5G over Cable Networks

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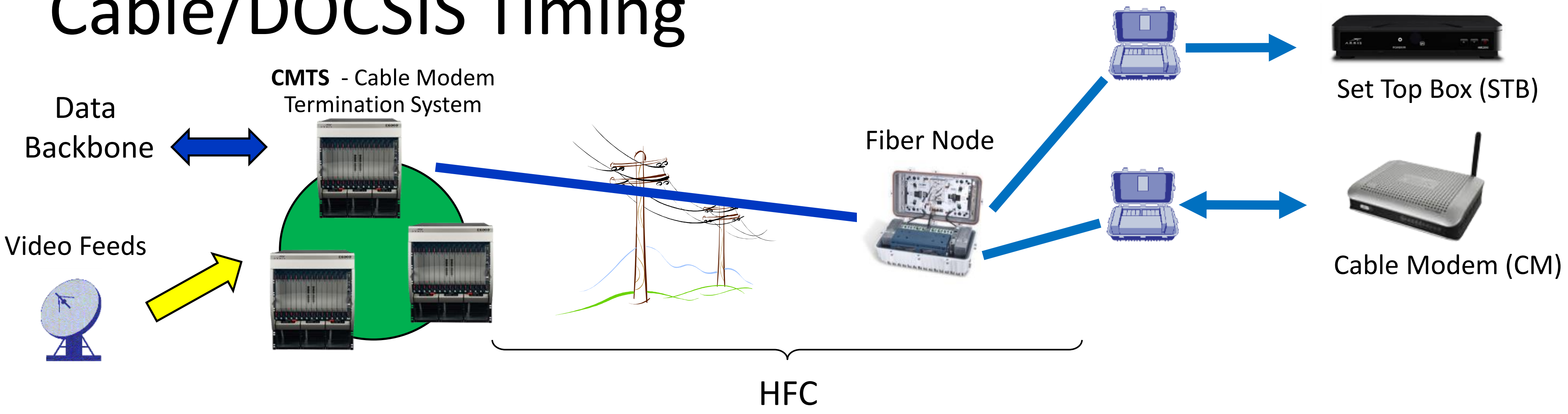
Agenda

- **Cable Timing introduction**
- Cable and Mobile - why even bother?
- DOCSIS Timing Protocol (DTP) – Cable's SYNC vehicle
- Preliminary results

Cable/DOCSIS Timing



- DOCSIS transport is Synchronous in nature and uses a common clock derived by the CMTS
- The CMTS delivers Timestamps on the downstream (64-bit in DOCSIS 3.1)
- The CM derives its frequency from the OFDM symbol clock and the "time reference" from the repeated timestamps
- +/-5 ppm on Clock accuracy (usually free running).
- Clock drift rate ≤ 10 ppb/second
- Phase steps are not allowed
- **The DOCSIS path delay is inherently asymmetrical (at the ms level…) and can contain a moderate to high amount of jitter (10s of µs…)**

Cable and Mobile – why even bother?

Why do Mobile over DOCSIS?

- HFC infrastructure provides many advantages for wireless backhaul when compared to pure fiber backhaul or microwave/wireless backhaul approaches:

  - ✓ **Ubiquity** – HFC networks run down every street and to every building in the city. This gives significant flexibility to wireless teams to design optimal small cell deployments.

  - ✓ **Power** – One of the most notable advantages of HFC over fiber and wireless backhaul is its ability to transport power to small cells.

  - ✓ **Deployment Speed & Simplicity** – HFC aerial architecture provides an ideal medium for fast small cell backhaul deployments.

Why do Mobile over DOCSIS – case study

- A North American operator wanted to further quantify the real-world benefits of using coax versus extending their fiber to feed their small cell deployments.
  - A highly dense location that was a likely candidate for upcoming small cell deployments was chosen.
  - Ideal locations were designed for their RF characteristics only and did not take into consideration proximity to HFC plant, power or fiber

Why do Mobile over DOCSIS – case study

- The fiber wireline design team designed a build to connect each of the ideal small cell locations to the nearest fiber location (typically the nearest fiber node).
- as comparison the design team completed a design that connected the small cells to existing coaxial infrastructure.
- They found that all the ideal small cell locations were within **10 meters of coax**….

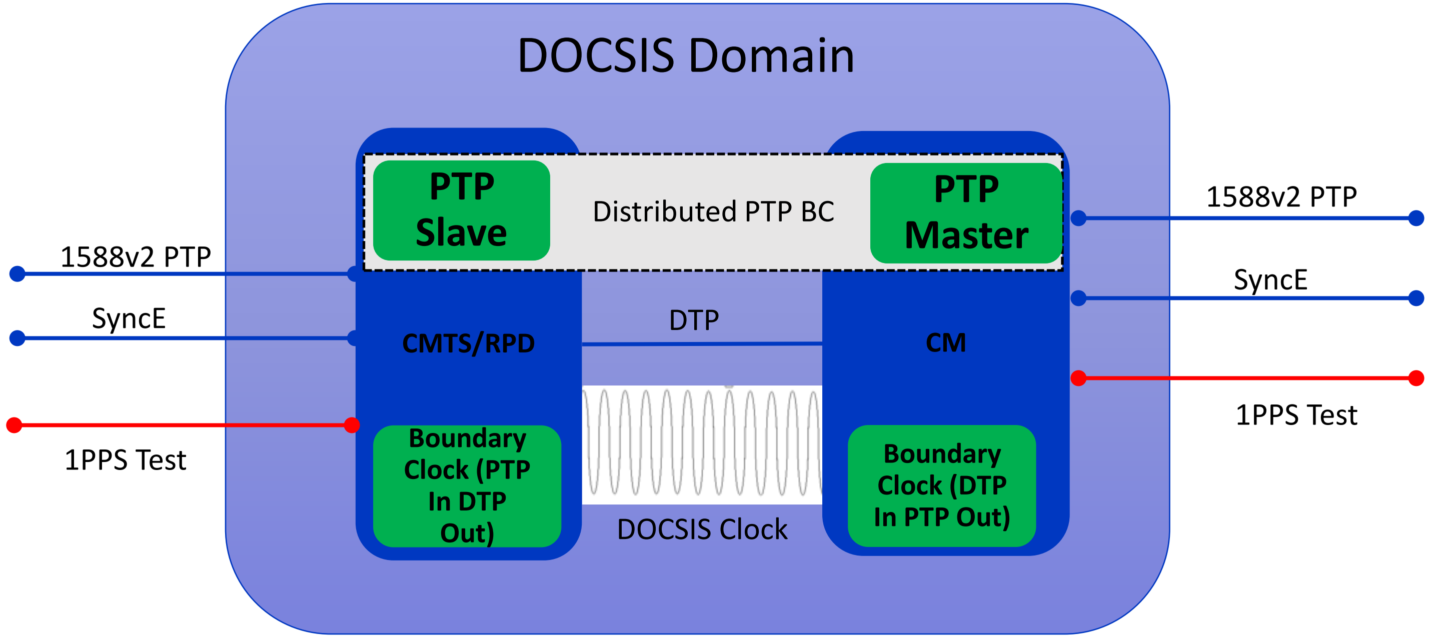
Small Cell Count	Backhaul Option	Backbone Fibers	Estimated Civil Build Cost	Estimated Build Time
15	DWDM	1	$183k	4-6 months
	Coax w/ couplers	0	$1.5k	1 week

Why do Mobile over DOCSIS – indoor femtocells

- At least one major NA operator is considering to backhaul their home femtocells using DOCSIS.
- Different approaches whether to combine the CM/gateway and eNb/gNb into a single device or not.

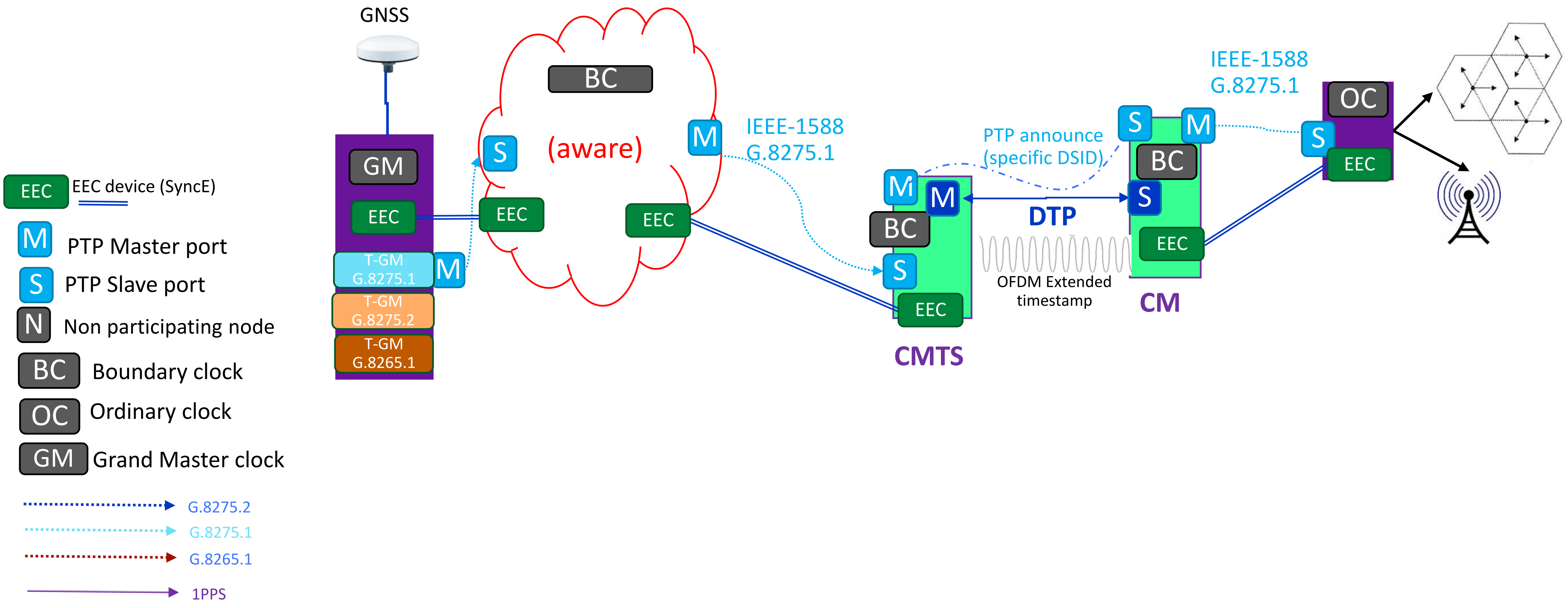
DOCSIS Timing Protocol (DTP) – Cable's SYNC vehicle

DOCSIS Domain Time Distribution



- CMTS synchronizes DOCSIS domain to network source
  - With IEEE1588v2, CMTS fulfills PTP Slave Port functions while syncing the DOCSIS Domain to its clock.
  - SyncE EEC may reside in CMTS, can be used to assist clock holdover and Locking time if SyncE primary reference clock is the same as PTP GM
- CM clock is tightly locked to CMTS (and ultimately PRTC) using DOCSIS Symbol clock.
- DOCSIS latency and asymmetry are measured and compensated for by DTP
- Using DOCSIS Time Protocol, the CM generates precision timing for subtending network (PTP Master and SyncE output functions reside in the CM)

MBH Sync over ICMTS – fully aware network (G.8275.1)



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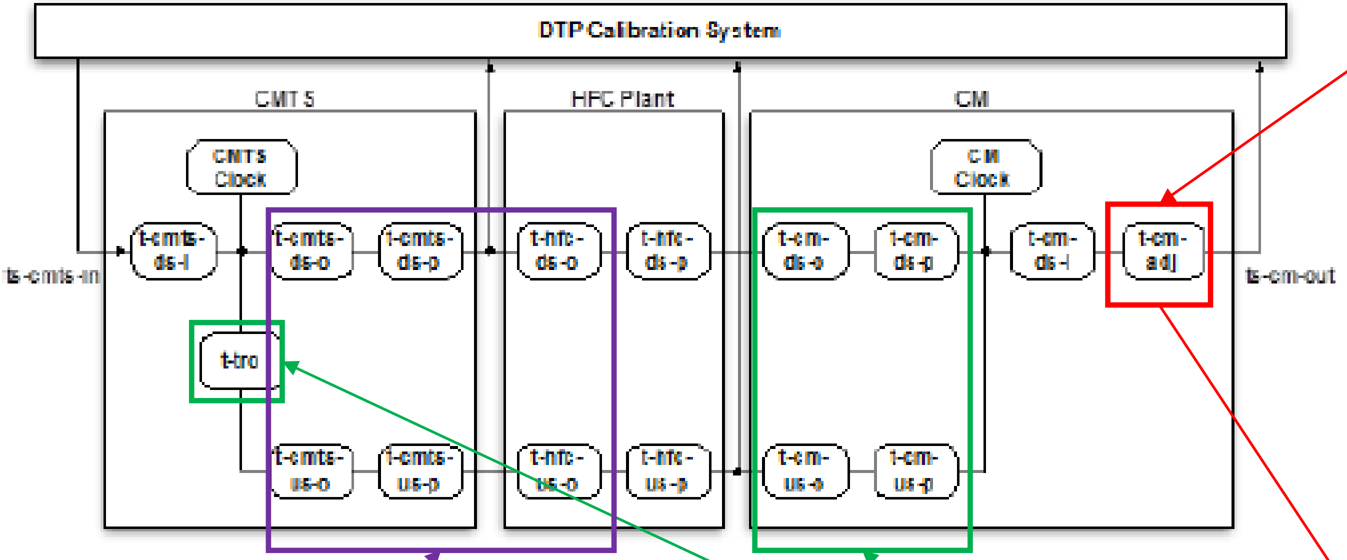
DTP – DOCSIS Timing Protocol

- Introduced in DOCSIS 3.1
- Defines a mechanism to measure and model the asymmetries in the HFC network and to provide an adjustment factor to the DOCSIS timestamp



Parameters sent by the CMTS

Parameters sent by the CM

Calculated by the DTP Master

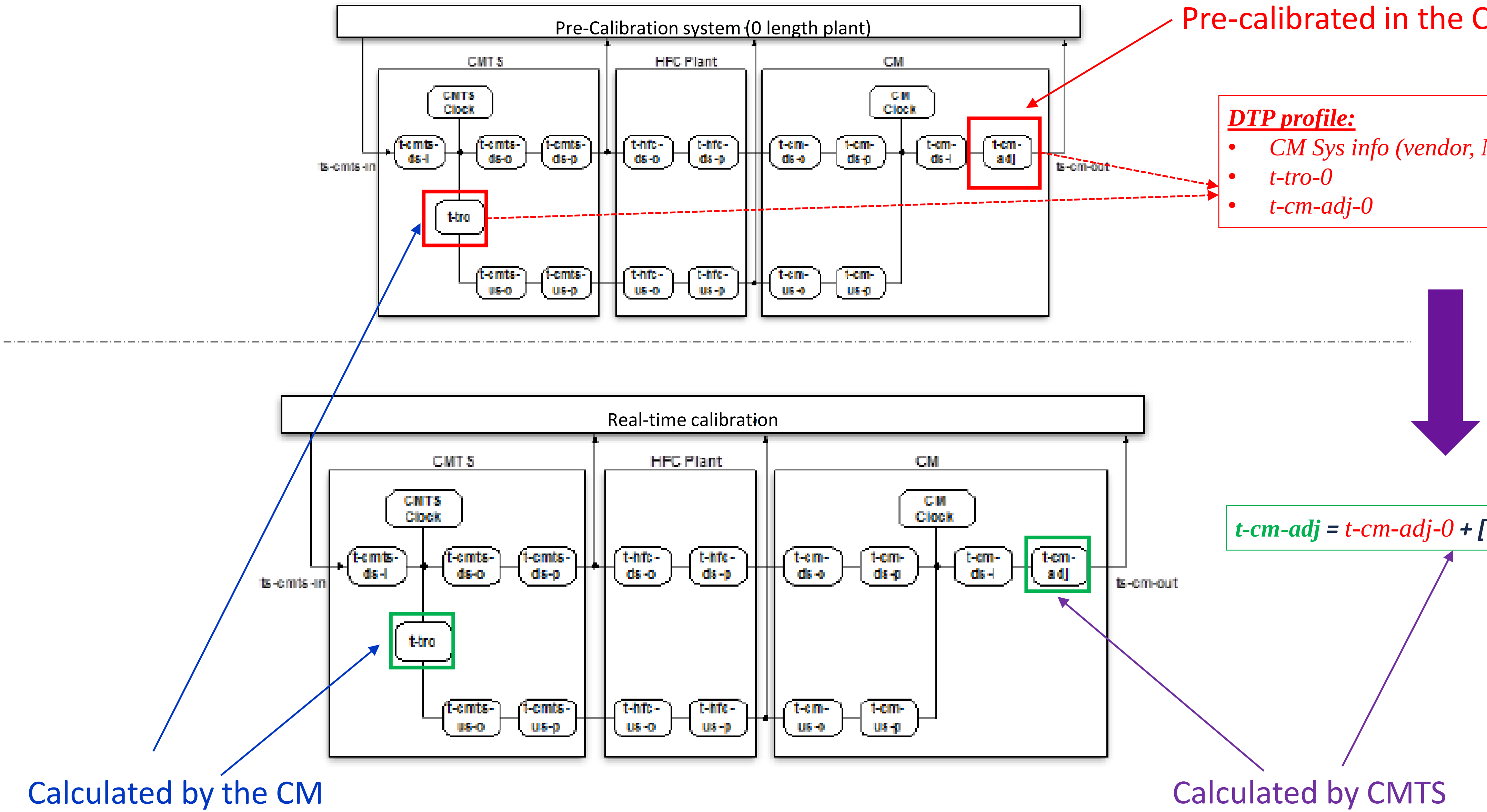
t-cm-adj = *t-cmts-ds-i* + *t-cmts-ds-o* + *t-cmts-ds-p* + *t-hfc-ds-o* + *t-hfc-ds-p* + *t-cm-d-o* + *t-cm-ds-p* + *t-cm-ds-i*

t-hfc-ds-p = (*t-tro* – *t-cmts-ds-o* – *t-cmts-ds-p* – *t-hfc-ds-o* – *t-cm-d-o* – *t-cm-ds-p* – *t-cm-us-o* – *t-cm-us-p* – *t-hfc-us-o* – *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-tro* – *t-cmts-ds-o* – *t-cmts-ds-p* – *t-hfc-ds-o* – *t-cm-d-o* – *t-cm-ds-p* – *t-cm-us-o* – *t-cm-us-p* – *t-hfc-us-o* – *t-cmts-us-o* – *t-cmts-us-p*) / 2 + *t-cm-d-o* + *t-cm-ds-p* + *t-cm-ds-i*

t-cm-adj = *t-cmts-ds-i* + *t-cm-ds-i* + (*t-tro* + *t-cmts-ds-o* + *t-cmts-ds-p* + *t-hfc-ds-o* + *t-cm-d-o* + *t-cm-ds-p* – *t-cm-us-o* – *t-cm-us-p* – *t-hfc-us-o* – *t-cmts-us-o* – *t-cmts-us-p*) / 2

DTP Profile pre-calibration



DTP profile:

- *CM Sys info (vendor, Model, HW Rev)*
- *t-tro-0*
- *t-cm-adj-0*

***t-cm-adj* = *t-cm-adj-0* + [*t-tro* - *t-tro-0*]/2**

MBH over DOCSIS "SYNC" spec

- There is a Cable labs working group dedicated for specifying the requirements needed for the DOCSIS network (CMTS/RMD/RPD and CM) to support MBH
- WG started to work in 2018.
- I01 was released:
  - Requirements of supporting phase over DOCSIS with full network support of 1588 (all the NE are 1588 BC using the G.8275.1 profile and based on ITU-T G.8273.2 performance requirements)
  - Requirements of supporting frequency over DOCSIS with full network support of SyncE
  - I-CMTS / DAA use cases
  - Testing concepts and requirements (e.g. 1 PPS, probing points etc.)
- I02 will include (planned for Q1/21):
  - New DOCSIS TLVs and MIBs (for CM configuration)
  - Fixes and updates to I01
- I03 will include (Planned for 2021):
  - Requirements of supporting phase over DOCSIS with partial network support of 1588 (some of the NE are 1588 BC using the G.8275.2 profile and based on ITU-T G.8273.4 performance requirements)

MBH over DOCSIS “SYNC” spec – Phase Budget (fully aware network)

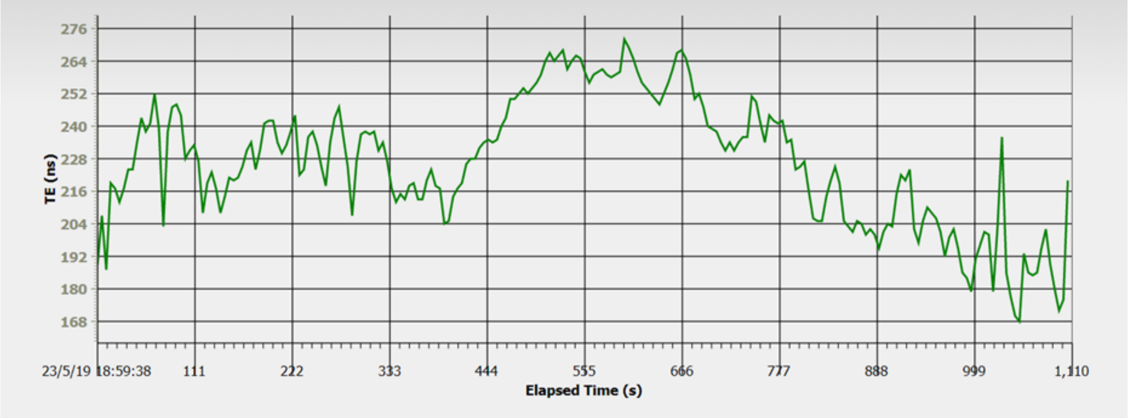
Budget Component	ITU-T Reference	I-CMTS n	I-CMTS @	I-CMTS TE	DAA n	DAA @	DAA TE
PRTC *(Class A is 100 ns, Class B is 40 ns, ePRTC is 30 ns)*	100	Class A		100	Class A		100
Network Holdover and PTP rearrangements	NA or 400			200			200
Network Dynamic TE and SyncE rearrangements	200 for 10 BC			200			200
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 & 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**

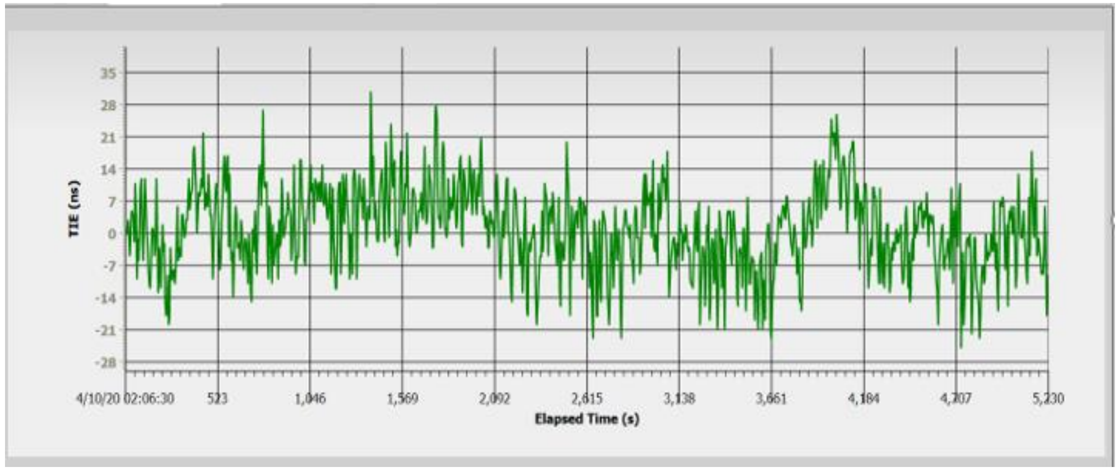
DOCSIS may “steal” up to 1/3 of the budget…

Preliminary Results

Slave Clock Time Error Performance with 3’ of Coax (zero length plant)

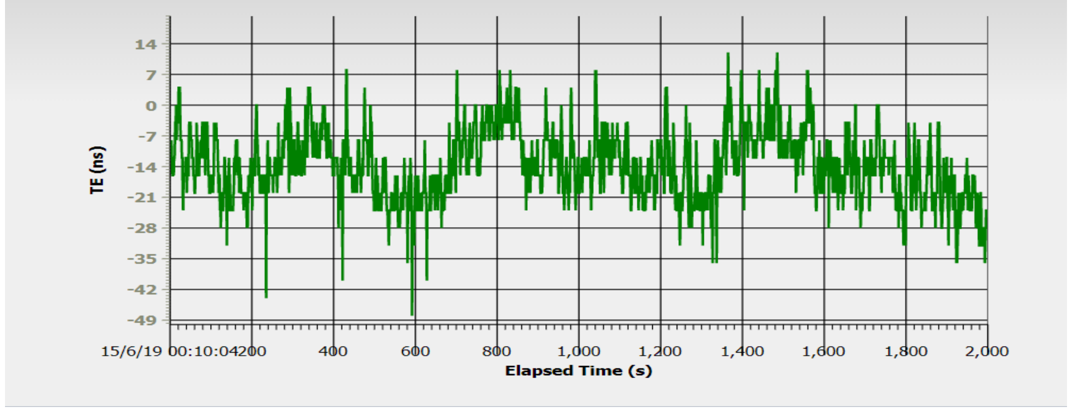
- TE of the recovered phase at the slave probe is compared to GPS time
- Measurement is performed with a 3-foot coax to approximate the zero-length plant for calibration
- Upper diagram shows the recovered phase has a TE of 220 ns with a variation of 100 ns peak-to-peak
- Results meet the ~500 ns TE budget for a Class A DOCSIS system defined in the Cable Labs SYNC specification
- Lower diagram shows recovered phase after further adjusting DTP parameters to reduce the cTE

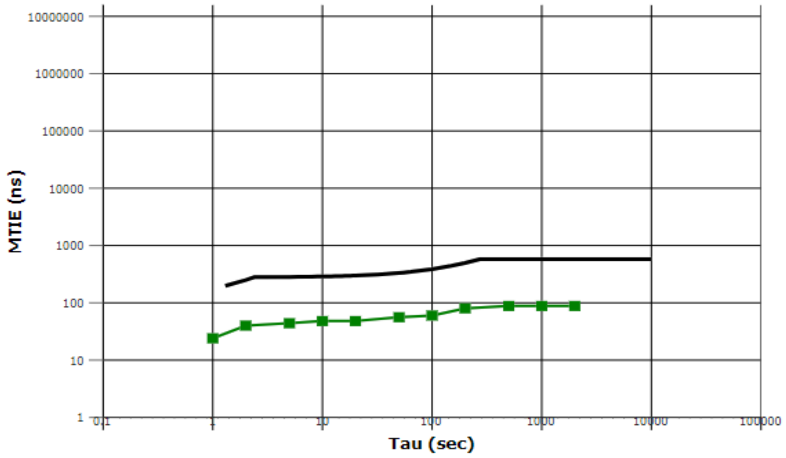




Slave Clock Time Error Performance with 400’ of Coax

- Plant cable length was increased to 400’
- DTP parameters were unchanged from calibrated values with 3’ coax
- The measured TE at the output of the CM is roughly
  -10 ns with a variation of 50 ns peak-to-peak
- MTIE is below 100 ns, which meets the requirement for phase delivery in G.8271.1
- Consistent results with 3’ coax





Tests Result

Interval (sec)	Result (ns)	Mask Stat	Margin Stat
0.1	N/A	N/A	N/A
0.2	N/A	N/A	N/A
0.5	N/A	N/A	N/A
1	24	N/A	N/A
2	40	OK	OK
5	44	OK	OK
10	48	OK	OK
20	48	OK	OK
50	56	OK	OK
100	60	OK	OK
200	80	OK	OK
500	88	OK	OK
1000	88	OK	OK
2000	88	OK	OK
5000	N/A	N/A	N/A
10000	N/A	N/A	N/A
20000	N/A	N/A	N/A
50000	N/A	N/A	N/A
100000	N/A	N/A	N/A

Results Summary

- Similar results were seen when using Remote PHY or traditional CMTS (DAA vs. CAA).
- Time transfer stability (Jitter) between the CMTS and CM (DTP) was < ±30 ns.
- Time transfer stability after RPD/CM reset was < 50 ns.
- After DTP calibration between RPD/CMTS - CM and network Asymmetry compensation at the RPD/CMTS, the end to end |TE| over DOCSIS was < 100 ns and MTIE < 100 ns.
- Results are within the MBH Sync Spec requirements (300-650 ns depending on DAA vs. CAA & class A vs. Class B devices).

Challenges

- There are conflict requirements between Mobile and DOCSIS that need to mitigated (for example):
  - DOCSIS frequency change limit of 10 ppb/s might influence the filter BW and affect compliance to G.8273.2
  - Phase steps are not allowed in DOCSIS, how to fix (relatively) large phase offsets quickly?
  - For RPHY use cases, how to support 2 different timing “applications” (R-PHY & Mobile) with different phase/frequency lock thresholds and limitations?

Conclusion

- The HFC network is a good candidate for backhauling (or even fronthauling) 5G
- Sync delivery can meet the 100-200 ns TE.
- Lab trials and field trials are planned for 2021 with multiple operators

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THANK YOU

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