# LTE-FDD and APTS support over Existing Cable Networks

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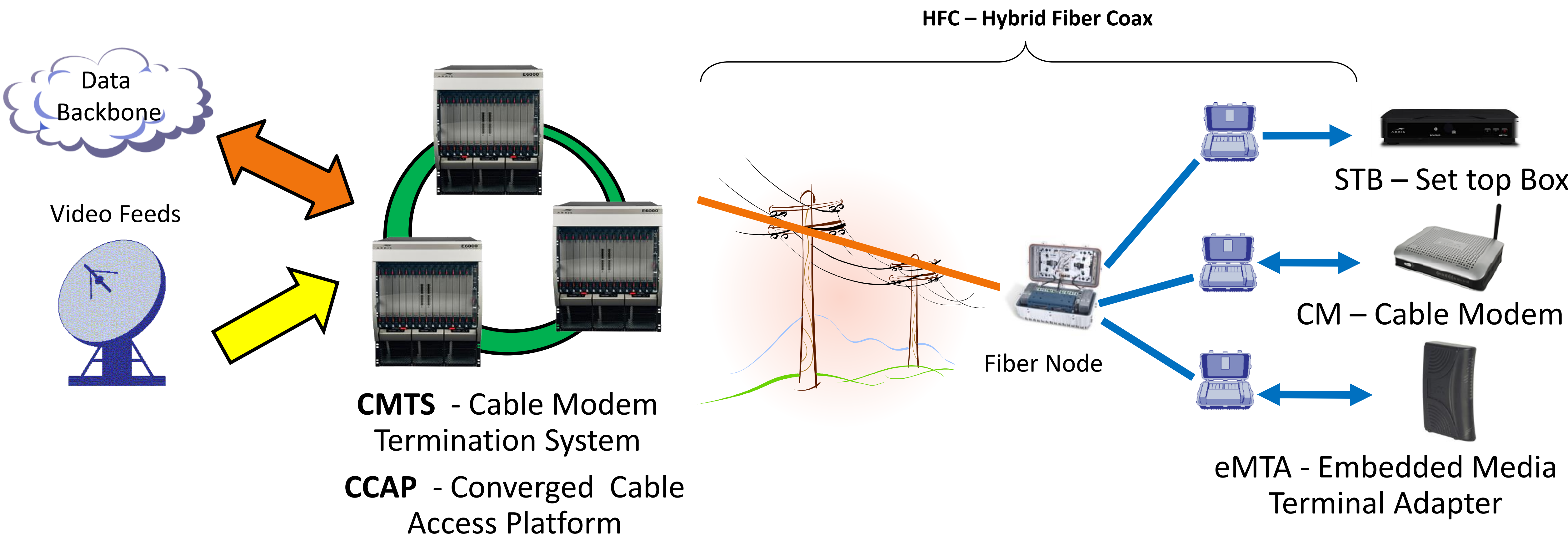
# Outline

- Mobile Backhaul Support through Cable Networks
- LTE-FDD /APTS frequency requirements
- Lab results for Frequency delivery
- Summary

# Cable Network Topology

- The HFC network provides the communications link between the CMTS/CCAP and the stations, STBs,  CMs and eMTAs.
- HFC plant consists of up to ~160 km of optical fiber, few hundred meters of coaxial cable, RF distributions and Amplifiers.

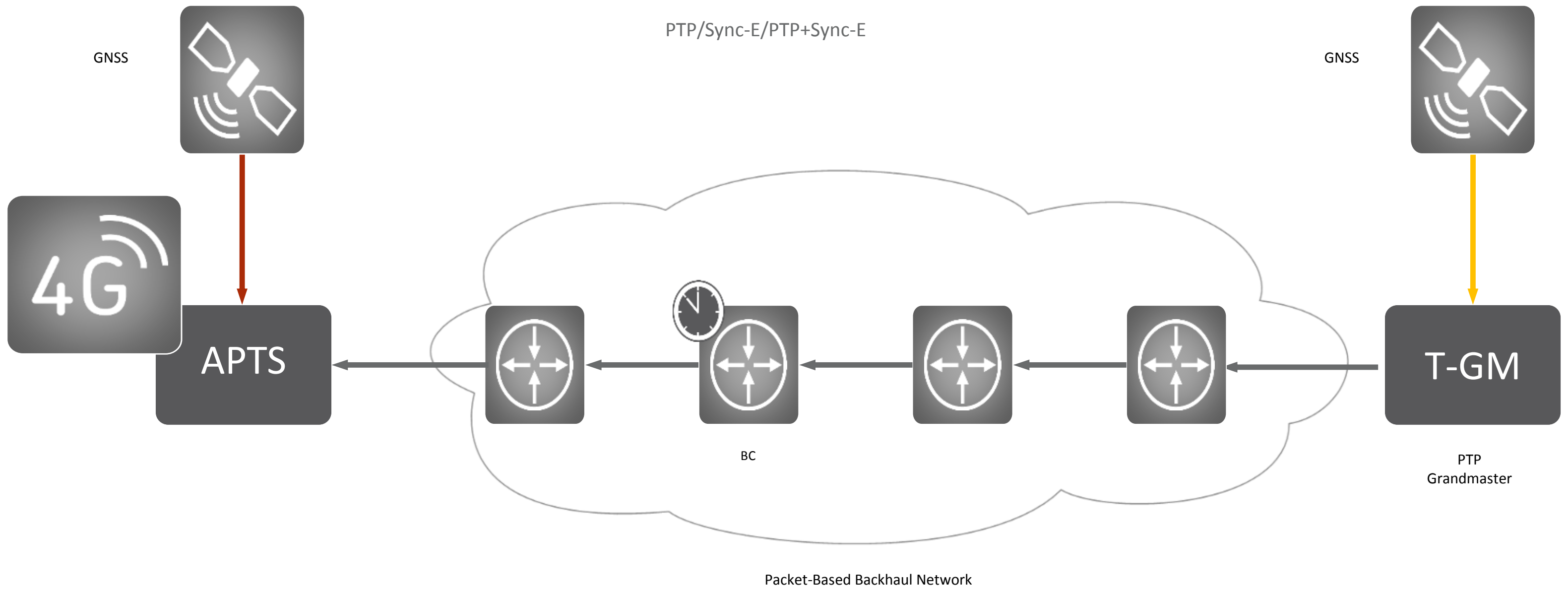


# Cellular Backhaul and DOCSIS

- Cellular Backhaul support through DOCSIS network is an opportunity for supporting femtocell, picocell, microcell and macrocells
- DOCSIS presents many challenges in order to support precise Timing delivery:
  - Asymmetry due the nature of DOCSIS upstream scheduling and HFC plant
  - Jitter (PDV) due to the Upstream Scheduling
  - Unknown delays and asymmetries in the CMTS and CM PHYs
- DOCSIS typical round trip latency of 5-10 ms poses challenge on eNodeB communication (might be reduced with special service flow implementations)
- New CableLabs WG has been established (Aug 2017) to work on the needed requirements for DOCSIS to support precise timing delivery for MBH.

# Potential Use Cases

- 3G/4G LTE FDD  - Frequency delivery
- 4G TDD/LTE-A  - APTS (Assisted Partial Timing Support) backup to local GNSS – use of frequency/calibrated phase recovered from PTP in case of local GNSS outage



# Cellular Backhaul and DOCSIS – Frequency

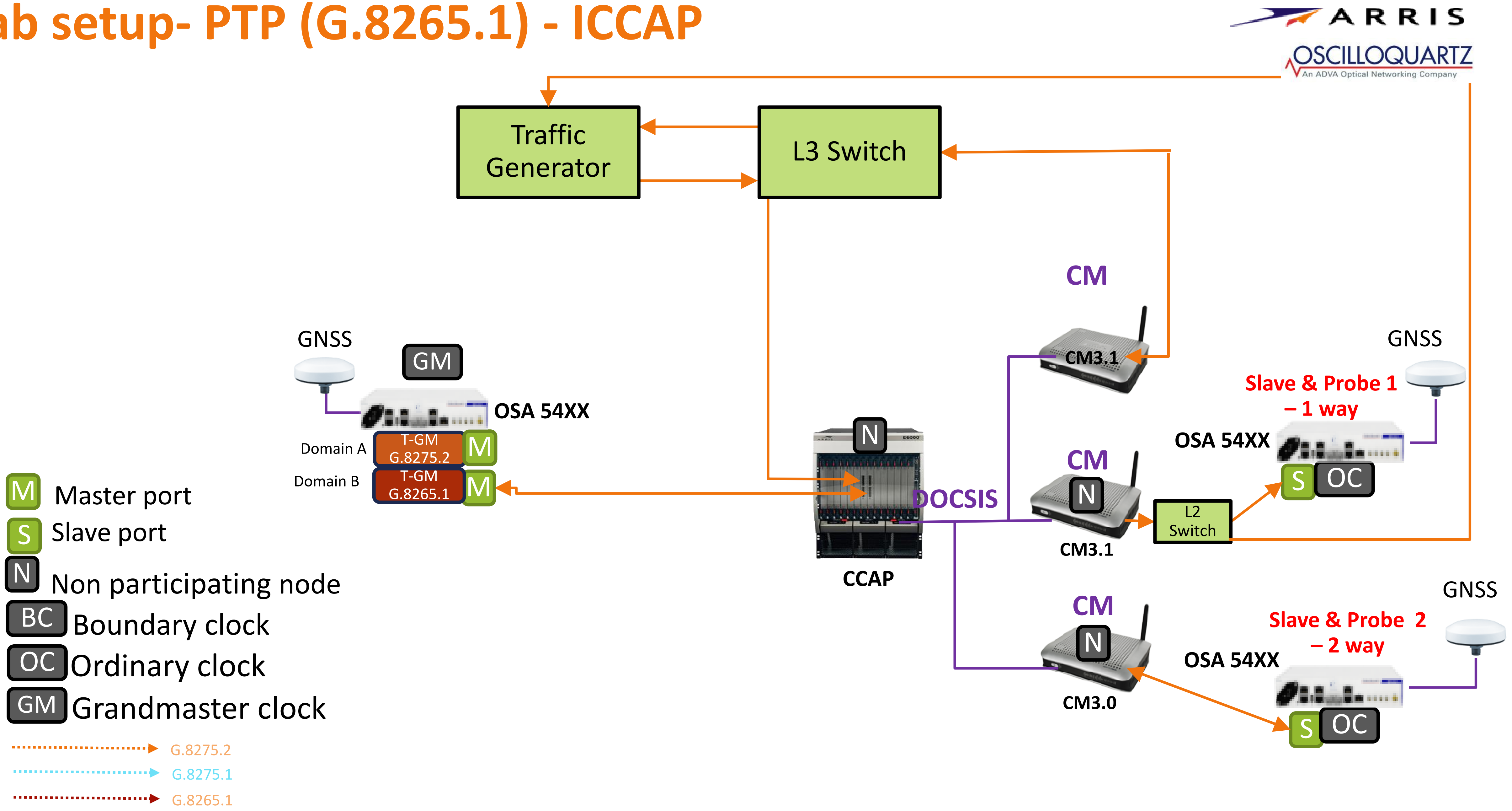
- While phase delivery over DOCSIS is a big challenge due to high asymmetry , the ability of supporting Frequency delivery should be considered.

Performance subject to PDV

Performance subject to PDV and Asymmetry

| Application | Radio Interface | | Backhaul | |
|---|---|---|---|---|
| | Frequency | Phase | Frequency | Phase |
| CDMA 2000 | ±50ppb | ±3 to 10µs | GPS | GPS |
| GSM/WCDMA | ±50ppb | n/a | ±16ppb | n/a |
| LTE (FDD) | ±50ppb | n/a | ±16ppb | n/a |
| LTE (TDD) (large cell) | ±50ppb | ±5µs | ±16ppb | ±1.1µs |
| LTE (TDD) (small cell) | ±50ppb | ±1.5µs | ±16ppb | ±1.1µs |
| LTE-A MBSFN | ±50ppb | ±1 to 5µs | ±16ppb | ±1.1µs |
| LTE-A CoMP* | ±50ppb | ±500nsec to 5µs | ±16ppb | 500ns - ±1.1µs |
| LTE-A eICIC* | ±50ppb | ±1 to 5µs | ±16ppb | ±1.1µs |

# Lab setup- PTP (G.8265.1) - ICCAP



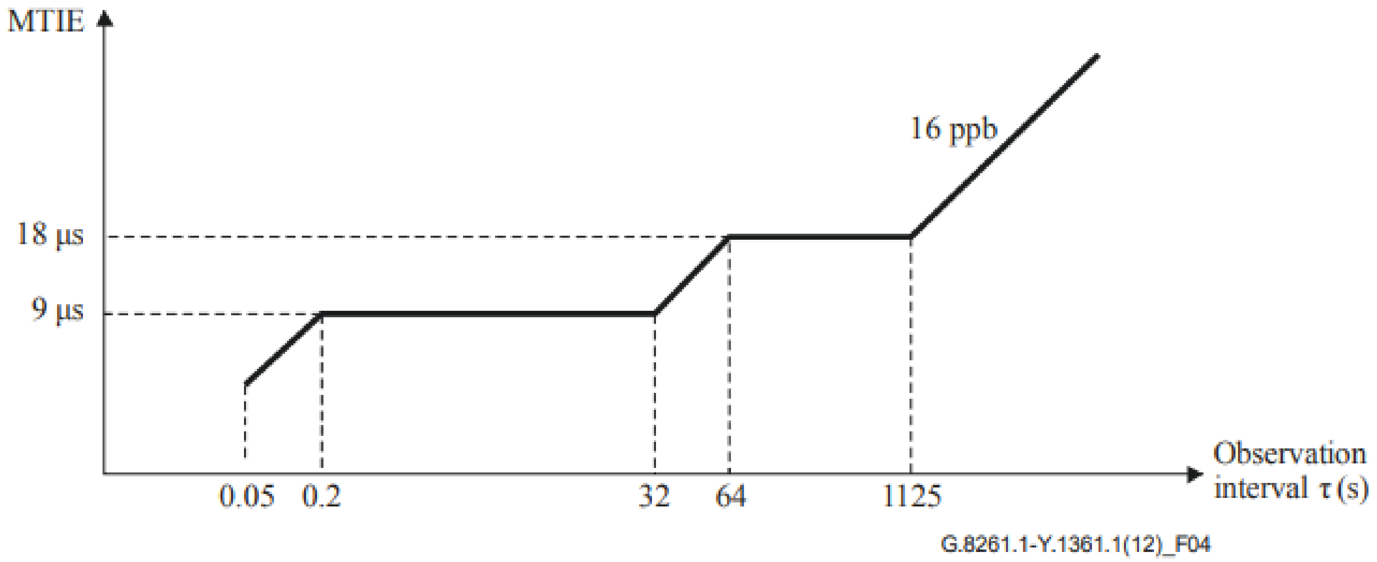
# Setup/test description

- PTP setup:
  - G.8265.1/G.8275.2 GM (GPS synced) was connected directly to the CMTS.
  - 64 sync/delay msg/sec.
  - 2 slaves were connected to two different CMs.
  - One slave was configured as a 1-way slave (frequency lock oriented using only sync messages from GM). No 1588 timing messages are sent on the US (except negotiation).
  - One slave was configured as a 2-way slave (Both DS and US are used for 1588 timing messages) – recover both frequency and phase .
  - 1588 packets were configured with DSCP value of 46
  - Tested in none assisted mode – GNSS was only used for measurement not for asymmetry calibration

- DOCSIS Setup:
  - 8x4 channel bonding was used for 3.0 CM (~250 Mbps DS & 125 Mbps US)
  - OFDM DS for 3.1 CM.
  - Traffic generator was used to load DS and US channels via a separate CM connected to the same US/DS channels (UDP traffic with various packet lengths).
  - Different load scenarios on US and DS (0% → over subscription scenarios).
  - A high priority DOCSIS service flow was configured for UDP ports 319 (1588 event packets).

# Setup/test description

- Both slaves were connected to a GPS and were comparing PTP slave lock to GPS for frequency and phase.
- Results were compared to ITU-T G.8261.1 network limits for frequency delivery (+/-16 ppb)
- Tests were run for 24H at least.



# Test results: 1-way Clock (8x4 SC-QAM)

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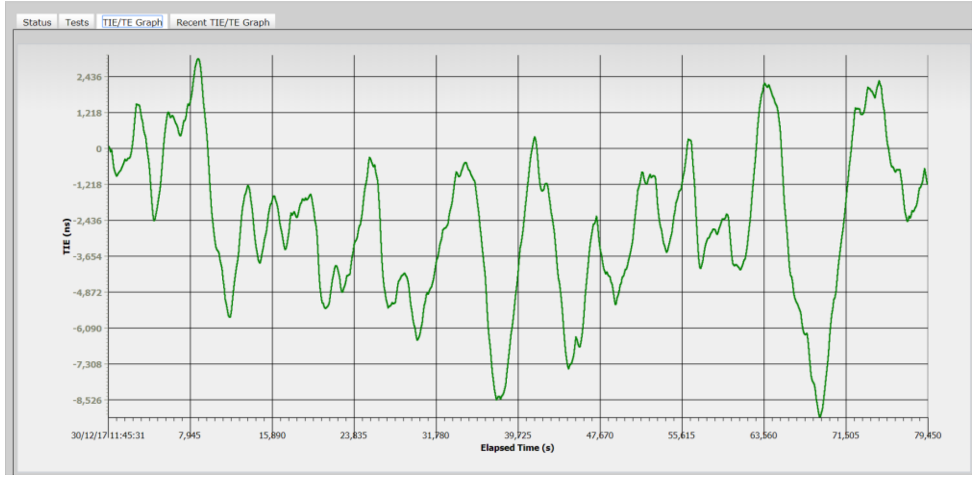
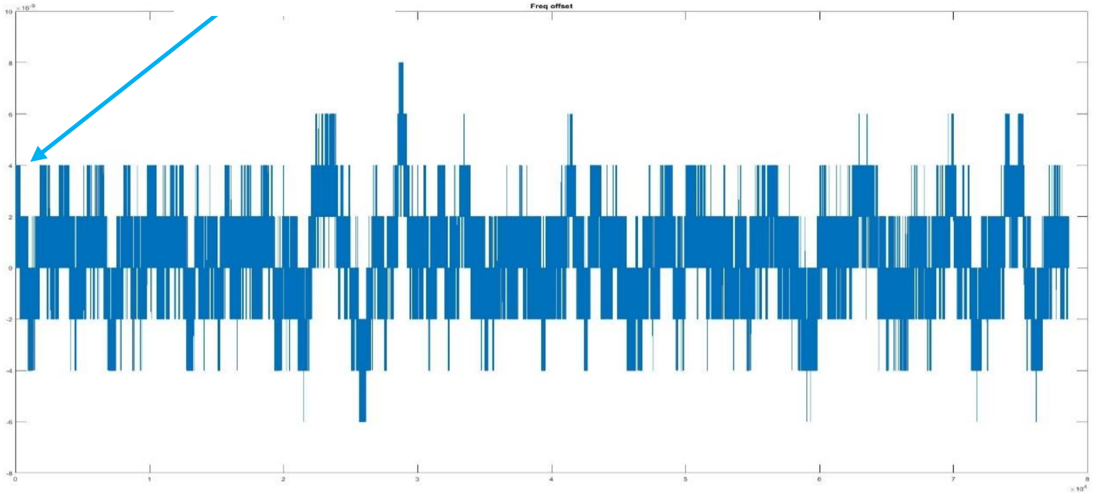
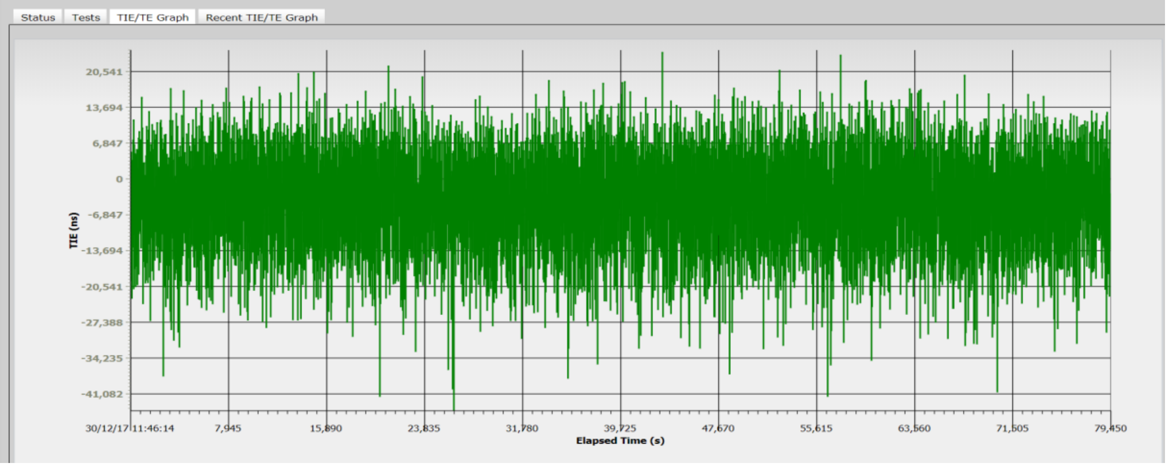
Output Clock TIE and derived FFO




4 PPB




PTP PDV (20-50 usec peak to peak)



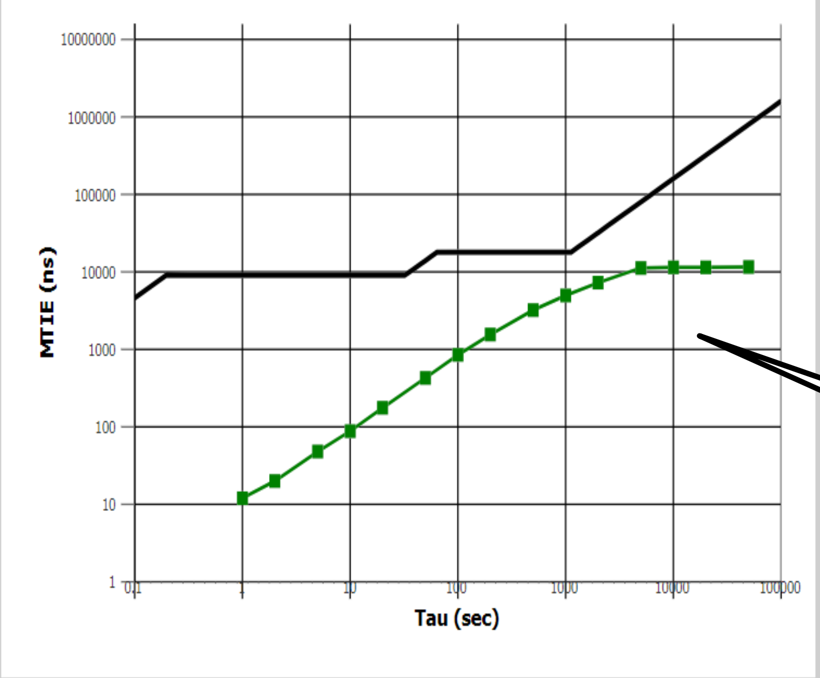

Note: “ lucky packets” in each 4 sec window are displayed

# Test results: 1-way Clock (8x4 SC-QAM)

- G.8261.1 MTIE mask

Status | Tests | TIE/TE Graph | Recent TIE/TE Graph

Export



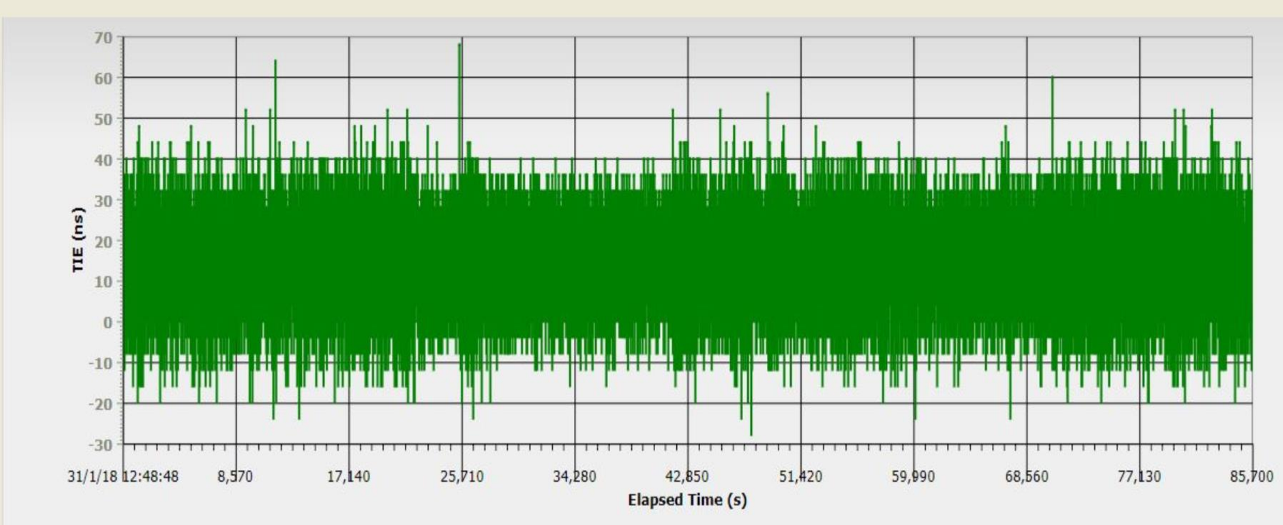

**Tests Result**

| 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 | 12 | OK | OK |
| 2 | 20 | OK | OK |
| 5 | 48 | OK | OK |
| 10 | 88 | OK | OK |
| 20 | 176 | OK | OK |
| 50 | 428 | OK | OK |
| 100 | 848 | OK | OK |
| 200 | 1556 | OK | OK |
| 500 | 3216 | OK | OK |
| [illegible] | 4968 | OK | OK |
| [illegible] | 7244 | OK | OK |
| 5000 | [illegible] | OK | OK |
| 10000 | [illegible] | OK | OK |
| 20000 | 11412 | [illegible] | OK |
| 50000 | 11588 | [illegible] | OK |
| 100000 | N/A | N/A | [illegible] |

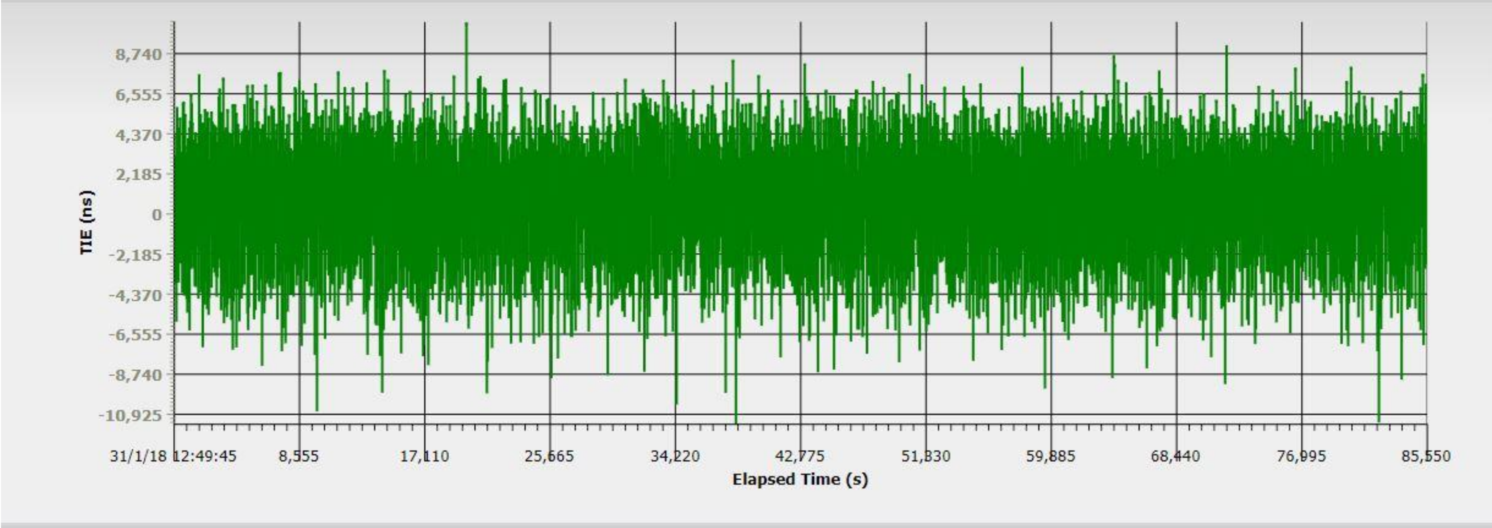
Sufficient for FDD BS , but not for APTS

# Test results: 1-way Clock (OFDM)

Output Clock TIE



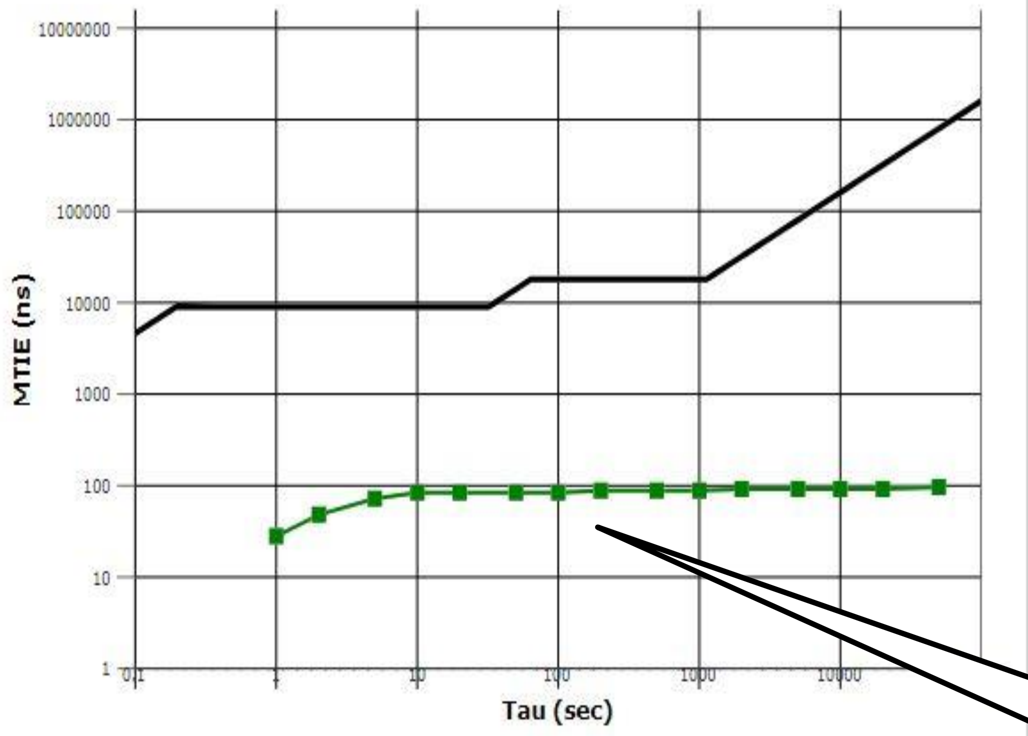

PTP PDV (5-10 usec peak to peak)




Note: " lucky packets" in each 4 sec window are displayed

# Test results: 1-way Clock (OFDM)

- G.8261.1 MTIE mask




**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 | 28 | OK | OK |
| 2 | 48 | OK | OK |
| 5 | 72 | OK | OK |
| 10 | 84 | OK | OK |
| 20 | 84 | OK | OK |
| 50 | 84 | OK | OK |
| 100 | 84 | OK | OK |
| 200 | 88 | OK | OK |
| 500 | 88 | OK | OK |
| 1000 | 88 | OK | OK |
| 2000 | 92 | OK | OK |
| 5000 | 92 | OK | OK |
| 10000 | 92 | OK | OK |
| 20000 | 92 | OK | OK |
| 50000 | 96 | OK | OK |
| 100000 | N/A | N/A | N/A |

**Identification**

**Entity ID:** CLOCK PROBE-1-1 **Name:** ClockProbe1

Good frequency stability which can be used in APTS

# Test results: 2-way Clock

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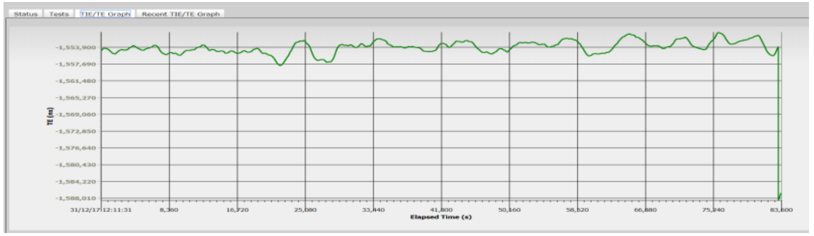
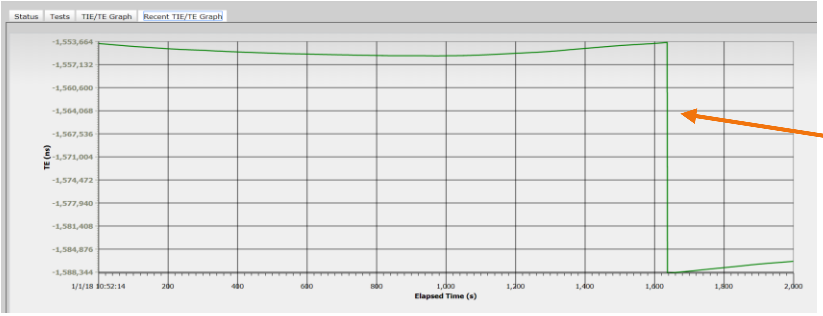
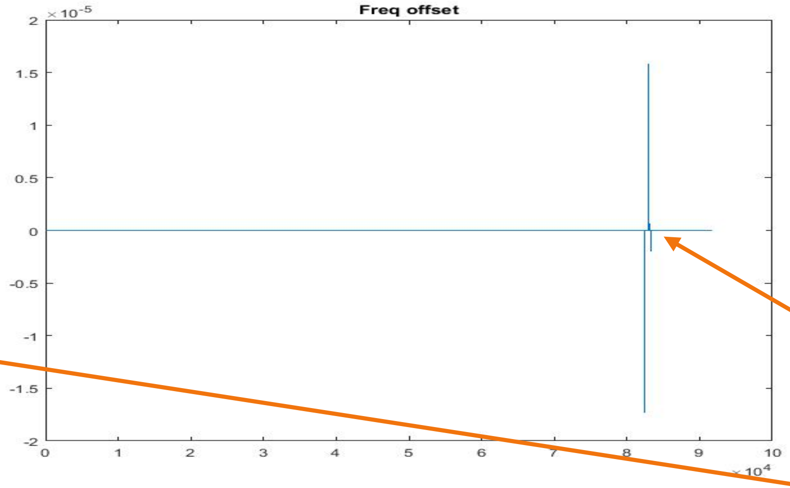
Output Clock TE and derived FFO

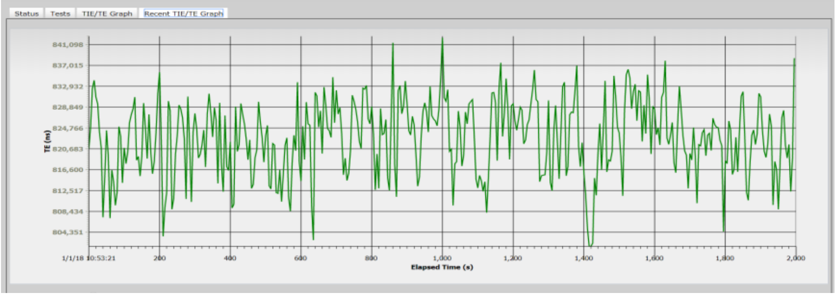







US BR Change

PTP packet delays DS



PTP packet delays US

Note: “ lucky packets” in each 4 sec window are displayed

# Test results: 2-way Clock

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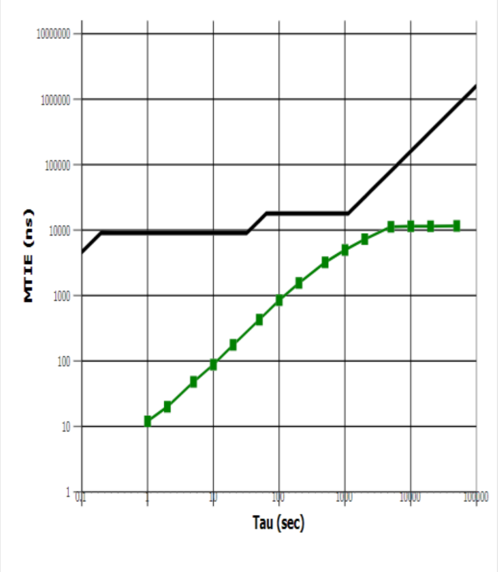
- G.8261.1 MTIE mask

Status | Tests | TIE/TE Graph | Recent TIE/TE Graph

Export



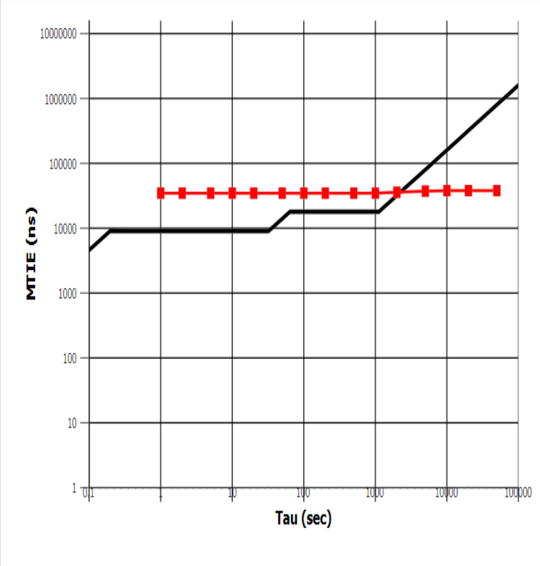

Tests Result

| 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 | 12 | OK | OK |
| 2 | 20 | OK | OK |
| 5 | 48 | OK | OK |
| 10 | 88 | OK | OK |
| 20 | 176 | OK | OK |
| 50 | 428 | OK | OK |
| 100 | 848 | OK | OK |
| 200 | 1556 | OK | OK |
| 500 | 3216 | OK | OK |
| 1000 | 4968 | OK | OK |
| 2000 | 7244 | OK | OK |
| 5000 | 11272 | OK | OK |
| 10000 | 11412 | OK | OK |
| 20000 | 11412 | OK | OK |
| 50000 | 11588 | OK | OK |
| 100000 | N/A | N/A | N/A |

US BR Change →

Status | Tests | TIE/TE Graph | Recent TIE/TE Graph

Export




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 | 34676 | Fail | Fail |
| 2 | 34676 | Fail | Fail |
| 5 | 34676 | Fail | Fail |
| 10 | 34676 | Fail | Fail |
| 20 | 34676 | Fail | Fail |
| 50 | 34676 | Fail | Fail |
| 100 | 34676 | Fail | Fail |
| 200 | 34676 | Fail | Fail |
| 500 | 34676 | Fail | Fail |
| 1000 | 34676 | Fail | Fail |
| 2000 | 35872 | Fail | Fail |
| 5000 | 37264 | OK | OK |
| 10000 | 37892 | OK | OK |
| 20000 | 37892 | OK | OK |
| 50000 | 37892 | OK | OK |
| 100000 | N/A | N/A | N/A |

# Test results

- Both slaves manage to lock properly on frequency within 30-45 minutes.
- 2-way slave locks on frequency faster than the 1-way slave (probably due to the use of both sync and delay timestamps).
- Both slaves pass the MTIE (Max time Interval Error) mask defined in ITU-T G.8261.1
- The 2-way slave manages to lock on phase after a long time… as expected the phase error is > 1.5 ms. Mostly due to US/DS Asymmetry with > 100 microsec of PDV.
- The 2-way slave is sensitive to phase changes caused by dynamic changes in DOCSIS asymmetry. Changes in US load causes changes in US delays (and overall asymmetry) and thus will cause the slave to adjust phase and frequency and as a result fail the G.8261.1 MTIE mask.
- 1-way slave is not affected by changes to US/DS loads (when high priority service flows are configured for 1588 packets).
- 1-way slave can be supported over DOCSIS 3.0 (bonded SC-QAM) and DOCSIS 3.1 (OFDM). DOCSIS 3.1 OFDM provides better results

# Summary

- With required optimization , delivery of frequency over DOCSIS 3.0 (bonded SC-QAM) and DOCSIS 3.1 (OFDM) using PTP  was able to meet G.8261 network limits.
- DOCSIS  modulation , PTP mode of operation and slave clock recovery algorithm quality are key factors.
- The use DOCSIS 3.1 OFDM significantly improves the results and provide safe margins and can be used for both use cases (frequency only  and APTS)
- Future work is planed towards  testing and quality  of phase which can be delivered over DOCSIS 3.1 in GNSS assisted and none assisted modes

# Thank You!

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