# Tales from the Base Station to the Substation

Delivering Phase
ITSF 2013

# Phase delivery in Telecom Networks

- Telecom LTE networks rely on accurate phase synchronization
  - Efficient and reliable use of spectrum
  - Hand-over
- Accuracy Requirements
  - LTE-TDD, Large-Cell, Small Cell
    - 1.5μs to 5.0μs phase synchronization application requirement
  - LTE-Advanced
    - <1.0μs phase synchronization application requirement

- SmartGrid networks rely on phase & time synchronization
  - Substation automation for efficient and reliable delivery of power
  - Reporting and auditing compliance
- Accuracy Requirements
  - C37.238 defines 1µs **absolute time** and phase synchronization over the network
  - Power Profile
    - Multicast
    - Peer-to-peer
    - Message rate: 1/sec
      - 1% FPP means only two min-delay pkts over 200 seconds which could arrive together

# Methods of Phase Synchronization

## GNSS deployed at each node

- Provides UTC traceable Time and Phase at every node within +/- 100 ns
  - No cumulative error effect; each node is independently synchronized
- Expensive solution with limited scalability
- Not possible in every deployment
  - e.g., micro cell, HetNet, urban canyon

## PTP for synchronization

- Unlikely to meet required phase synchronization for power profile, LTE-Advanced or LTE TDD without partial on-path support or strict limit of hops
- Delay asymmetry is a major problem
- BCs and TCs solve the problems in different ways; one solution is not always ideal
- Addition of SyncE can improve PTP synchronization

## GNSS + PTP

- GNSS deployed at strategic locations, PTP used to extend reach or as backup to GNSS, mitigates weaknesses in GNSS and PTP

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# Time Error Budgets

## ITU-T G.8271.1 suggests ± 1.5 µs total Time Error budget

- **50 ns** per node asymmetry over 11 hops
- **18 ns** per hop over 11 hops of Dynamic Time Error (uncorrected timestamp error)
- ~1/3 of total budget assigned to network equipment inaccuracy

| Budget Component | TE Budget |
|---|---|
| PRTC / T-GM | ± 100 ns |
| Random Network Variation | ± 200 ns |
| Node Asymmetry, 11 nodes | ± 550ns |
| Fiber Link Asymmetry | ± 250 ns |
| Short Term Holdover | ± 250 ns |
| End Application | ± 150 ns |
| ***Total*** | ***± 1,500 ns*** |

## IEEE C37.238 TE budget < +/-1µs across 16 hops

- 200ns for GM
- 50 ns per PTP network element
- No budget defined for slave

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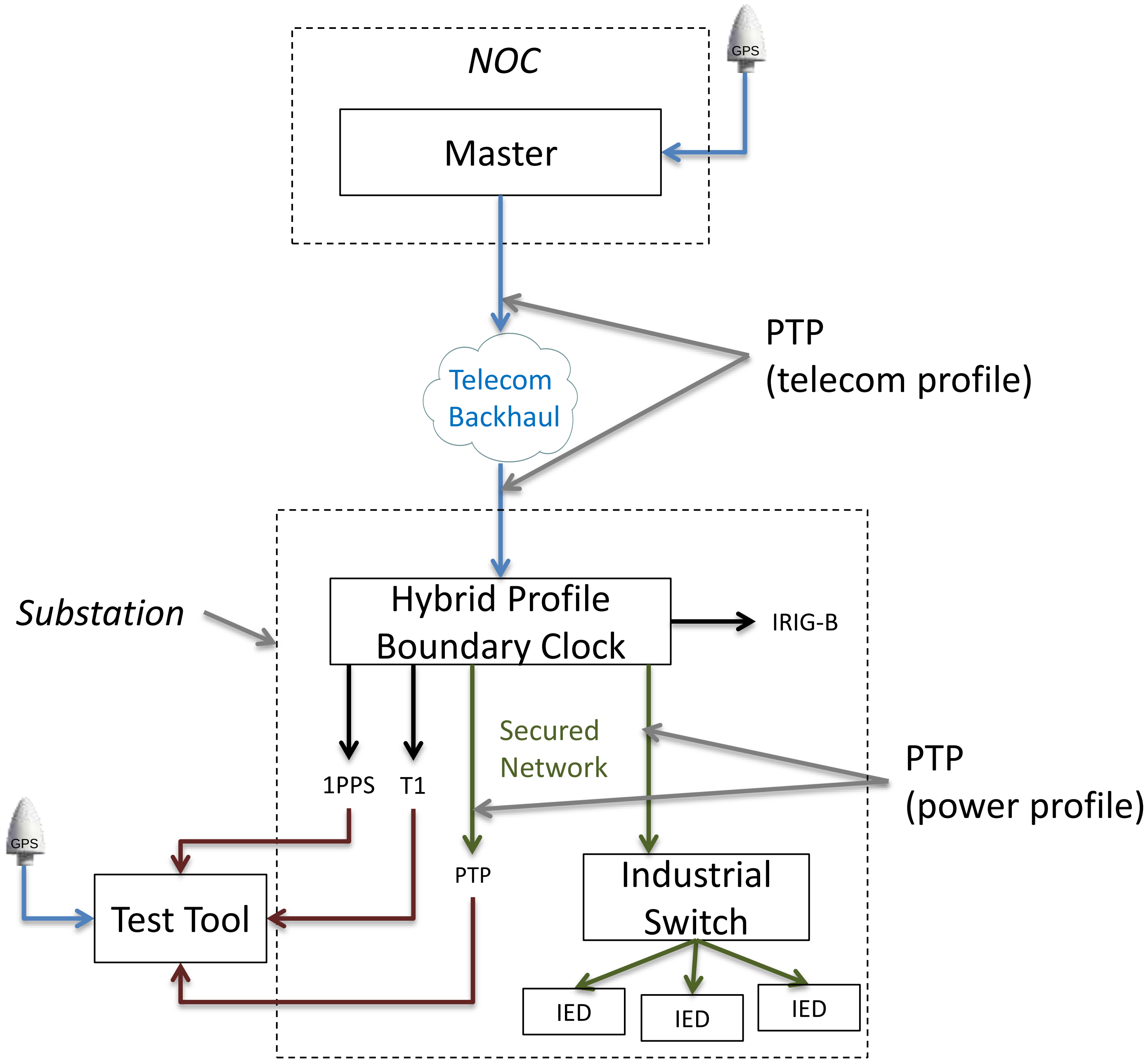
# Large U.S. Power Company

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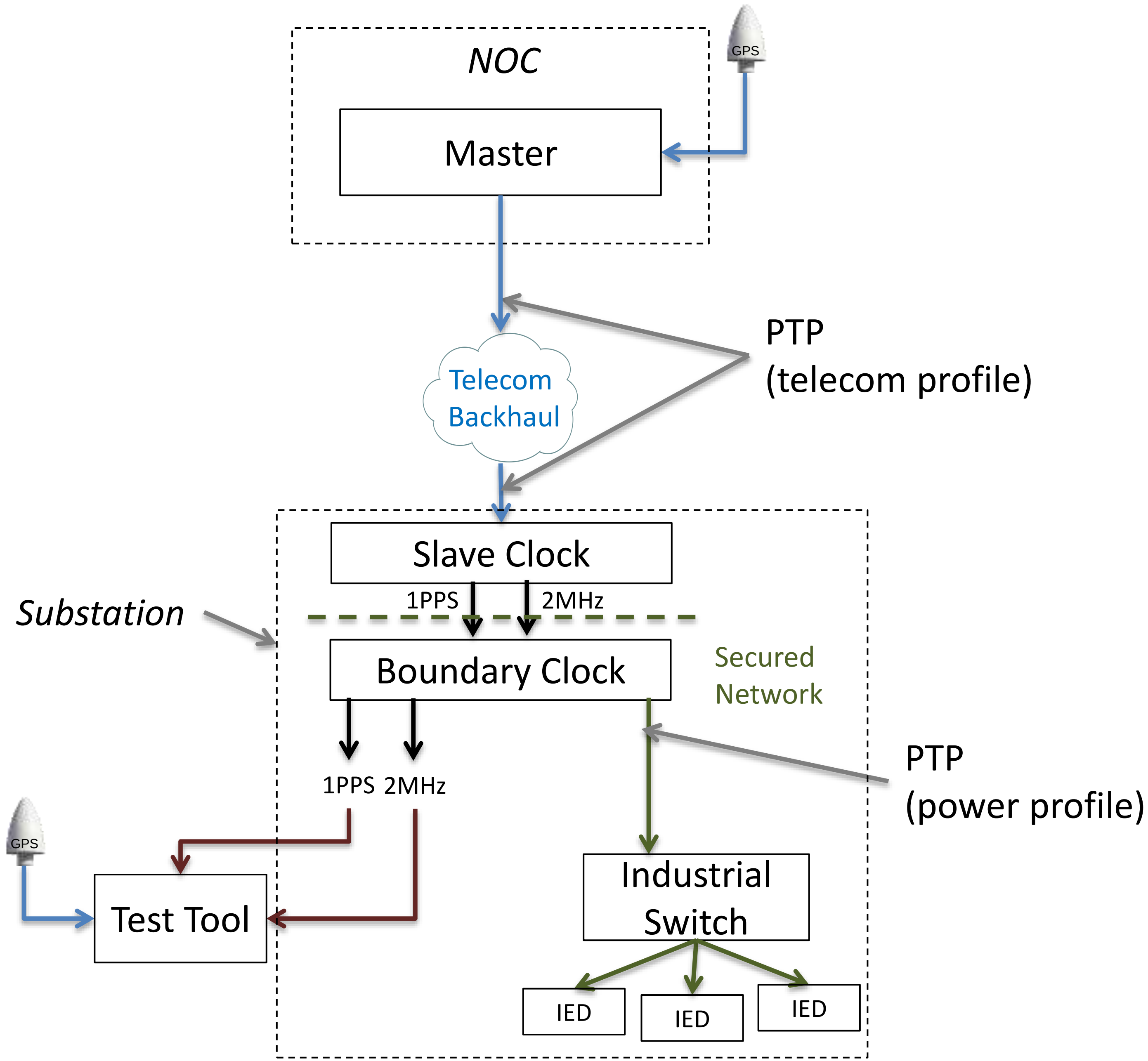
# Large Canadian Power Company



# Impediments to Phase Synchronization

## GNSS

- Unavailability
  - Urban Canyon, HetNet, Stadium/Campus
- Vulnerability
  - Jamming, spoofing

## PTP

- Path & delay asymmetry
  - Dependent on traffic congestion, network design and topology
  - Leads directly to phase error if not corrected
- PDV: Head of line blocking, floor delay
  - Highly traffic dependent
- Timestamp Inaccuracies
  - BC and TC implementation
- Protection Switch events, link failover, dissimilar routing paths

# Phase vs. PTP Timestamp Error

Phase is derived from PTP Timestamps

PTP Timestamp Error

- Measurement of timestamp accuracy at remote site
- Indication of accumulation of error & delay
  - PTP Origin Timestamp inaccuracies
  - Network delays (including asymmetry)
  - Boundary Clock Inaccuracy
  - Transparent Clock Correction Field Error
- Recovered time adjusted using delay request mechanism
  - Assumes symmetric delay

Phase Synchronization **depends** on accurate PTP Timestamps

# PTP Asymmetry

## PTP and Asymmetry

- PTP for frequency only not impacted by asymmetry
- PTP for Time / Phase Transfer not tolerant of asymmetry
- Existing networks can work fine for frequency but fail with time and phase

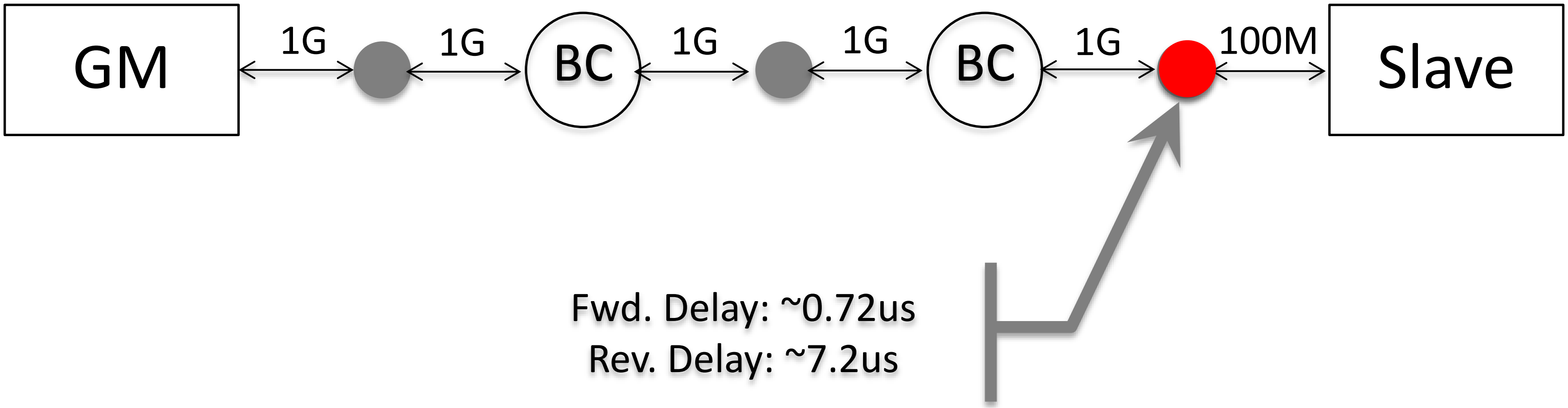
## Asymmetry caused by

- **Rate asymmetry**
  - Different port speed at master & slave
  - Can lead to large asymmetry (**9 µs)**
  - **4.5 µs** of recovered Time/Phase transfer results
- Head-of-line Blocking
  - Causes delay of PTP packet
  - Variable and function of asymmetric traffic congestion and packet sizes
    - More likely congested on downstream link
    - Less likely on upstream link due to decreased congestion

# Rate Asymmetry problem with “partial on-path support”

Asymmetry is caused by link speed differences at PTP-unaware nodes

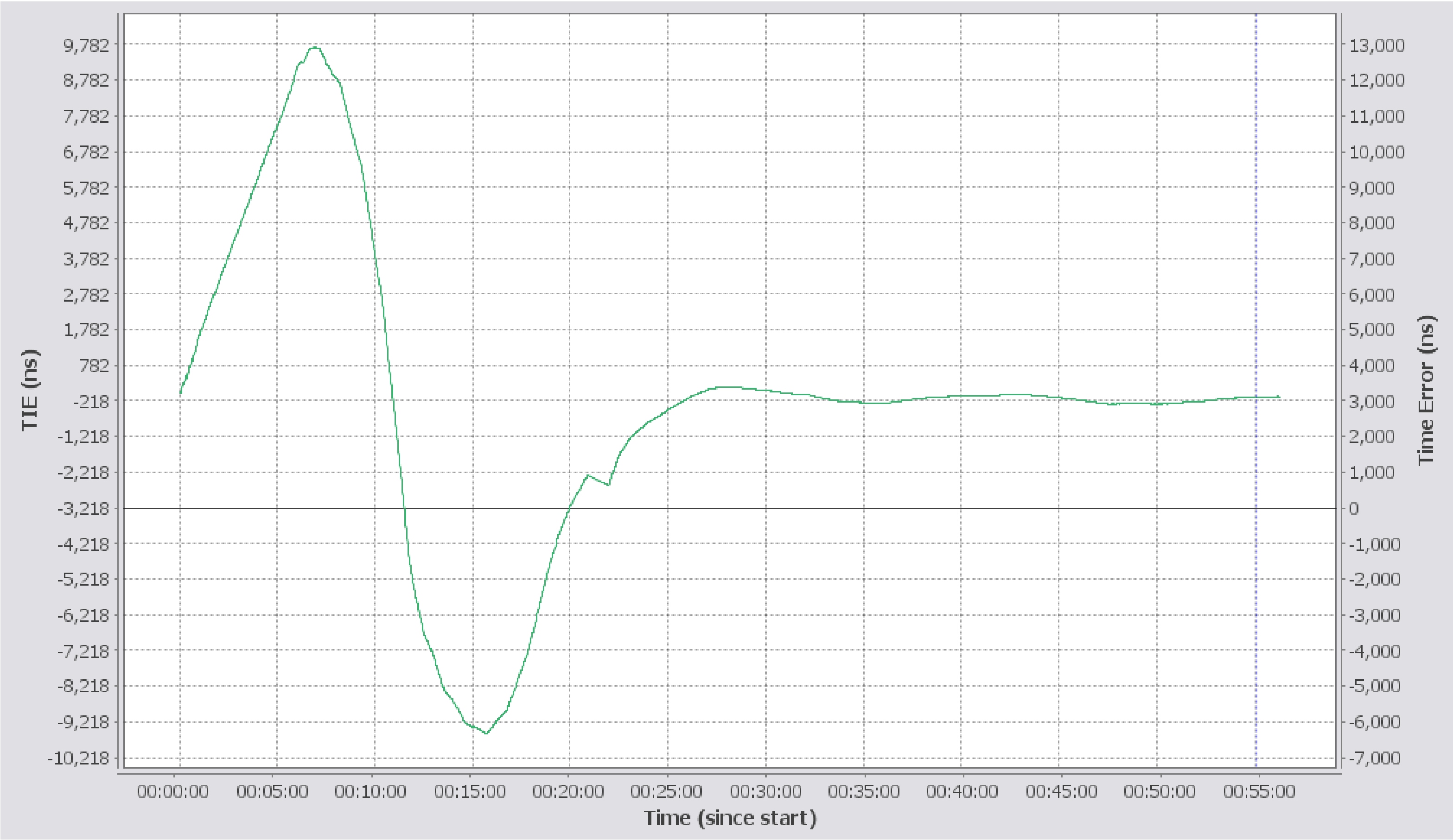
This is a significant issue for delivery of phase
over networks with partial (or no) support for PTP




*~3.24us of phase error at Slave*

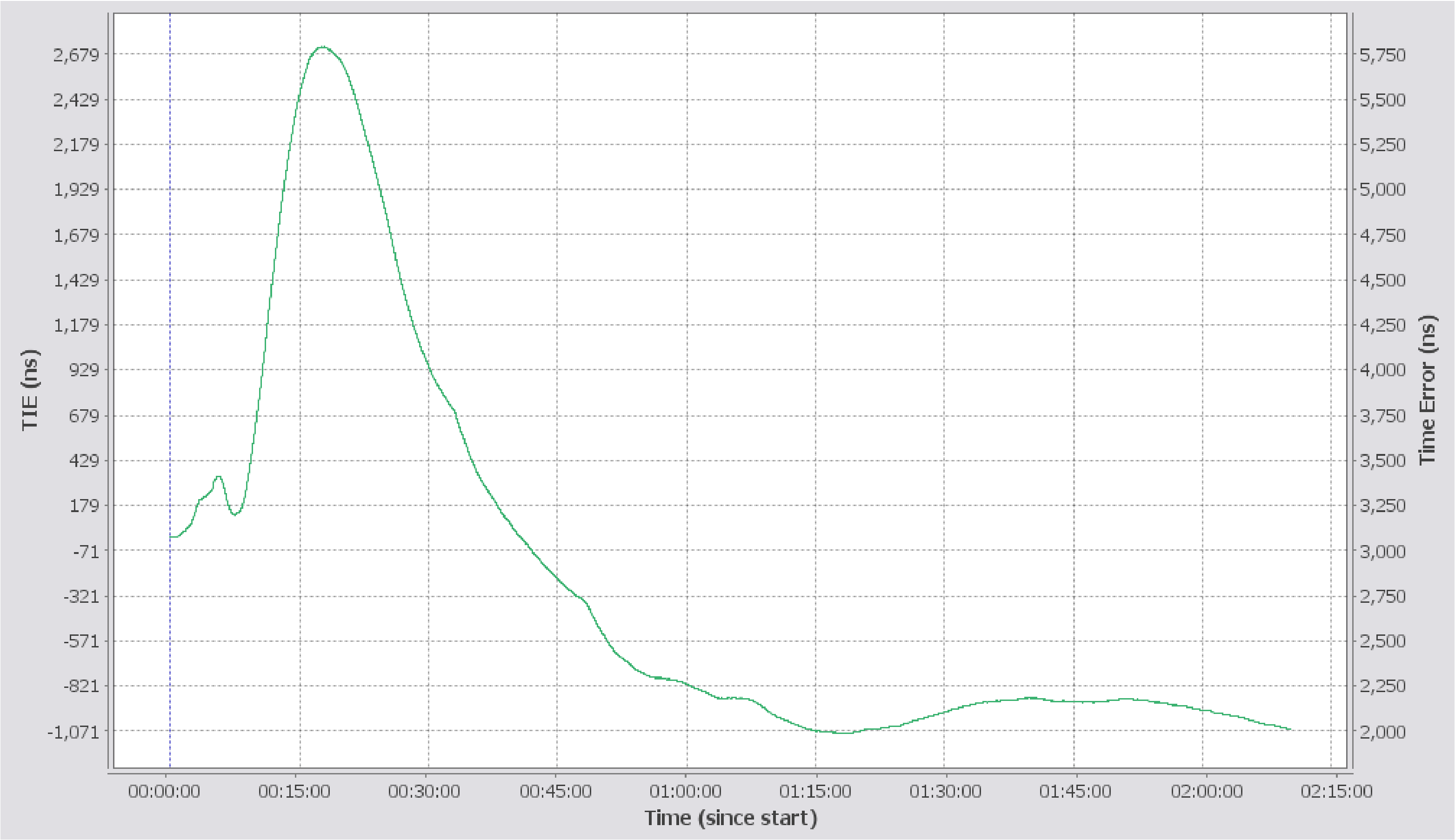
Existing work-arounds are not scalable or interoperable

# Rate asymmetry (1G@Master  & 100M@Slave)




- Rate asymmetry causes TE (e.g. 3.1us error after convergence)
    - Cause: different port speed at master & slave (e.g. 1G master /100M slave)
    - Various solutions exist, but may not be interoperable
        - E.g. pre-program the slave to expect the master to be 1G

# Rate asymmetry combined with CES packet head-of-line blocking ("Beating effect")




- Rate Asymmetry (same as before) + 256B CES traffic
    - Cause: different port speed at master & slave
    - Cause: 256-byte packet asymmetric load impairment on downstream
    - Result: 2.0 μs TE (-1.1 μs caused by CES packets – "beating effect")

# Testing Phase Synchronization

## Testing recovered 1PPS phase directly

- Evaluate recovered 1PPS phase directly by comparing with traceable UTC clock

## Testing Network Elements

- Grand Master Clocks & Boundary Clocks
  - PTP Timestamp Error
  - 1PPS vs. PTP Timestamp Error
- Transparent Clock Accuracy
  - Bidirectional testing essential in identifying asymmetry that can lead directly to phase error

## Testing Networks

- Evaluate ability of network to deliver accurate Time / Phase
  - Assess and Qualify existing networks for next-generation requirements
- Delay Asymmetry
- PDV, load, congestion

## Long-term performance & trends

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# Concluding Thoughts

- Characterize network elements in the lab
- Test production network performance
- Verify PTP slave's ability to recover ToD and phase
- Consider network protection schemes
- GNSS is great but has limits and vulnerabilities
- Don't assume if it is works  now that it will continue to work

Thank You