIS network
- Customized for the HFC network, the accuracy can be guaranteed
  - Regardless of network load, works better than over-the-top Precision Time Protocol (PTP)
  - Regardless of the HFC network topology and location of the cable modem (CM)



GM: Grand Master
n*E: n number of Ethernet Switches
n*A: n number of Amplifiers



DTP message flow

Why is DTP needed?

- Time division duplex (TDD) 4G LTE and 5G NR require base station (BS) synchronization ≤ 1.5 μs
- The sync signal needs to be provided in mobile backhaul where GPS signals are not available, e.g., indoor and urban canyon
- MSOs are deploying mobile networks and provide mobile backhaul for other operators
- DOCSIS network, as a mobile backhaul candidate, needs DTP to provide high-accuracy sync signals

DTP status

- Invented by Cisco in 2011 [1]
- Added to the DOCSIS SYNC specification in April 2020 [2]
- Many vendors have developed or are developing DTP solutions
- CableLabs, Charter Communications, Cisco and Hitron initiated DTP PoC testing in Q3 2020 [3]. This presentation provides the DTP PoC test plan, methodology and up-to-date status.

[1] John T. Chapman, "The DOCSIS Timing Protocol (DTP)," in *SCTE Spring Technical Forum*, 2011.

[2] Cable Television Laboratories, Inc., "Data-Over-Cable Service Interface Specifications; Synchronization Techniques for DOCSIS® Technology," April 2020.

[3] Cable Television Laboratories, Inc., "DOCSIS Time Protocol Proof of Concept Phase I Technical Report CM-TR-DTP-V01-2108915," September 2021.

DTP PoC test plan

Phase 1: September 2020 to July 2021

- Evaluate DTP time error (TE) in lab environment: no network load, no amplifier, minimum fiber and coaxial cable length
- Evaluate TE of LTE signal in the air transmitted by a base station that is synced by DTP/PTP
- Compare the measured TE of the above scenarios with the DTP TE budget

Phase 2: August 2021 to December 2021

- Compare DTP vs. PTP 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 node, switch, amplifier, adjusting cable/fiber/Ethernet length and changing modulation, interleaver, cyclic prefix and upstream frame size in the HFC network

Phase 3: Automated DTP calibration. Timeframe is to be determined.

- Setting up a network timing lab at CableLabs/Kyrio; determine procedures and methodologies for certification and calibration tests; develop a cloud database that distributes calibration data to operational CMTSs
- Add a feature in the CMTS that automatically downloads the calibration data from the cloud database and applies the calibration data
- Verify the performance of the cloud database and the corresponding CMTS automatic calibration feature

Phase 2 test plan

Parameter		Baseline test value	Comparative test values	Extreme value (optional test)
DS load		0	25%, 50%	75%
US load		0	25%, 50%	75%
Coax length (R-PHY to CM)		a few meters	1/4 and 1 mile	
Fiber length (Router to R-PHY)		tens of meters	25 km	
Number of amplifiers		0	1, 2	
CMTS config change (DS)	Interleaver	2	1	16
	Modulation	4096-QAM	1024-QAM, 256-QAM	
	Cyclic prefix	1 (1.25 μs, 256 samples)	2 (2.5 μs, 512 samples)	3 (3.75 μs, 768 samples)
CM config change (US)	Frame size	K = 6	K = 9, BW ≥ 72 MHz K = 18, BW < 48 MHz	
	OFDMA modulation	256-QAM	64-QAM	1024-QAM
	Cyclic prefix	6: 256 samples	4: 192 samples	

Phase 3 automated DTP calibration

DOCSIS 3.1 timestamp includes the downstream time delay due to HFC plant length and equipment impairment.

DTP improves DOCSIS 3.1 timestamp accuracy:

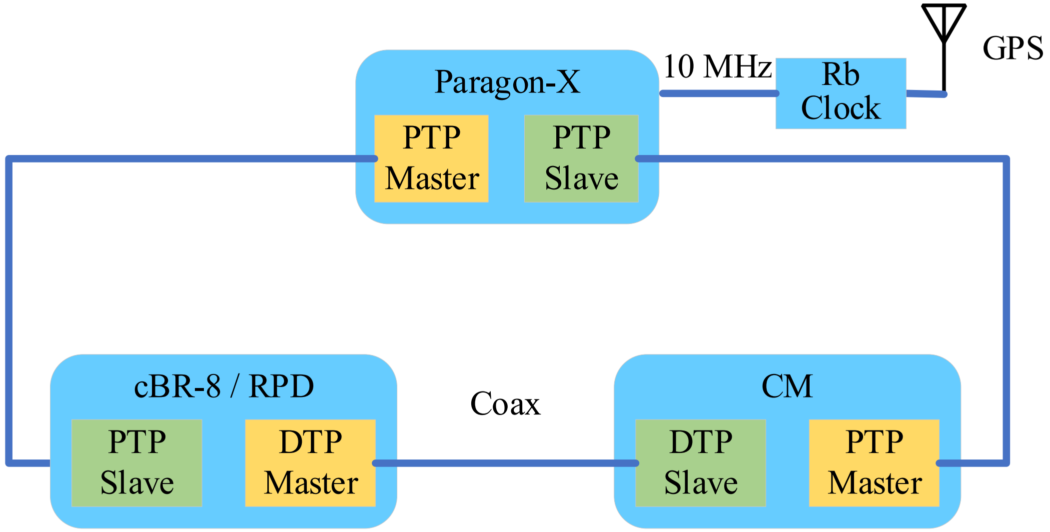
- Using TRO that corrects the symmetrical time error;
- Still has asymmetrical time error.

Calibrated DTP further improves DOCSIS 3.1 timestamp accuracy:

- Using TRO that corrects the symmetrical time error;
- DTP calibration corrects the asymmetrical time error.

Test method

- No time measurement equipment is available that supports DTP
- DTP performance is measured between the input PTP timestamp to the CMTS and the output PTP timestamp of the CM



Test setup

- Cisco integrated CMTS: cBR-8
- Cisco remote-PHY device (RPD): SmartPHY 120
- Hitron CM ODIN-1112 with MaxLinear's Puma 7 chipset/protocol
- Calnex Paragon-X

Time error budget

Specifically calculated for the test setup

- Ethernet and dynamic aspects of Ethernet TE budget: 470 ns
- DOCSIS network TE budget: 510 ns
- Base station network TE budget: 0 (no base station in this setup)
- Total TE budget: 980 ns

Budget Component	DAA			DTP test setup		
	n	@	TE	n	@	TE
PRTC *(Class A is 100 ns, Class B is 40 ns, ePRTC is 30 ns)*	Class A		100	Class A		0
Network holdover and PTP rearrangements			200			200
Network dynamic TE and SyncE rearrangements			200			200
T-BC *(Class A is 50 ns, Class B is 20 ns)*	4	50	200	0	A@50	0
T-BC *(Class C is 10 ns, Class D is 5 ns)*				1	B@20	20
Link asymmetry			50			50
Ethernet and Dynamic Aspects of Ethernet TE Budget			**750**			**470**
I-CMTS/RPD/RMD *(Class A is 200 ns, Class B is 100 ns)*	Class A		200	Class A		200
DTP			50			50
HFC path			10	DAA		10
HFC node			10	DAA		0
HFC amp/LE	N+3	10	30	N+0	10	0
CM *(Class A is 250 ns, Class B is 100 ns)*	Class A		250	Class A		250
DOCSIS Network TE Budget			**550**			**510**
Rearrangements and short holdover in the end application			0			0
Base station slave or intra-site distribution	Class A		50	Class A		0
Base station RF interface			150			0
Base Station Network TE Budget			**200**			**0**
Total TE Budget			**1500**			**980**

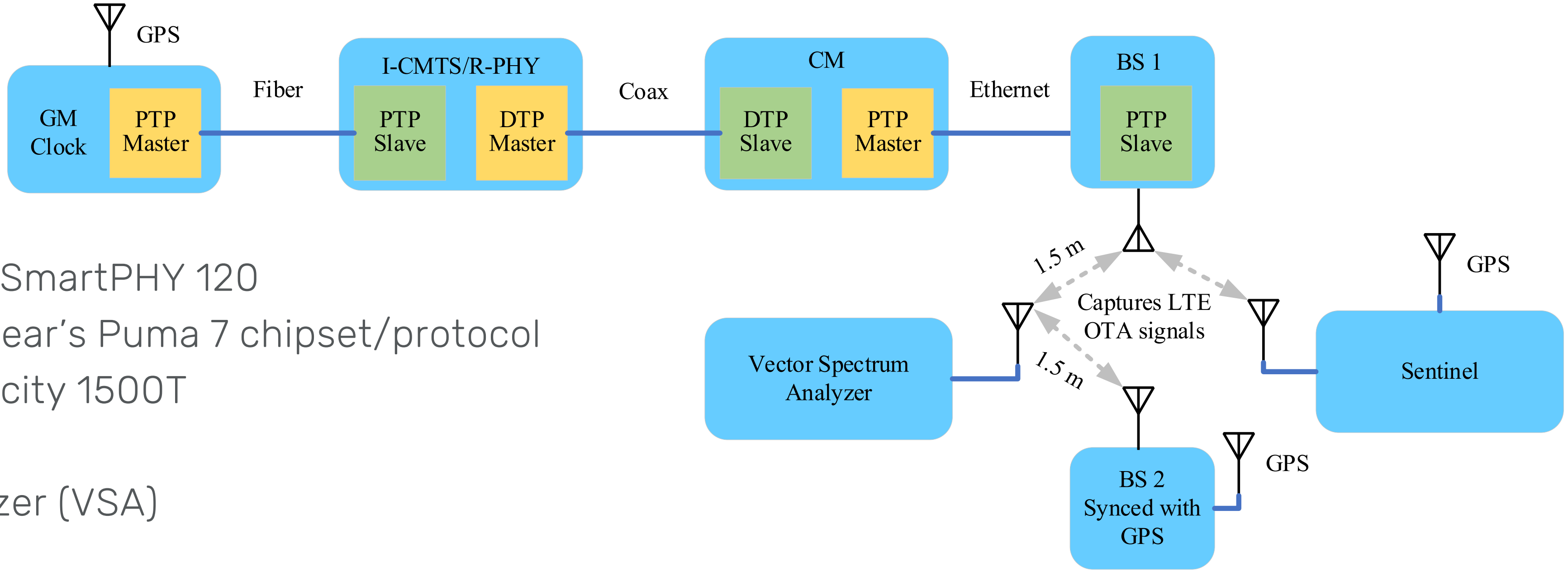
Phase 1 time error results

Met requirement except run 4 in the Charter testbed

- PoC tests were conducted in CableLabs, Charter and Cisco
- Many TE statistical results were analyzed by the Paragon-X, here we mainly focus on the two-way TE
- The results are listed in the table below:
  - cTE is smaller than 31 ns
  - The max TE and min TE are all within ±200 ns, which meet the 980 ns TE budget requirement
  - The only exception is run 4 in the Charter testbed. A PTP Delay_Response message in run 4 arrived at the Paragon-X ~9 s later than expected. This was not observed in the other four runs in the Charter and CableLabs data.

All TE results unit in ns			Test setup with RPD				
			Two-way Time Error				Peak-to-peak dynamic TE
	Run	Time duration	Mean (cTE)	Max	Min	Max-Min	
CableLabs	1	3600 s	30	46	-47	163	157
	2	3600 s	13	146	-94	240	220
	3	3600 s	31	118	-47	165	144
	4	3600 s	21	138	-67	205	183
	5	3600 s	29	125	-81	206	190
Charter	1	3 hours	-29	97	-151	248	226
	2	3 hours	-30	102	-146	248	225
	3	3 hours	-19	110	-183	293	231
	4	3 hours	13607	9,404,370,078	-147	9,404,370,224	9,449,878,963
	5	3 hours	-26	115	-141	256	222
Cisco	1	1076 s	-20	121	-122	242	225

LTE Timing Performance Using DTP in Backhaul



Test setup

- Cisco integrated CMTS: cBR-8
- Cisco remote-PHY device (RPD): SmartPHY 120
- Hitron CM ODIN-1112 with MaxLinear's Puma 7 chipset/protocol
- Airspan LTE base station: AirVelocity 1500T
- Calnex Sentinel
- Keysight Vector Spectrum Analyzer (VSA)

Test method: VSA

- LTE downlink bursts are captured by the VSA
- Compare the rising edges of downlink burst from two base stations

Test method: Sentinel

- The Calnex Sentinel decodes the time of day from the BS1 LTE signal
- The Sentinel uses GPS and an internal Rubidium clock as a reference to evaluate the accuracy of LTE timing

Time error budget

Specifically calculated for the VSA setup

- Ethernet and dynamic aspects of Ethernet TE budget: 570 ns
- DOCSIS network TE budget: 510 ns
- Base station network TE budget: 500 ns (two BSs)
- Total TE budget: 1580 ns

Specifically calculated for the Sentinel setup

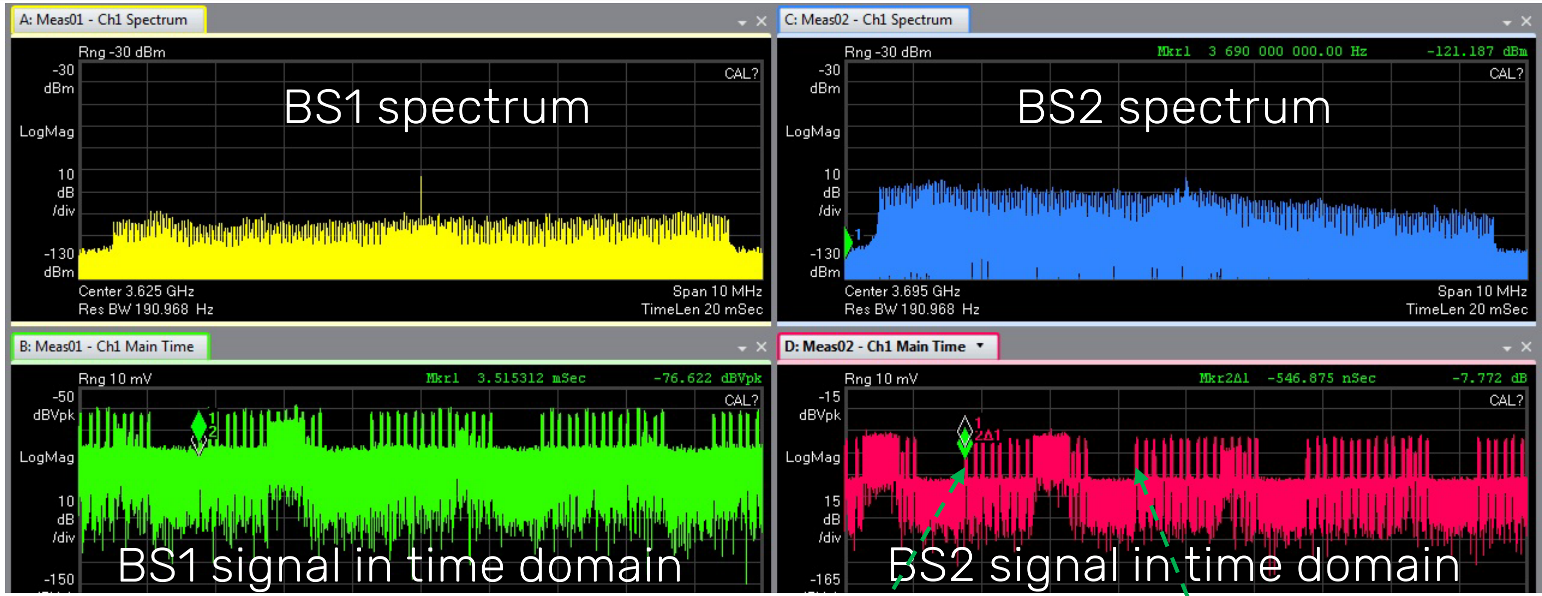
- Ethernet and dynamic aspects of Ethernet TE budget: 570 ns
- DOCSIS network TE budget: 510 ns
- Base station network TE budget: 200 ns (one BS)
- Total TE budget: 1280 ns

Budget Component	VSA			Sentinel		
	n	@	TE	n	@	TE
PRTC *(Class A is 100 ns, Class B is 40 ns, ePRTC is 30 ns)*	Class A		100	Class A		100
Network holdover and PTP rearrangements			200			200
Network dynamic TE and SyncE rearrangements			200			200
T-BC *(Class A is 50 ns, Class B is 20 ns)*	0	A@50	0	0	A@50	0
T-BC *(Class C is 10 ns, Class D is 5 ns)*	1	B@20	20	1	B@20	20
Link asymmetry			50			50
Ethernet and Dynamic Aspects of Ethernet TE Budget			**570**			**570**
I-CMTS/RPD/RMD *(Class A is 200 ns, Class B is 100 ns)*	Class A		200	Class A		200
DTP			50			50
HFC path	DAA		10	DAA		10
HFC node	DAA		0	DAA		0
HFC amp/LE	N+0	10	0	N+0	10	0
CM *(Class A is 250 ns, Class B is 100 ns)*	Class A		250	Class A		250
DOCSIS Network TE Budget			**510**			**510**
Rearrangements and short holdover in the end application			0			0
GPS receiver PRTC clock	1	A@100	100	0	A@100	0
Base station slave or intra-site distribution	2	A@50	100	1	A@50	50
Base station RF interface	2	150	300	1	150	150
Base Station Network TE Budget			**500**			**200**
Total TE Budget			**1580**			**1280**

VSA time error results

The VSA measures LTE signals in the frequency domain and converts them into the time domain

- BS1 uses 3620-3630 MHz and BS2 uses 3690-3700 MHz
- The VSA compares LTE signals from BS1 and BS2 in the time domain



Markers for two BSs are synced and comparable

- Marker 1 is placed on the rising edge of the burst for the BS1 signal (green)
- Marker 2 is placed on the rising edge of the burst for the BS2 signal (red)
- The time difference between two markers is 529 ns, which indicates the relative time error between BS1 and BS2 LTE signals is much smaller than the required TE budget of 1580 ns

Requirement met!

Period: 5 ms

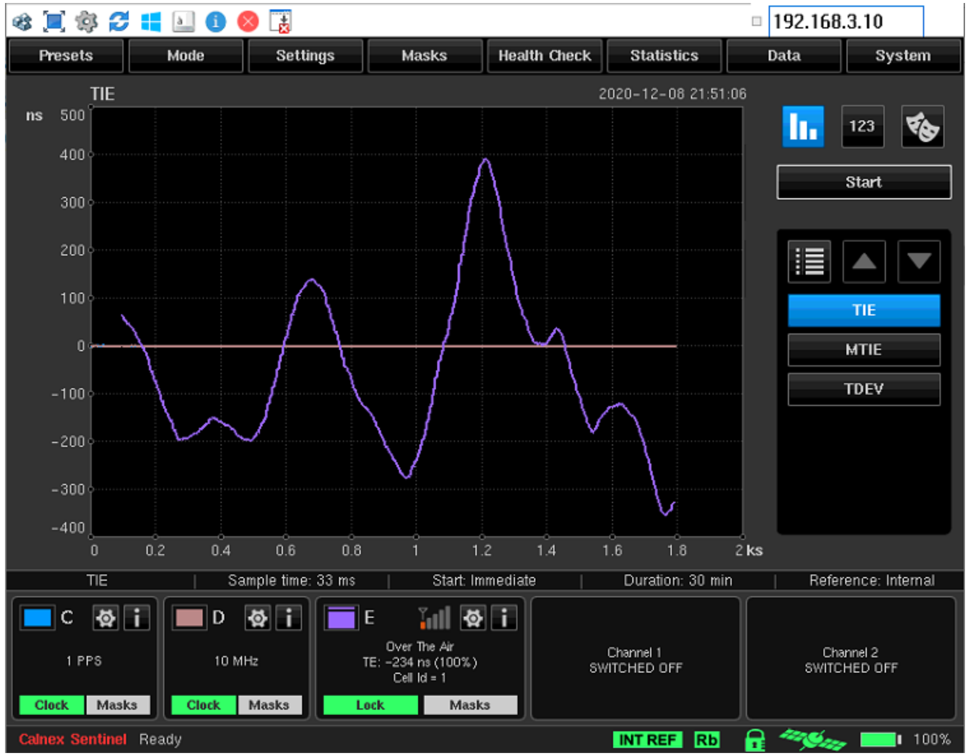
Subframe number									
0	1	2	3	4	5	6	7	8	9
D	S	U	D	D	D	S	U	D	D

LTE TDD configuration 2 subframe structure
D: downlink; U: uplink; S: special subframe

Sentinel time error results

- The LTE signal uses 3620 to 3630 MHz with a cell ID of 1
- Channel E on the Sentinel decodes the time of day on the LTE signal
- This time of day is compared with the GPS time of day
- The figure shows an example of Sentinel measurement data. The OTA LTE signal TE varies from -354 to 392 ns, with a mean value of -51 ns
- Five runs of data are listed in the table
  - The average LTE signal TE is between -71 and 9 ns
  - The largest peak-to-peak variation is 746 ns
  - All the TE results meet the ±1.5 μs 3GPP requirement

Requirement met!



Run	Time duration (s)	Two-way Time Error (ns)			
		Mean (cTE)	Max	Min	Max-Min
1	1800	-51	392	-354	746
2	1800	-25	269	-255	524
3	1800	-41	186	-286	472
4	3600	9	159	-107	266
5	3600	-71	131	-332	463

Conclusion

- DTP is designed to provide accurate synchronization for the backhaul of TDD and FDD mobile networks over DOCSIS
- DTP PoC testing was conducted by CableLabs, Charter, Cisco and Hitron. PoC testing was divided into three phases:
  - Phase 1 validates that DTP works in a basic lab environment
  - Phase 2 evaluates DTP performance in sophisticated environments that mimic field deployments
  - Phase 3 verifies automatic DTP calibration in field deployments by using an AWS cloud server to distribute calibration data
- This paper reported up-to-date progress of DTP PoC testing
- The phase 1 results successfully demonstrated that DTP works in a lab environment
  - The measured DTP time error results meet the time error budget
  - Using DTP and PTP in the backhaul, LTE over-the-air signals meet the 3GPP synchronization requirement

Future work

- DTP is being evaluated in various HFC network configurations (phase 2 PoC testing)
- An AWS cloud server is being developed to enable automated DTP calibration [4]

[4] Ruoyu Sun, Rahil Gandotra, Jennifer Andreoli-Fang, Elias Chavarria Reyes, John T. Chapman, Mark Poletti, “Designing a Cloud-Based DOCSIS Time Protocol Calibration Database,” in *SCTE-Expo 2021*, Atlanta, GA, October 11-14, 2021.

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Thank You!

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