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5G Synchronization Design, Testing & Deploying Timing

Deploying Timing Across the Transport

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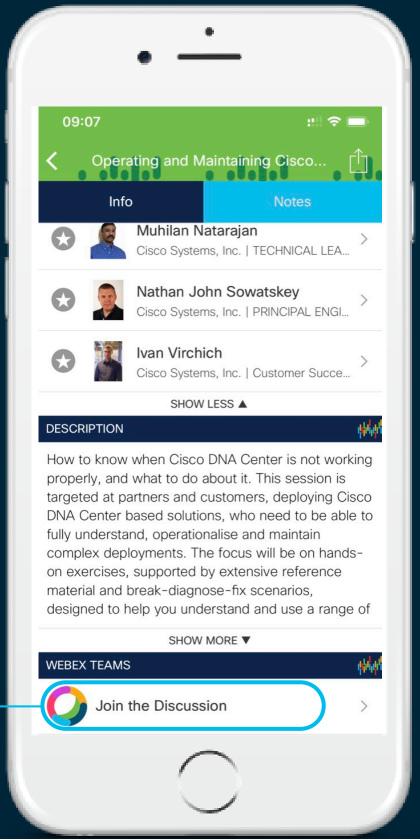
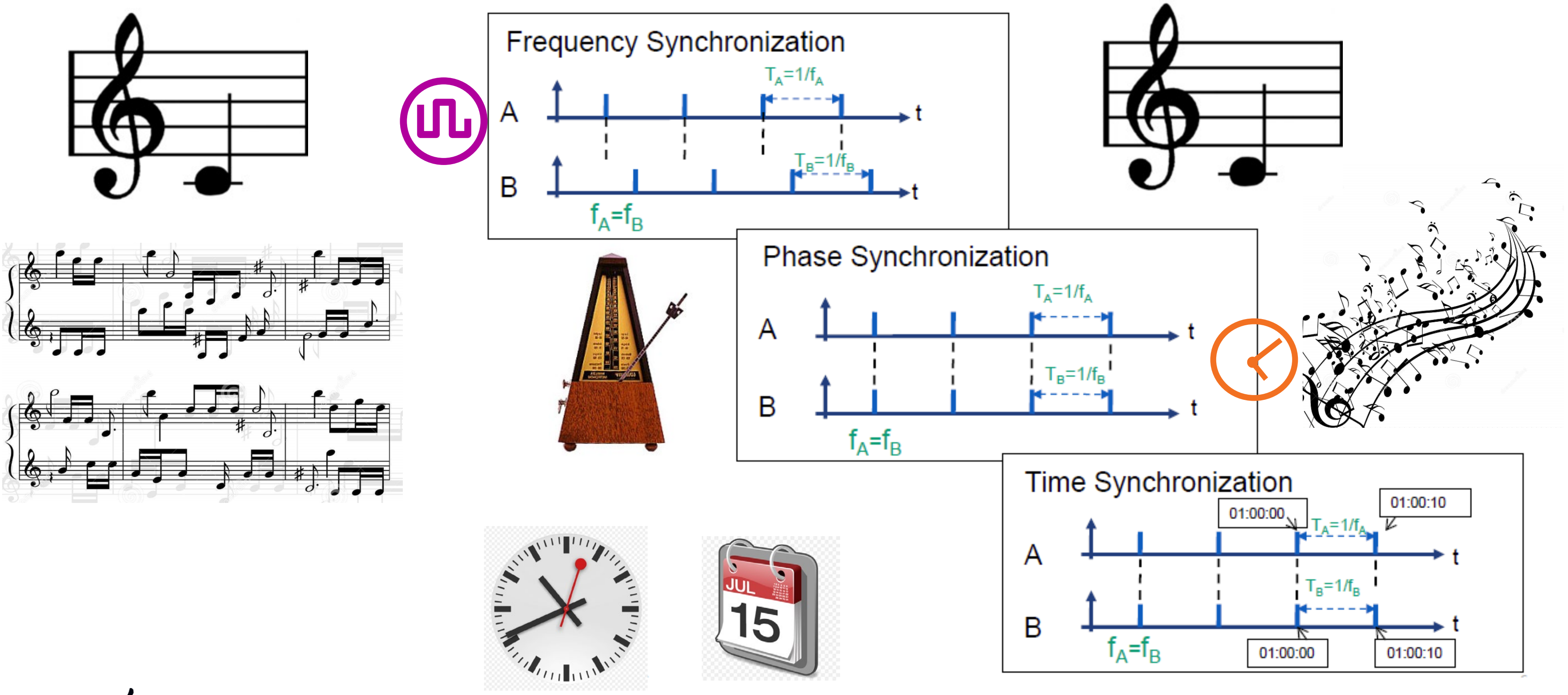


Agenda

- Introduction
- Overview of timing (short)
- 5G? But I need timing and I'm not a mobile operator!
- Timing Deployment Topologies
- Testing Timing
- Deployment Lessons and Traps
- Conclusion and Further Information

Overview of Timing

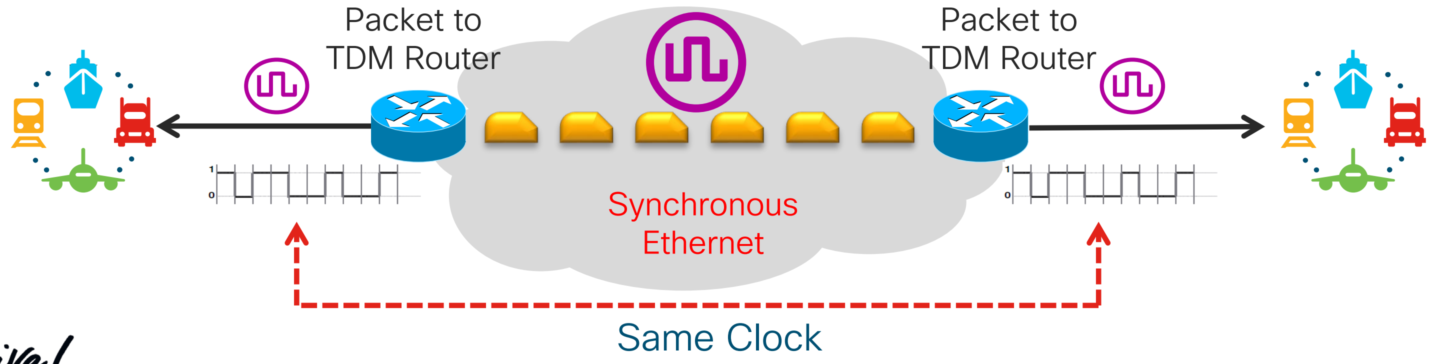
What types of Sync are there?



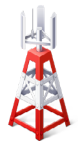
Frequency Synchronization

TDM = Time Division Multiplexing
SONET = Synchronous Optical Network
SDH = Synchronous Digital Hierarchy

- Avoid Slips on TDM Interfaces (E1/T1, ...)
- Make Synchronous networks (SONET/SDH) work
- 2G, 3G, and 4G FDD Cellular Networks – ensure radios transmit exact frequency
- Service Providers, power grids, railways = Circuit Emulation (CEM)
- Carried with Synchronous Ethernet (preferred) or packet transport (PTP)

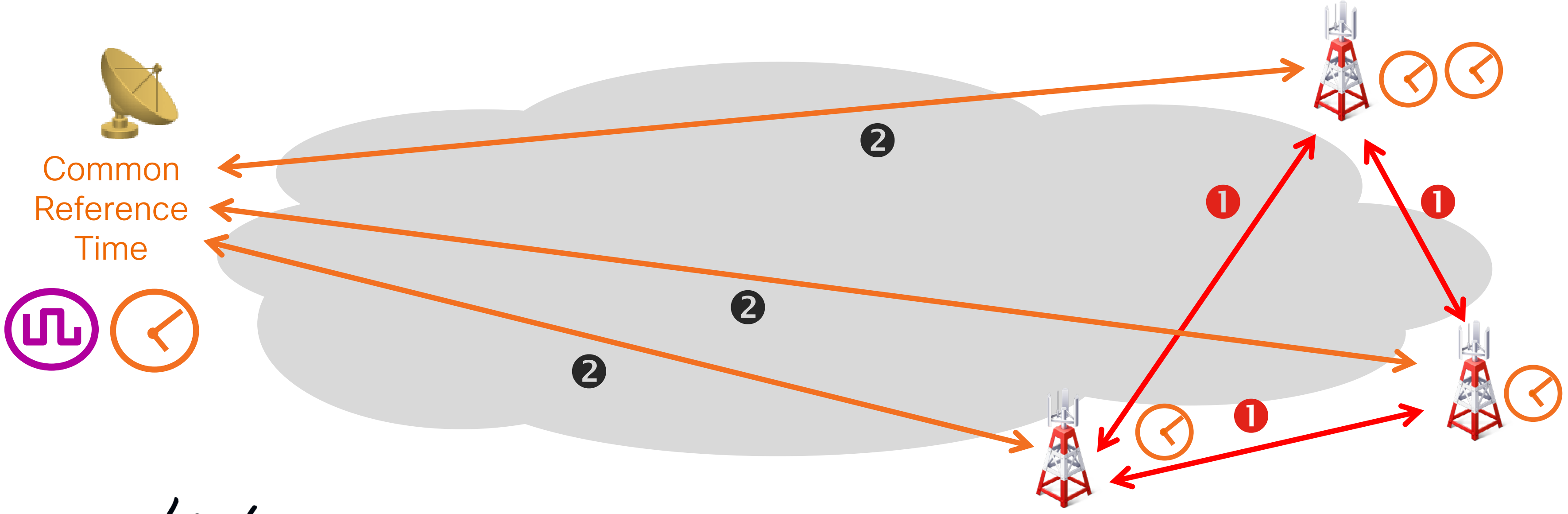


Phase Synchronization



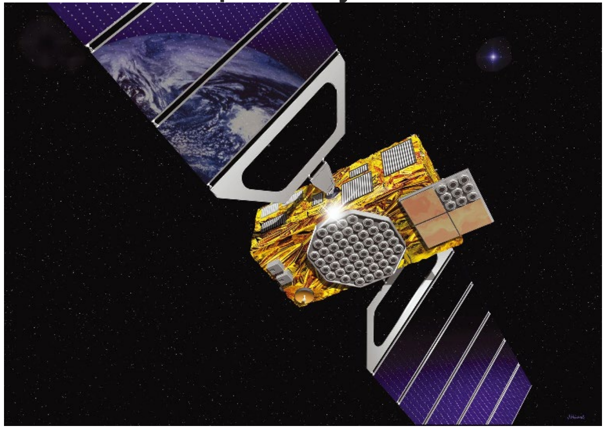
❶ Requirement (TDD, LTE-A radio co-ordination): 3μs between base stations

❷ Implementation: ±1.5μs from a common reference time

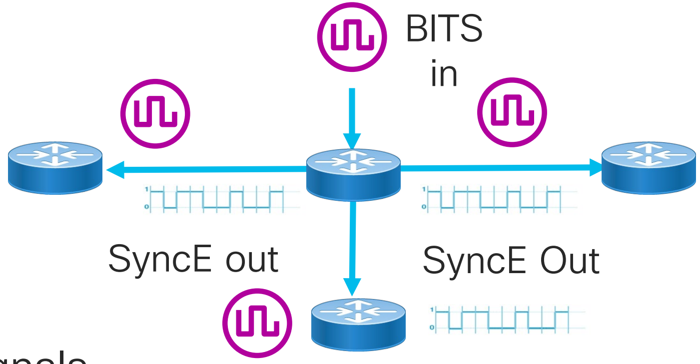


Sources of Time

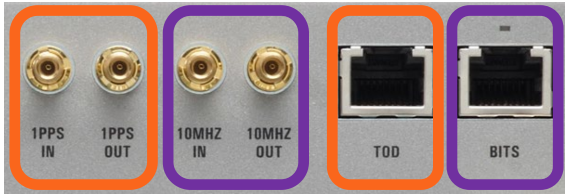
- PRC = Primary Reference Clock = source of Frequency
  - Atomic clocks (yours or those from national labs)
  - GNSS satellite systems (a flying network of atomic clocks)
  - BITS/SSU network (normally sourced from the first two)
- PRTC = Primary Reference Time Clock = phase, time and frequency
  - Atomic clocks PLUS calibration to UTC
  - GNSS satellite systems (GPS, GLONASS, Galileo, ...)
  - Standards for “enhanced” versions:
    - ePRTC (defined in G.8272.1)
    - PRTC-B (defined in G.8272 with PRTC-A)



Distributing Time

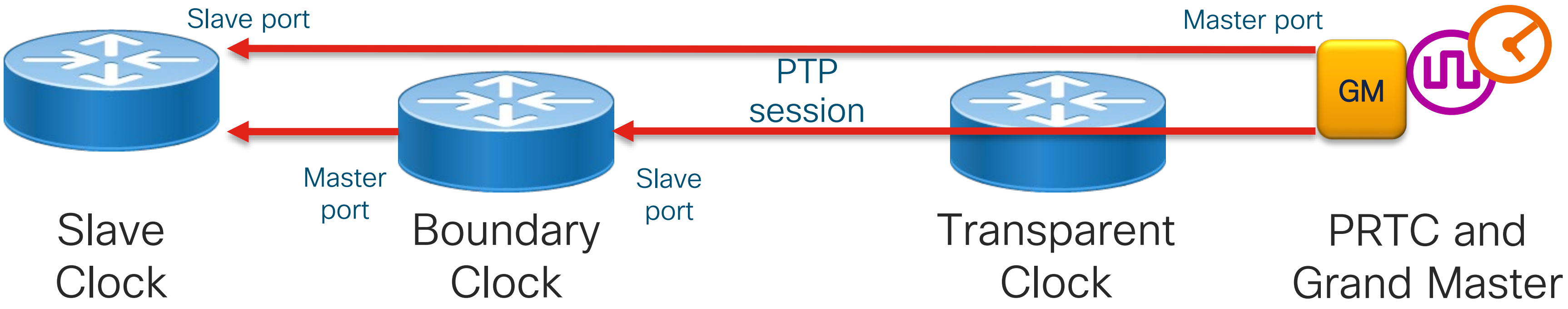


- Frequency
  - SyncE/ESMC (frequency is in the Ethernet signal)
  - BITS/SSU TDM network and 10MHz/2MHz/E1/T1 signals
  - PTPv2 (packet based)
- Phase/Time
  - PTPv2 (packet based)
  - 1PPS (1 Pulse per Second = wires)
  - ToD (RS232/RS422)
  - IRIG-B (physical signal = wires)
  - GNSS systems (also for frequency)

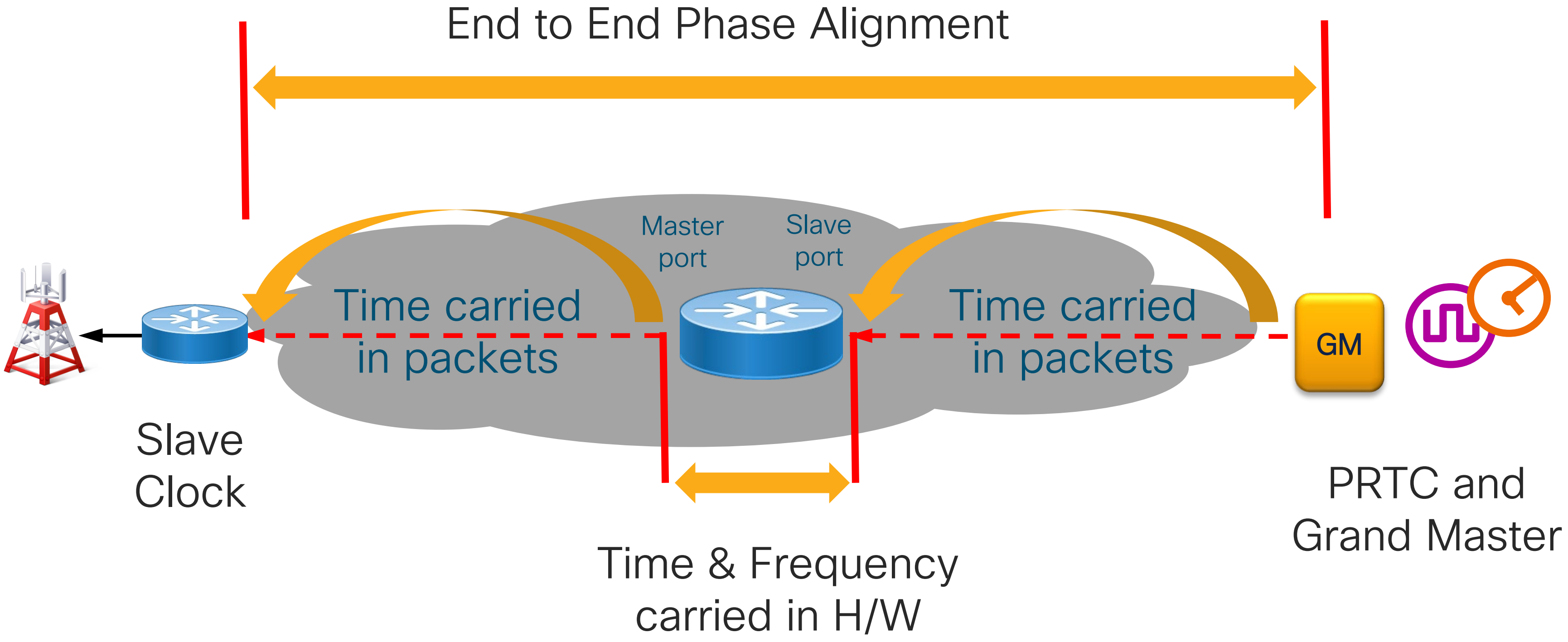


What is PTPv2?

- IEEE 1588-2008 = Precision Time Protocol = PTPv2
- PTP is, like NTP, a Two-Way Time Transfer (TWTT) protocol
  - Designed for sub-microsecond (ns!) accuracy & precision
  - V1 about industrial automation, v2 for WAN (i.e. IP) deployment and extensibility
  - A new version of PTP (V2.1) is (still) under development by IEEE. 2020?



Boundary Clocks = PTP Aware



Major PTP Profiles

T-GM = Telecom Grand Master
T-TSC = Telecom Time Slave Clock
T-TC = Telecom Transparent Clock

-P = Partial
-A= Assisted

	IEEE 1588 Default Profiles	IEEE 802.1AS	IEEE C37.238	ITU-T G.8265.1	ITU-T G.8275.1	ITU-T G.8275.2
Segments	Industrial	Audio/Visual	SmartGrid	Mobile	Mobile	Cable
Transport	IP, L2, etc	L2 Ethernet	L2 Ethernet	IPv4 (IPv6)	L2	IPv4 (IPv6)
Transmission	Multi-/Unicast	Multicast	Multicast	Unicast Neg.	Multicast	Unicast Neg.
Delay Mech.	Both (J.3/J.4)	Peer-delay	Peer-delay	Delay-Resp	Delay-Resp	Delay-Resp
Clock Modes	One/Two step	Two-step	Two-step	Any	Any	Any
BMCA	Default	Alternate	Default	Alternate	Alternate	Alternate
TLV Extns.	Optional	Yes	Yes	No	No	Yes
Clocks	OC, BC, TC	Time aware bridge & end station	OC, TC, BC	OC only	T-GM, T-BC, T-TSC, T-TC	T-GM, T-TSC-P, T-BC-P, T-TC-P, T-TSC-A
Network	Any	Full support	Full support	No on-path	Full + SyncE	Partial

Timing for non-Mobile

What about Timing for non-Mobile?

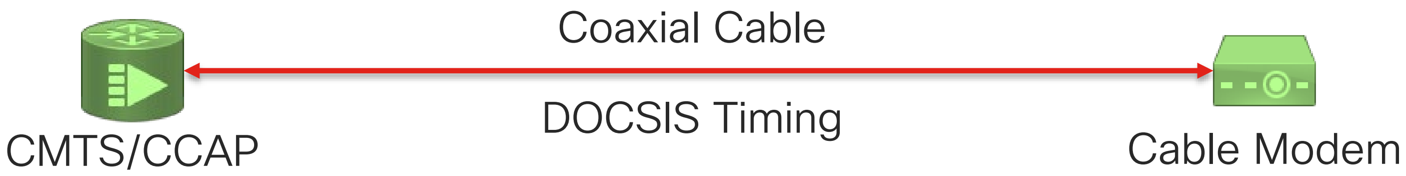
Why do I need to care about this?

- ITU-T has written many standards for timing and Sync
  - Legacy TDM timing for SDH networks, Synchronous Ethernet for packet networks
  - Network requirements, topology & end-to-end budgets (mainly mobile use-case)
  - Models and performance specification for various clocks (EEC, SEC, BC, TC, GM)
  - Telecom Profiles (more on this later)
  - Standards work together to deliver end-to-end timing solution with defined results
- Other industries have taken similar approaches
  - Applying Telecom solution to use cases in other industries
  - Increasingly Telecom standards being used in conjunction with other standards

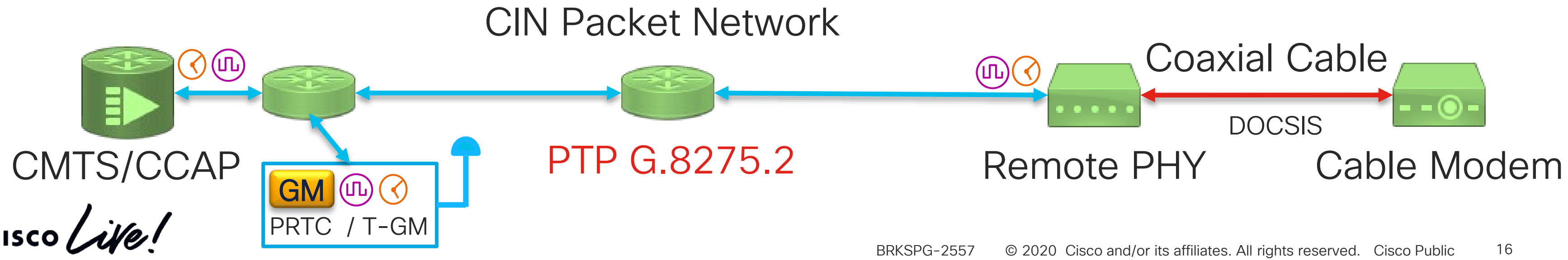
Cable and Remote PHY

https://blogs.cisco.com/sp/remote-phy-why-cin-architectures-matter

- Transport between CCAP head-end and Cable Modem now "packetized"
- DOCSIS timing needs to be created at location remote from CCAP/CMTS
- Before:



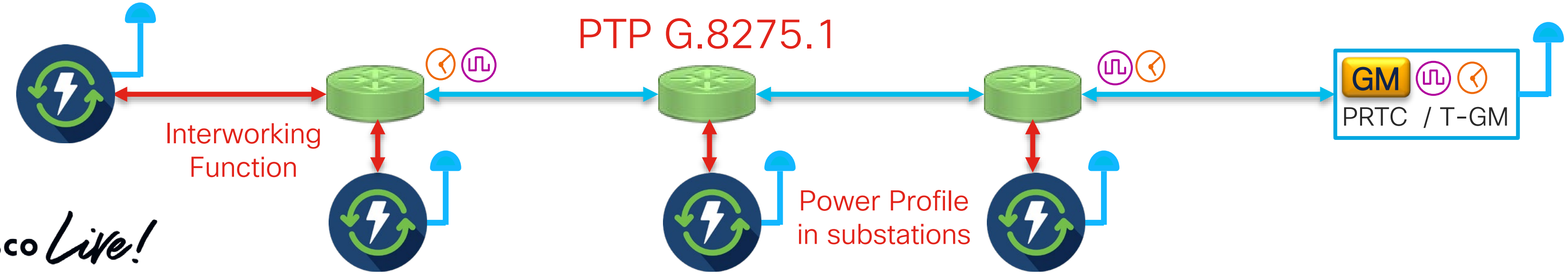
- After:



Power and Smart Grid

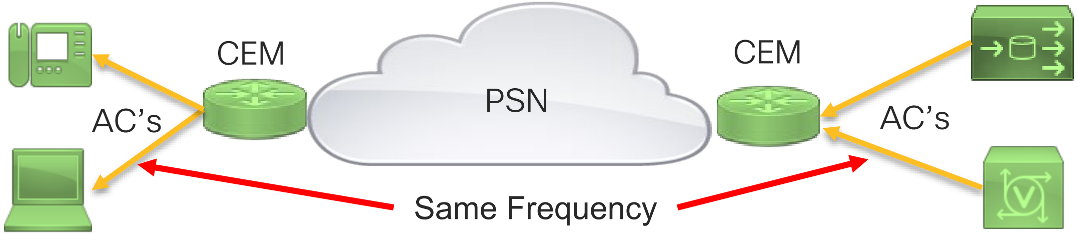
Connecting Timing Domains together

- Power systems already use phase timing (e.g. legacy IRIG-B and others)
  - Grid monitoring and awareness: protection and operation of distribution network
  - Time-stamped voltage & current vector values sent @ up to 120 samples/second
  - Traveling wave fault localization – detecting a wave/pulse from a fault in the line
- There are PTP "Power Profiles" that distribute time in substation
  - Parallel Redundancy Protocol (PRP) & High-avail. Seamless Redundancy (HSR)
  - GPS is normally used as a source of time for each substation – redundancy?

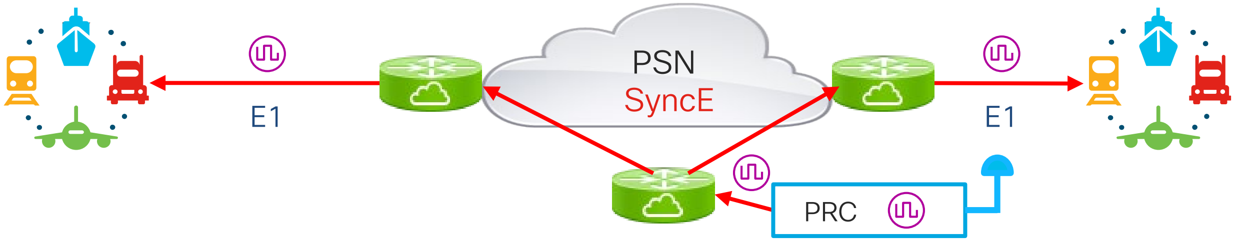


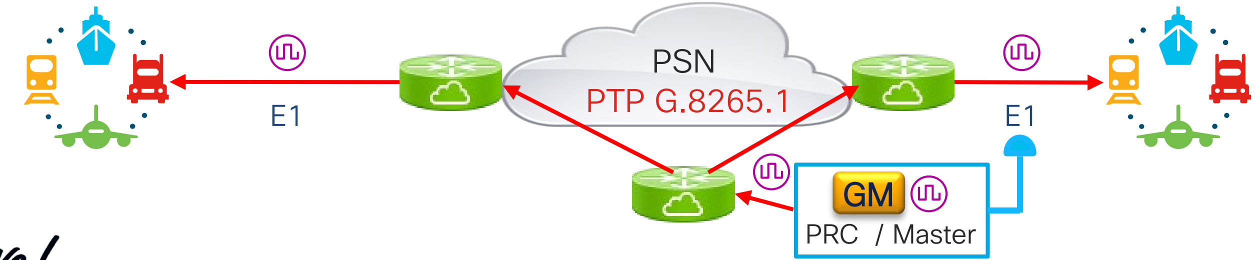
Circuit Emulation

Replacing TDM Circuits



- Breaking TDM chain with packets requires a way to transport frequency
  1. SyncE L1 timing with ESMC quality levels packets for traceability
  2. PTP where L1 Sync is not available – recommended G.8265.1

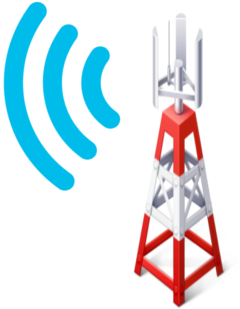




Broadcasting

Single Frequency Networks need Phase Sync

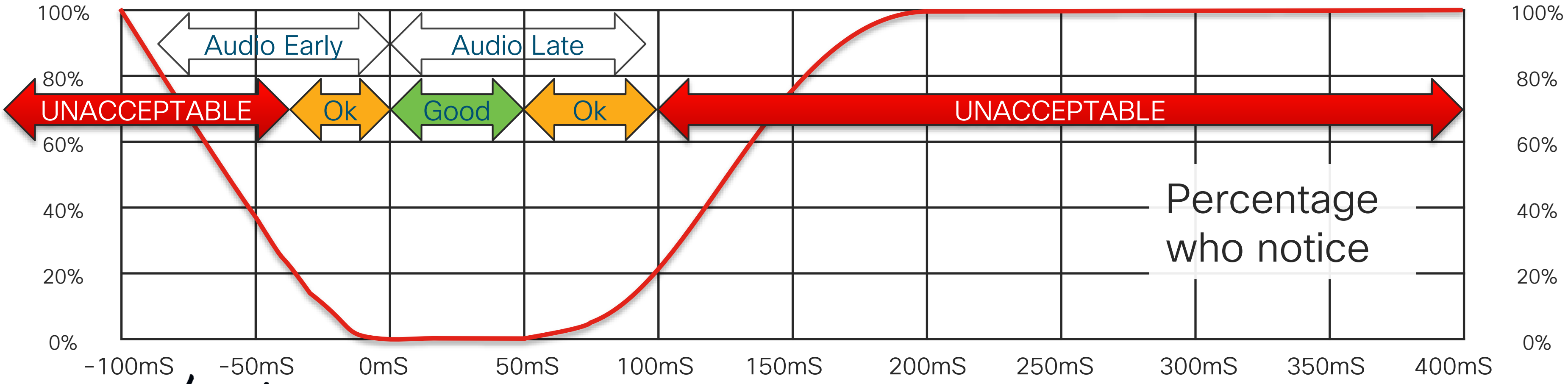
- Even without SFN's, network splits and merges need ~40ms alignment
- SFN transmitter synchronisation error needs <10-300µs, down to 1µs
- Commonly uses GPS as a source of phase and frequency
- Frequency/phase not only accurate, but cannot move suddenly (stable)
- GPS receivers backed up over video distribution network (PTP G.8275.1)



Audio Visual

Synchronization across the whole Audio/Video network

- Audio and Video must be Synched with each other – people quickly notice!
- AES67 and SMPTE are two PTP profiles used in A/V industry
- Based on L3 multicast – not much use of Telecom profiles



Deployment Topologies

Network Deployment Topologies

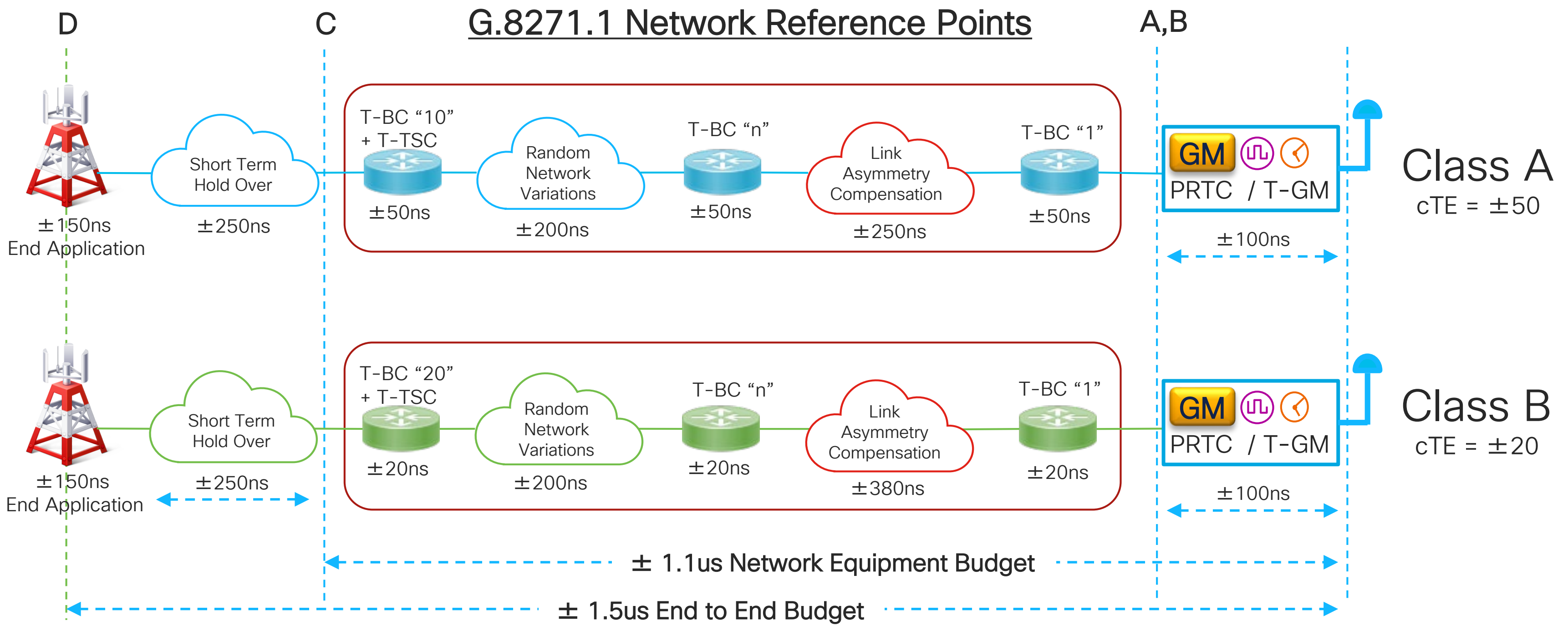
Standardized by the ITU-T

- Two types of network elements
  - “PTP Aware” – understand PTP, process PTP and pass time accurately
  - “PTP Unaware” – PTP is just another packet or frame, sensitive to traffic variation
- Phase: Two end-to-end network models for each network nodes type:
  - G.8271.1: full timing support to the protocol level from the network (FTS)
  - G.8271.2: partial timing support from the network (PTS)
- These network models also divide up the end-to-end budget
  - For LTE-A and 5G backhaul, this is ±1.1µs/1.5µs
  - Assigns the budget to the different possible causes of time error
- There are two Telecom Profiles defined, one for each use case

Nodes supporting PTP

- PTP aware nodes carry time in hardware
  - Therefore, they (should) have *predictable* performance
- Performance is standardized by the ITU-T (G.8273.2)
  - Class A = original implementation, max|TE| of 100ns, cTE of ±50ns
  - Class B = newer devices, max|TE| of 70ns, cTE of ±20ns
  - Class C = becoming available, max|TE| of 60ns, cTE of ±10ns
  - Equivalent standard for T-TC transparent clocks for classes A, B (G.8273.3)
- With better clocks, can cross more hops or a meet a lower budget
  - E.g. 5G Fronthaul may have stricter requirements (see BRKSPG-3295)
- It is easy to test/confirm this performance (coming up)

Allocating Timing Budget v Node Performance



Class A: includes 10 x T-BC and 1 x T-TSC (11 x 50ns = 550ns)

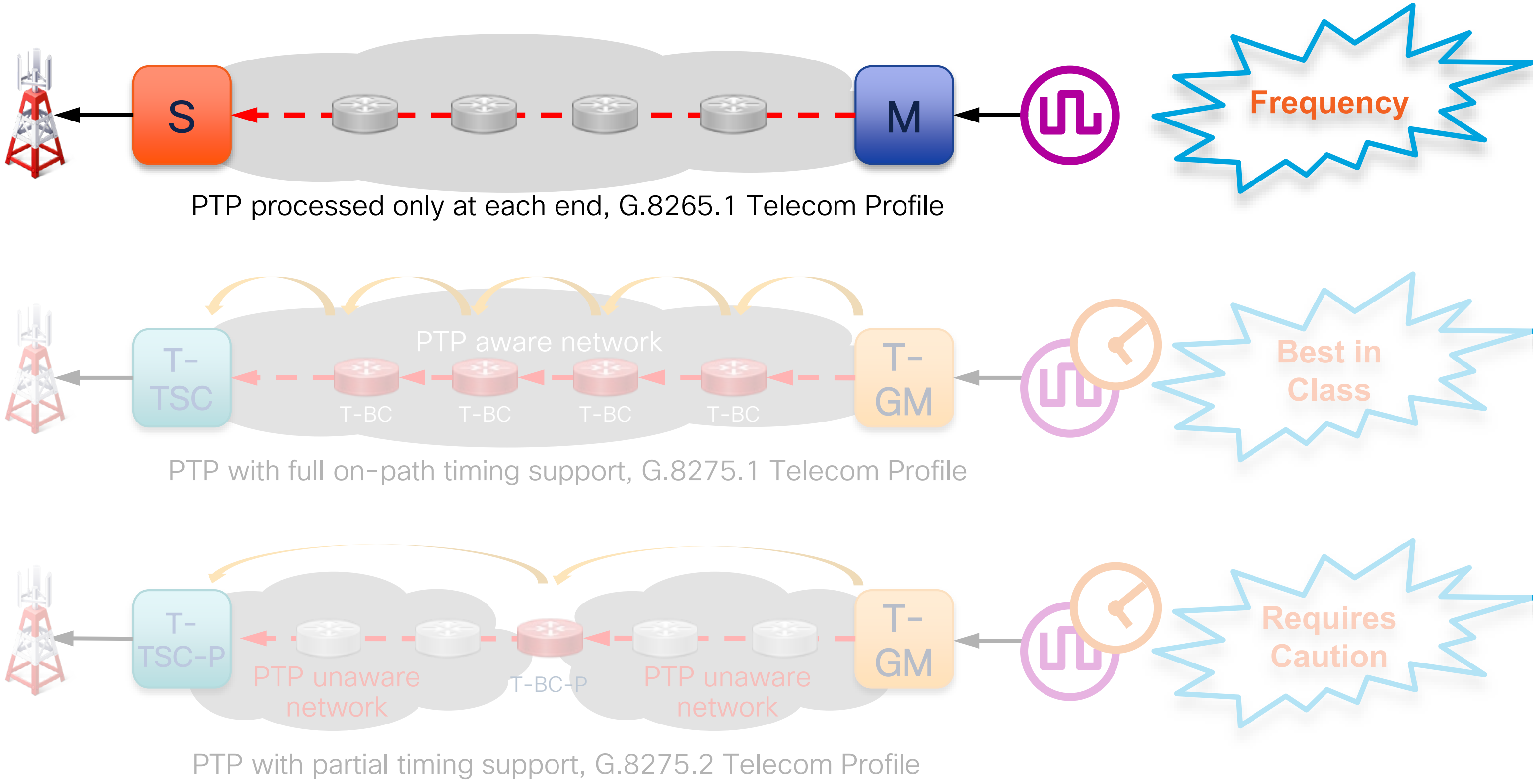
Class B: includes 20 x T-BC and 1 x T-TSC (21 x 20ns = 420ns)

PTP Telecom Profiles - Frequency

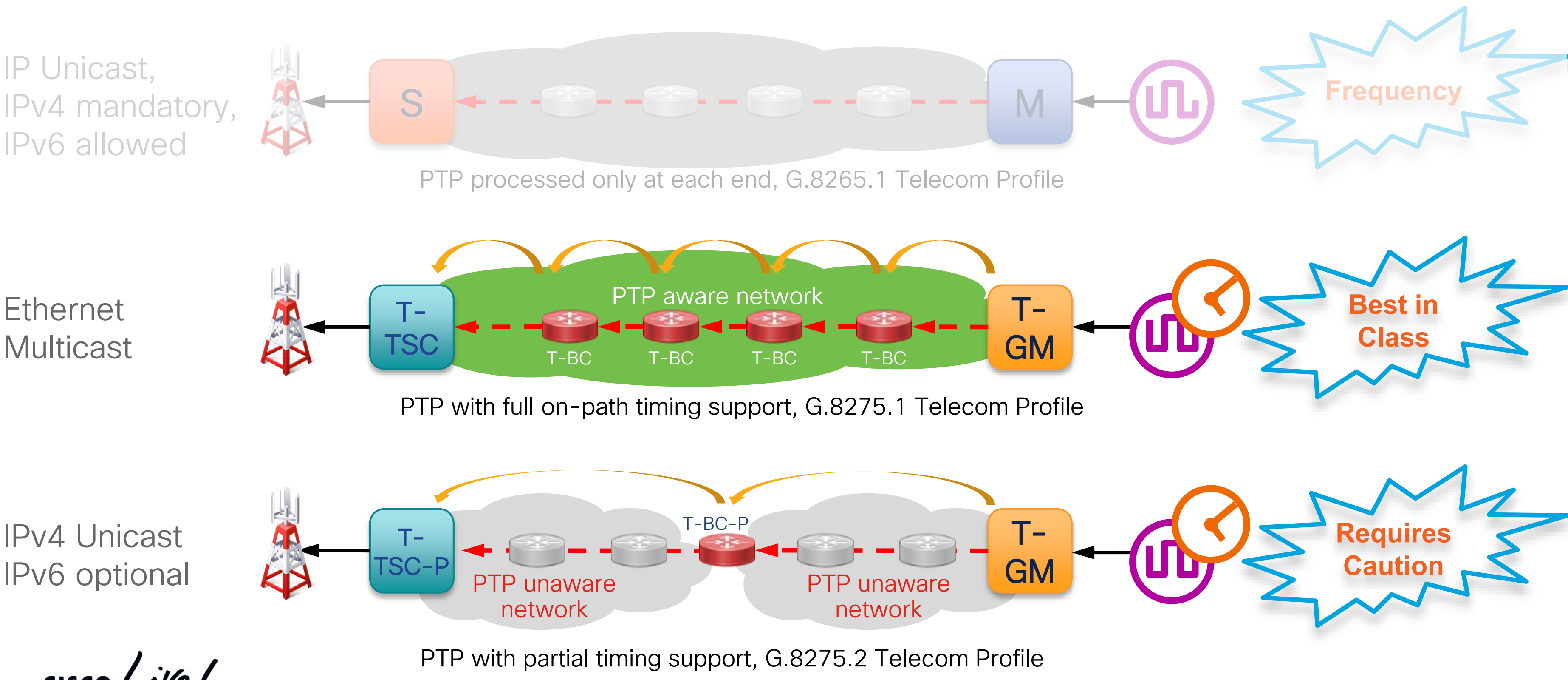
IP Unicast,
IPv4 mandatory,
IPv6 allowed

Ethernet
Multicast

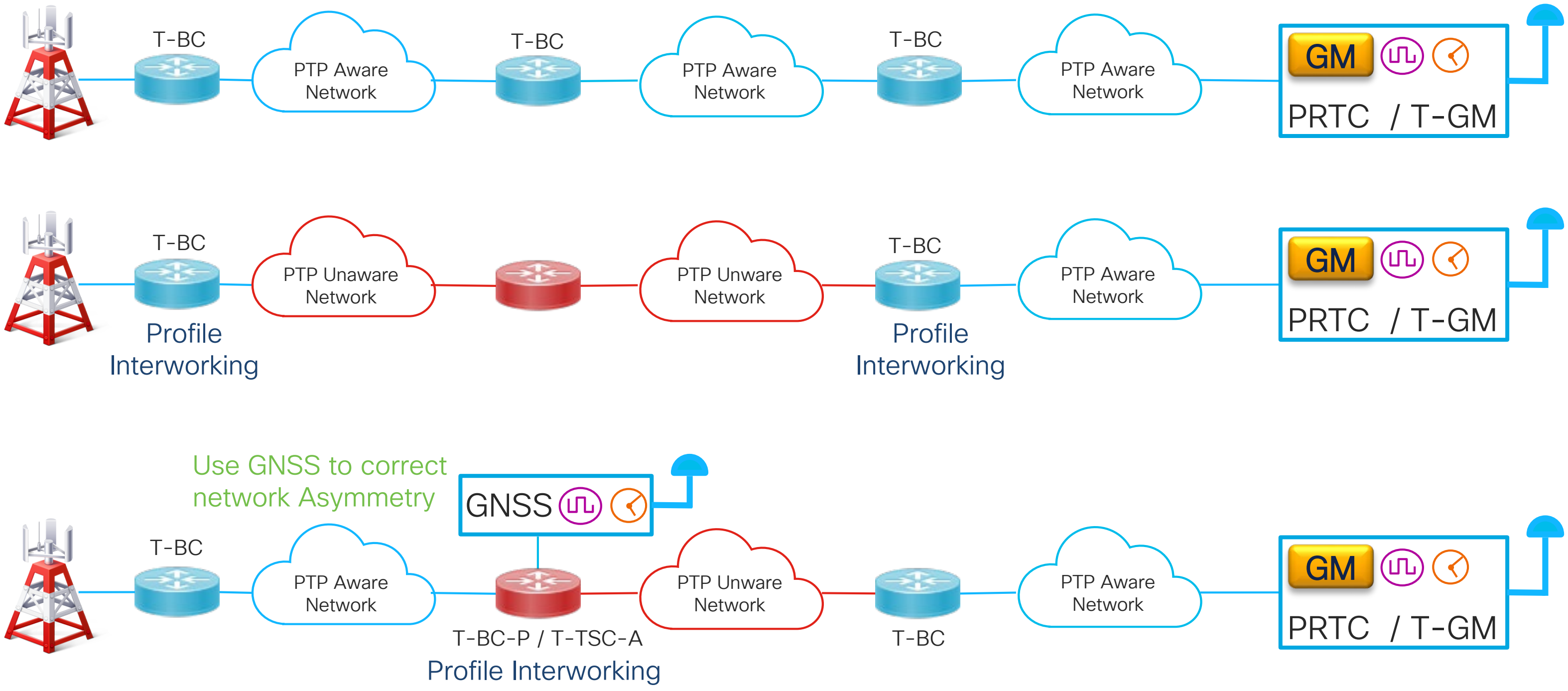
IPv4 Unicast
IPv6 optional



PTP Telecom Profiles - Phase



Solution Options



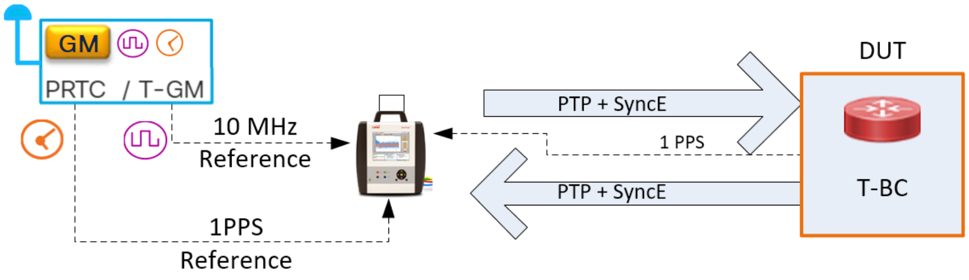
Testing Timing

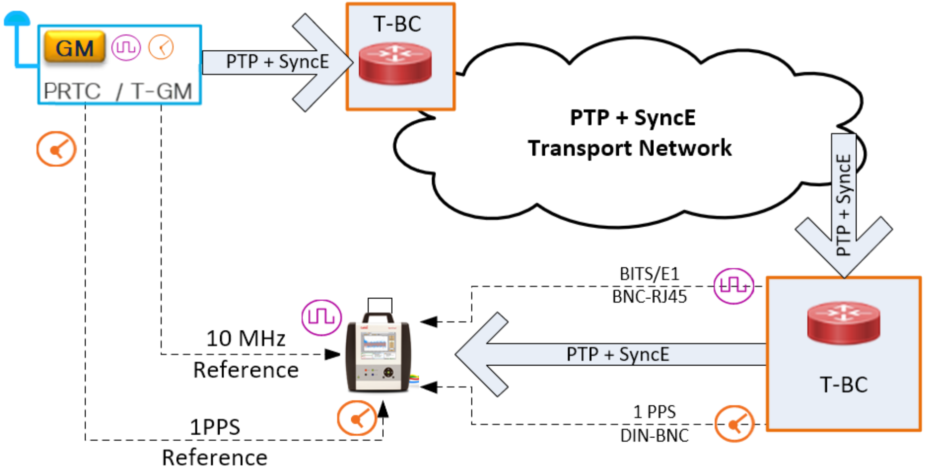
Testing for Timing

- Testing for timing requires knowledge and specialized equipment
- Much of the testing of time has been standardized for ages
- You can test whatever you want, but
  - You cannot then compare the results to those of standardized tests
  - Be sure unnecessary time errors are calibrated out (e.g. 2 PRTC's)
- Most common test equipment is based on Calnex Solutions
  - Paragon-X: very widely used lab equipment
  - Sentinel: portable device for field testing
  - Paragon neo: newest generation for Class-C and 100GE testing
  - They have a LOT of documentation on their site to help you successfully test

Do Not Mix Different Types of Testing

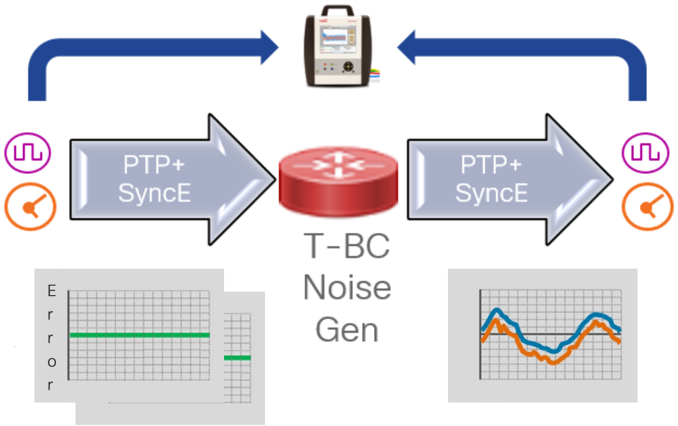
- Two basic types of testing for both frequency and phase:
  - End-to-end (performance after several hops)
  - Node testing (performance of a single node)
  - Frequency: SyncE or 2/10 MHz/E1/T1
  - Phase: PTP or 1PPS





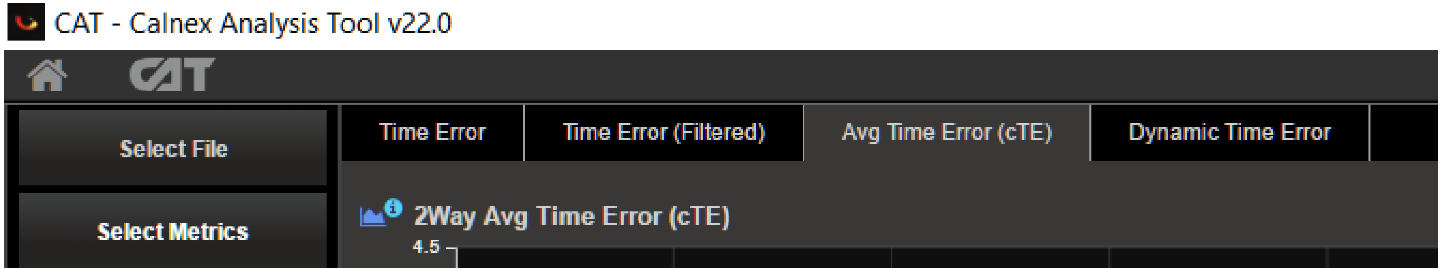
Class A/B/C T-BC Boundary Clock Testing

- When we talk about Class A/B/C Boundary Clocks:
  - T-BC (boundary clock) G.8273.2 *Noise Generation* performance
  - Other tests: PTP ⇔ SyncE noise transfer, tolerance, etc.
  - Same test equipment should generate the time *input* & measure time *output*
  - Stand-alone, back-to-back
  - NO traffic or impairment
  - i.e. IDEAL/PERFECT inputs
  - Measure 1PPS or PTP out



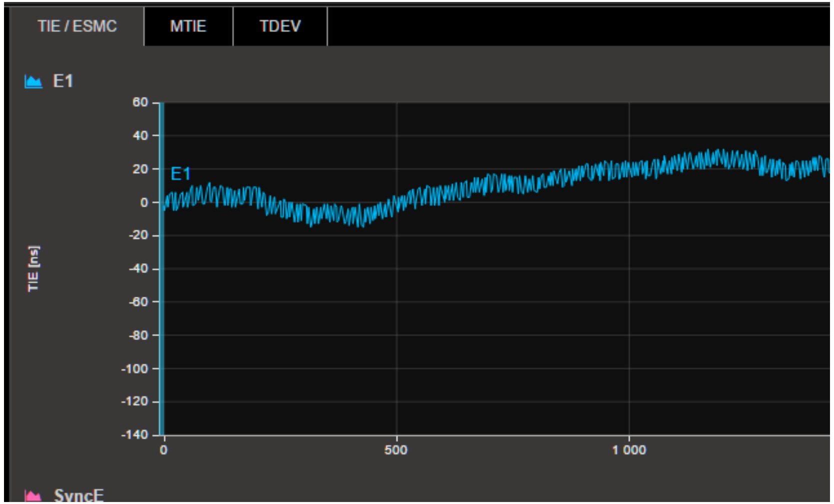
Measurement Statistics

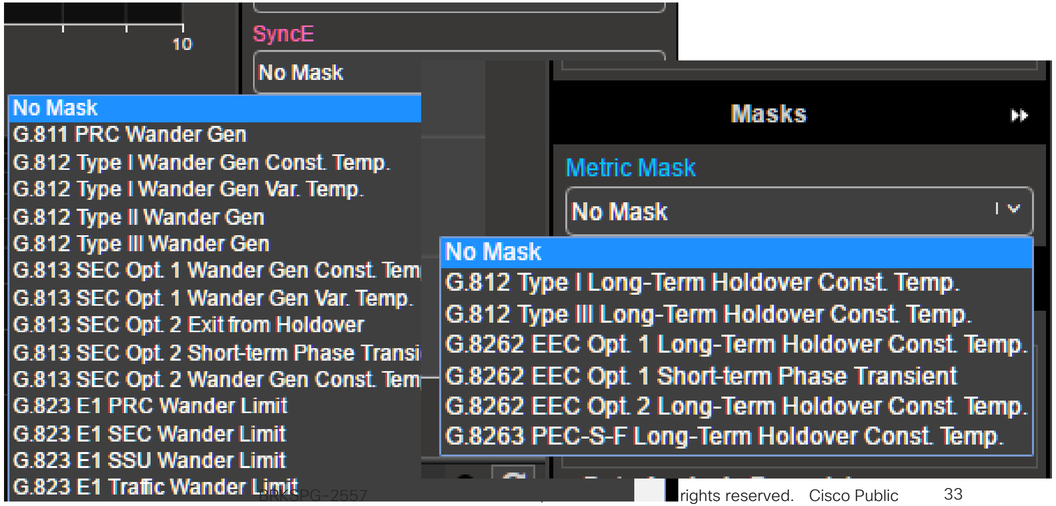
- Many statistical measurements, tools and masks:
  - Tester samples the “raw” Time Error – other metrics are derived
  - 2-Way Time Error (2wTE), constant TE (cTE), max|TE|, dynamic TE (dTE)
  - There are high-pass (HF) and low-pass (LF) filters also possible
  - Class A/B/C we normally talk max|TE| and cTE (Class B = 70ns & ±20 ns)
  - cTE is average TE over 1000 seconds (use the appropriate tool)
  - Select the threshold (e.g. ±50 ns) for pass/fail indication



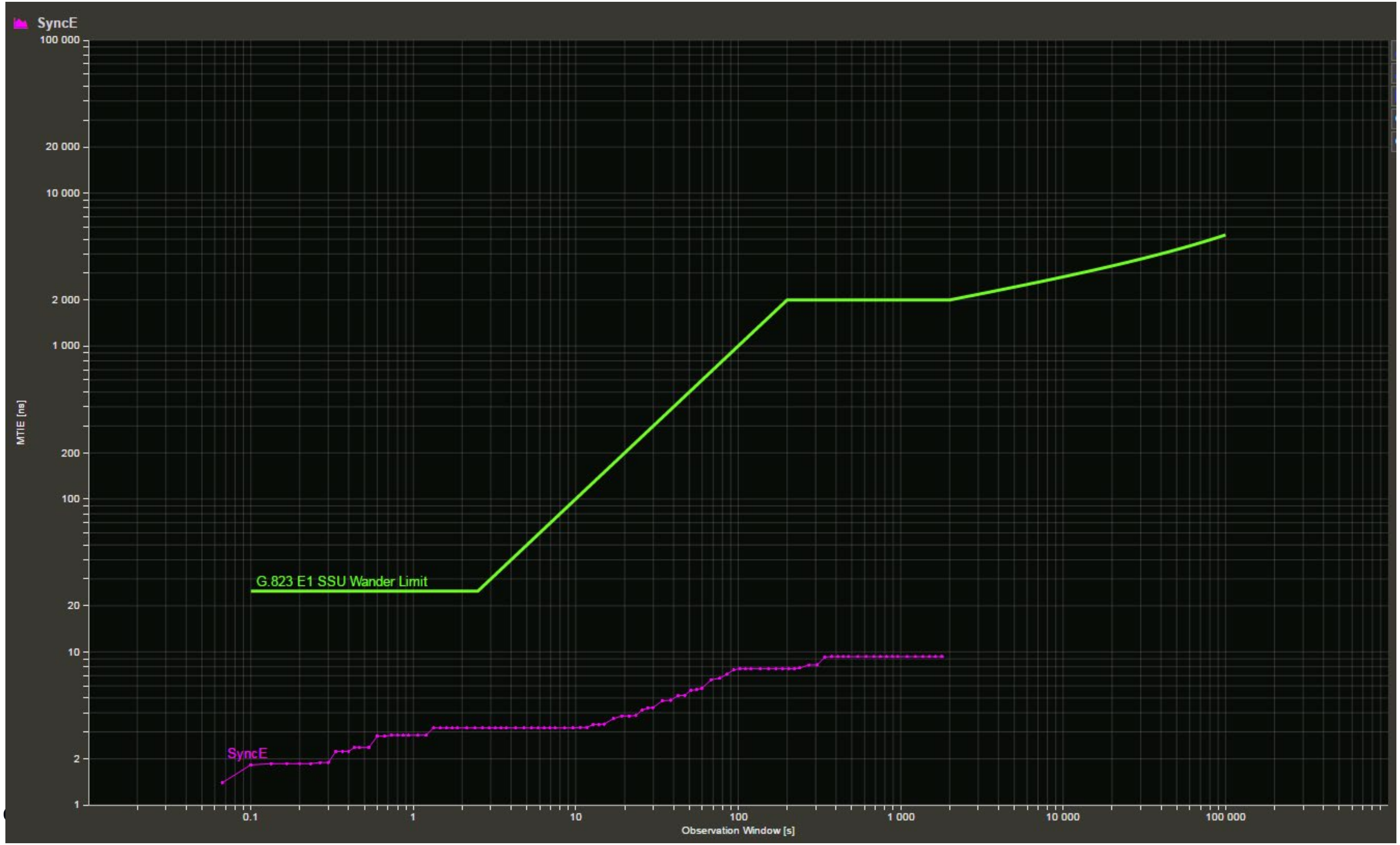
Measurement Statistics

- Masks mostly based on MTIE & TDEV (statistical derivations on TIE):
  - Masks per role or test suite (end-to-end, single node, T-GM, T-BC)
  - Different masks for quality levels (e.g. PRC, SEC, G.8xx masks)
  - Select right one for freq. v phase, role, performance level, topology

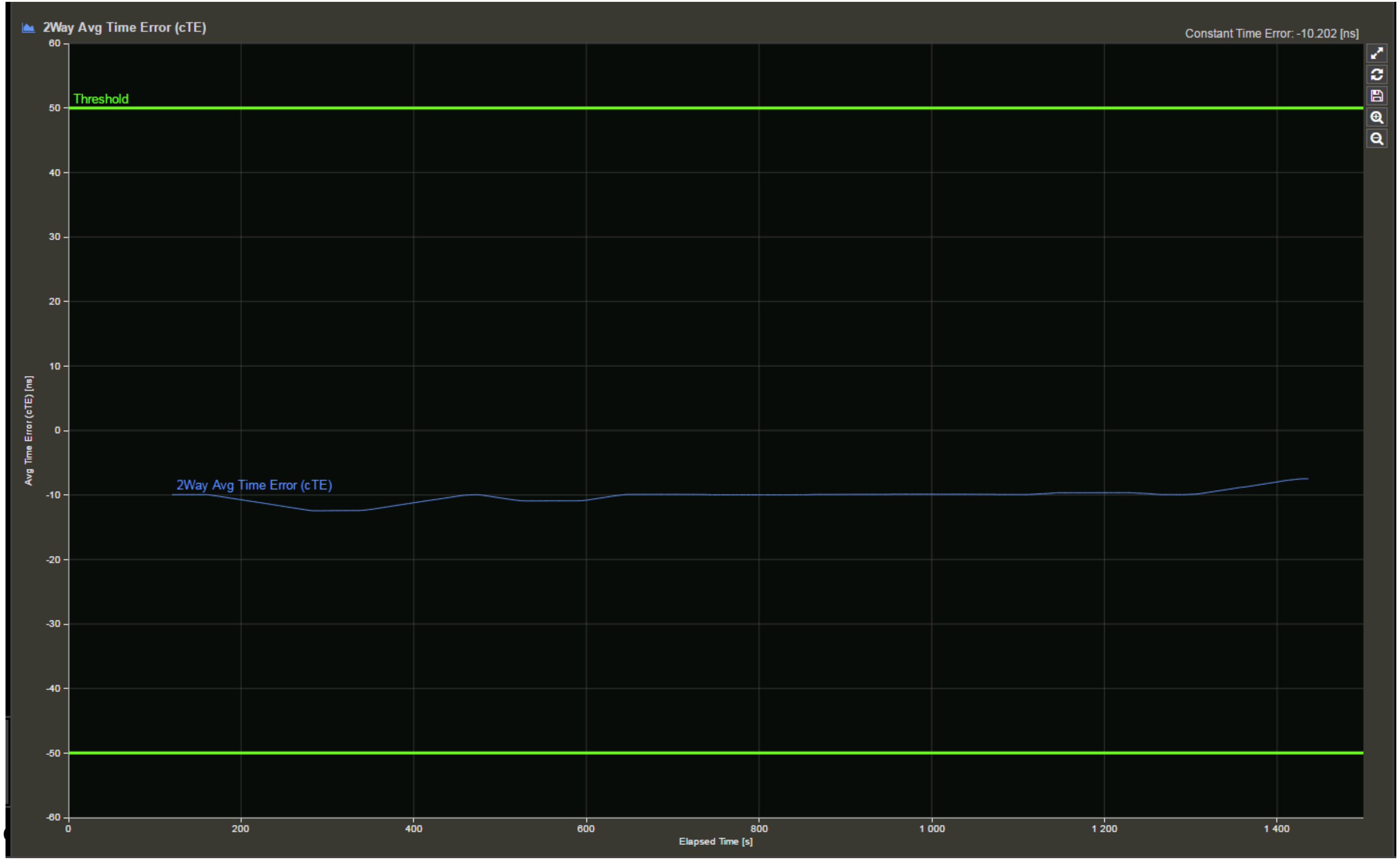




Nice Frequency Result – MTIE



Nice Phase Result – cTE with ±50ns Threshold



Deployment Lessons

Synchronization Decision Tree

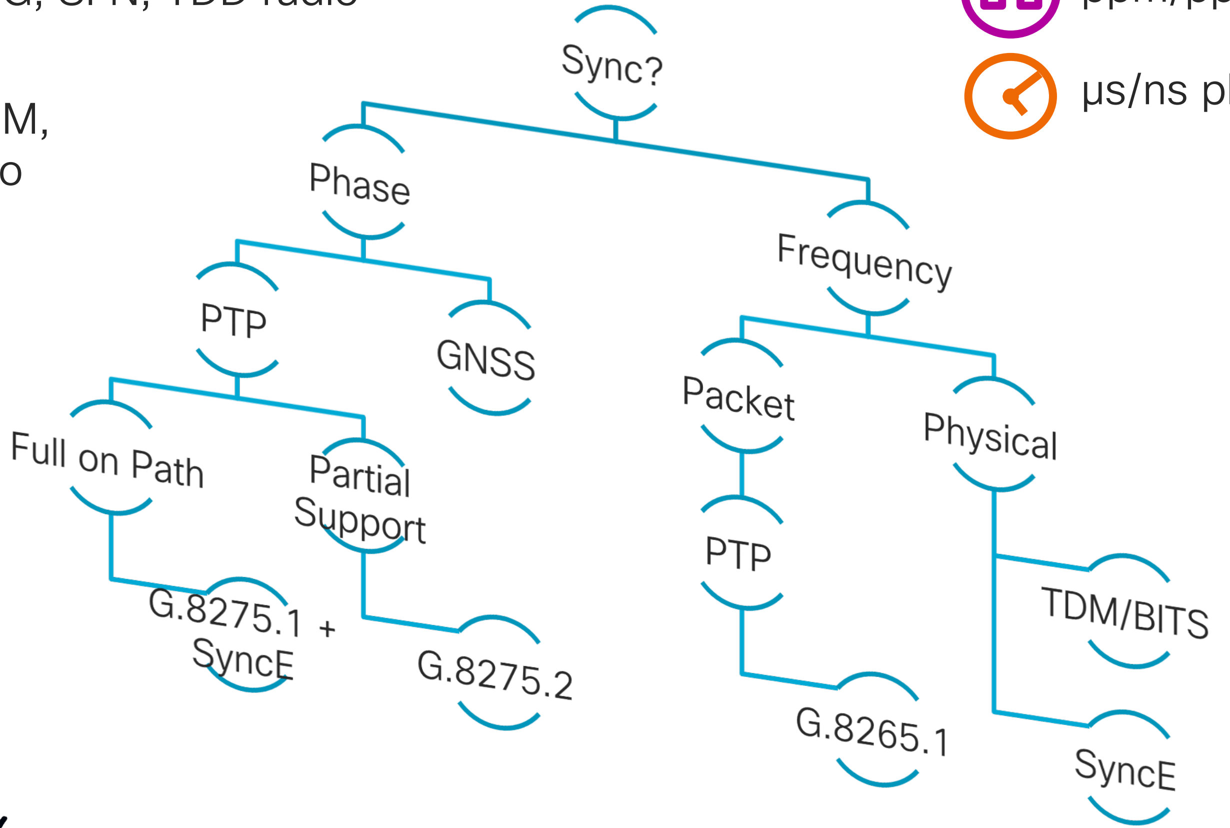
LTE-A, 5G, SFN, TDD radio

CEM, TDM,
FDD radio

Requirements?

ppm/ppb

μs/ns phase offset



Deploying Synchronization (general)

General Guidelines for Successful Deployments

- What form of sync does the end application require? At what accuracy?
  - Frequency sources are BITS/SyncE, Phase/time needs GNSS and/or PTP
  - Most solutions use a mix of GNSS over the air and PTP or SyncE over the transport
- PTP is required to carry phase and time when no GNSS solution available or when a backup to a localized GNSS outage is required
  - If only frequency is needed, SyncE is the best solution. General rule, SyncE always helps.
- Phase/time Synchronization network design is about time error budgets
  - Boundary clocks wherever possible to reduce time error and reset the PDV
  - The more PTP awareness you have, the more hops you can cover
  - The more accurate the boundary clocks you have, the more hops you can cover
  - Distance itself isn't a problem

Deploying Synchronization (general)

General Guidelines for Successful Deployments

- Physical Frequency (e.g. SyncE) should be used wherever possible:
  - For frequency only, use SyncE instead of PTP wherever possible
  - For phase, use SyncE in combination with PTP wherever possible
- Minimize hops:
  - Distribute sources of time to meet budget
  - Do not centralize two PRTC+GM in HQ and try to run PTP across the whole country
- Transport Remediation: minimize Packet Delay Variation (PDV) or Packet Jitter
  - Design: excessive PDV will make successful packet solutions almost impossible
  - Microwaves/GPON/DSL/DWDM are problematic, unless they are PTP aware
  - On path support wherever possible to reduce time error and PDV
- Engineer a timing solution – it's a timing problem, not a transport one

Deploying Synchronization (Phase)

Guidelines for Successful PHASE Deployments

- Reference solution: 75.1 Telecom Profile with Full On-path Support (L2 multicast)
- Deploy only with SyncE (this is mandatory according to the G.8275.1 standard)
- Frequency PTP only worries about PDV, Phase PTP adds asymmetry to it
- Minimize phase time error
  - Eliminate asymmetry – this feeds directly into time error
  - Minimize hops – expect to deploy T-GM’s out in the pre-aggregation network
  - Minimize Packet Delay Variation (PDV) or Packet Jitter
- Understand the transport (again, asymmetry and PDV)
- If you run PTP for frequency, you cannot just “turn on” phase and expect it to work
- Beware IP protocols for PTP: rerouting, routing asymmetry, ECMP, bundles

Deploying Synchronization (Phase)

Guidelines for Successful PHASE Deployments

- Careful of asymmetric transports (GPON, Cable, Microwave)
- Tight timing budgets over many hops will need new hardware! (Class C, D)
- GNSS deployments aren't as easy as they seem
  - Antenna installation and rental can be very costly
  - If you aren't an expert on GNSS installation and calibration, hire one!!
- Use the standards based solution designed for you (e.g. the correct profile)
- What about security? MACsec plus PTP?
- We talk about some of these in detail…

Network Design

What the network designer has to do:

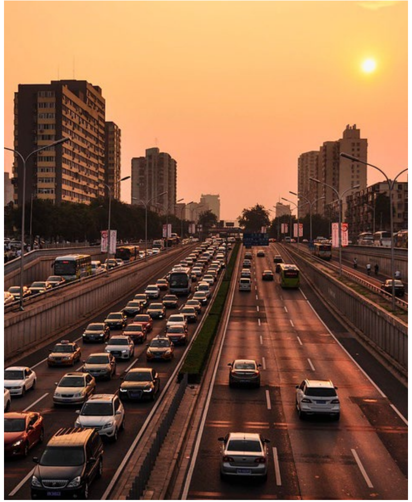
- Frequency Synchronization
  - If possible, use physical distribution (i.e. SyncE) not packet
  - G.8265.1 interoperates with SONET/SDH & SyncE (but disallows aware nodes)
  - Packet distribution: reduce PDV (e.g. minimizing hops)
  - Asymmetry isn't an issue
- Phase Synchronization
  - Deploy G.8275.1 with physical frequency (i.e. SyncE)
  - Reduce PDV (e.g. boundary clocks reset PDV)
  - Reduce Asymmetry (routing, link, node, transport,...)
  - Remediation of transport layer

Select the Correct Profile

Some profiles have advantages over others

Feature	G.8275.1 PTPoE	G.8275.2 PTPoIP
Network Model	Full on-path support	Partial on-path support
IP Routing	Not applicable	Problematic (rings, asymmetry)
Transit traffic	Not allowed	Problematic (jitter, asymmetry)
Performance	Best	Variable
Configuration Model	Physical Port	L3 device
PTP over Bundles	No issue	Being worked on (for BC's)
Asymmetry	Reduced (T-BC on every node)	T-BC good, not T-BC = bad
PDV/jitter	Timestamping on wire (small)	T-BC good, not T-BC = bad

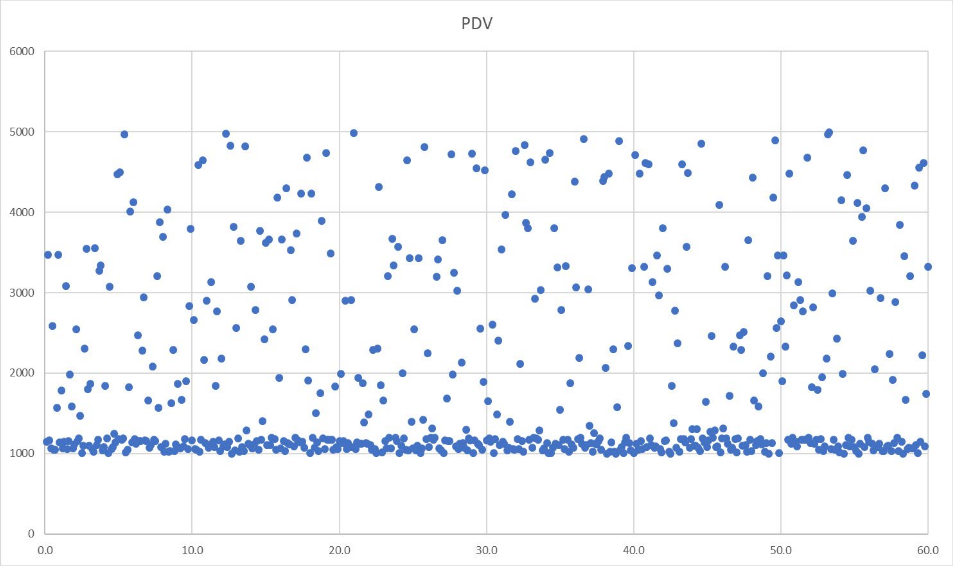
Reduce Asymmetry

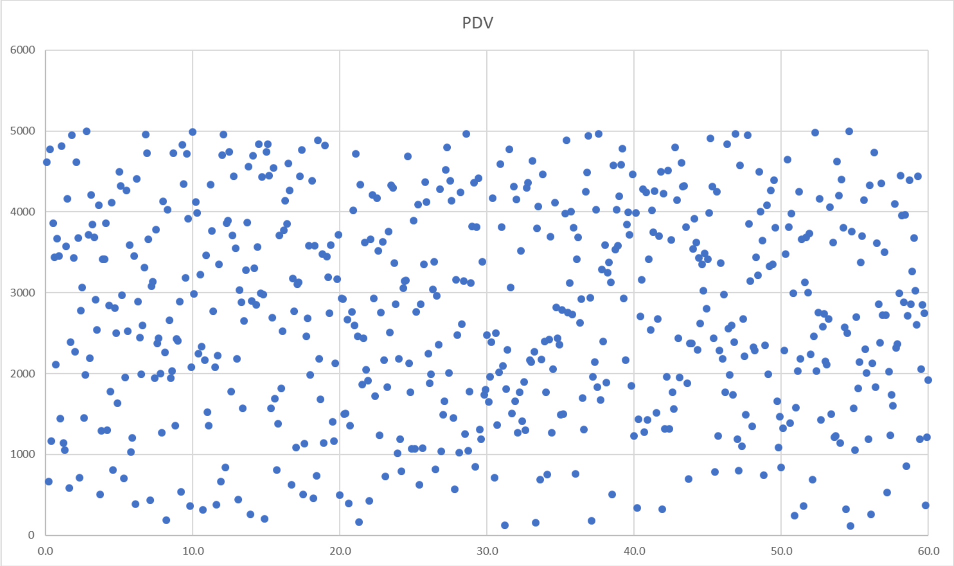


- Asymmetry can come from:
  - Routing (especially in complex topologies, rings, ECMP)
  - PTP unaware transit nodes (esp. with varying traffic patterns)
  - Transport (PON, Cable, DWDM, complex optics)
  - Every 2 microseconds of asymmetry = 1 microsecond of time error
- Doing this on an unaware network is very problematic
  - And QoS cannot really solve the problem – but it helps
- Boundary clocks handle the asymmetry problem in the nodes
  - Assuming they are properly engineered and built

Reduce PDV

- Packet Delay Variation is bad for unaware nodes:
  - Must have a “floor” of lucky packets arriving in minimum time
  - Accumulates with every unaware node – fixed with T-BC’s





Remediating Transport Asymmetry

Timing over Active Optical Components

Similar issues for PON, Cable, DSL, microwave…

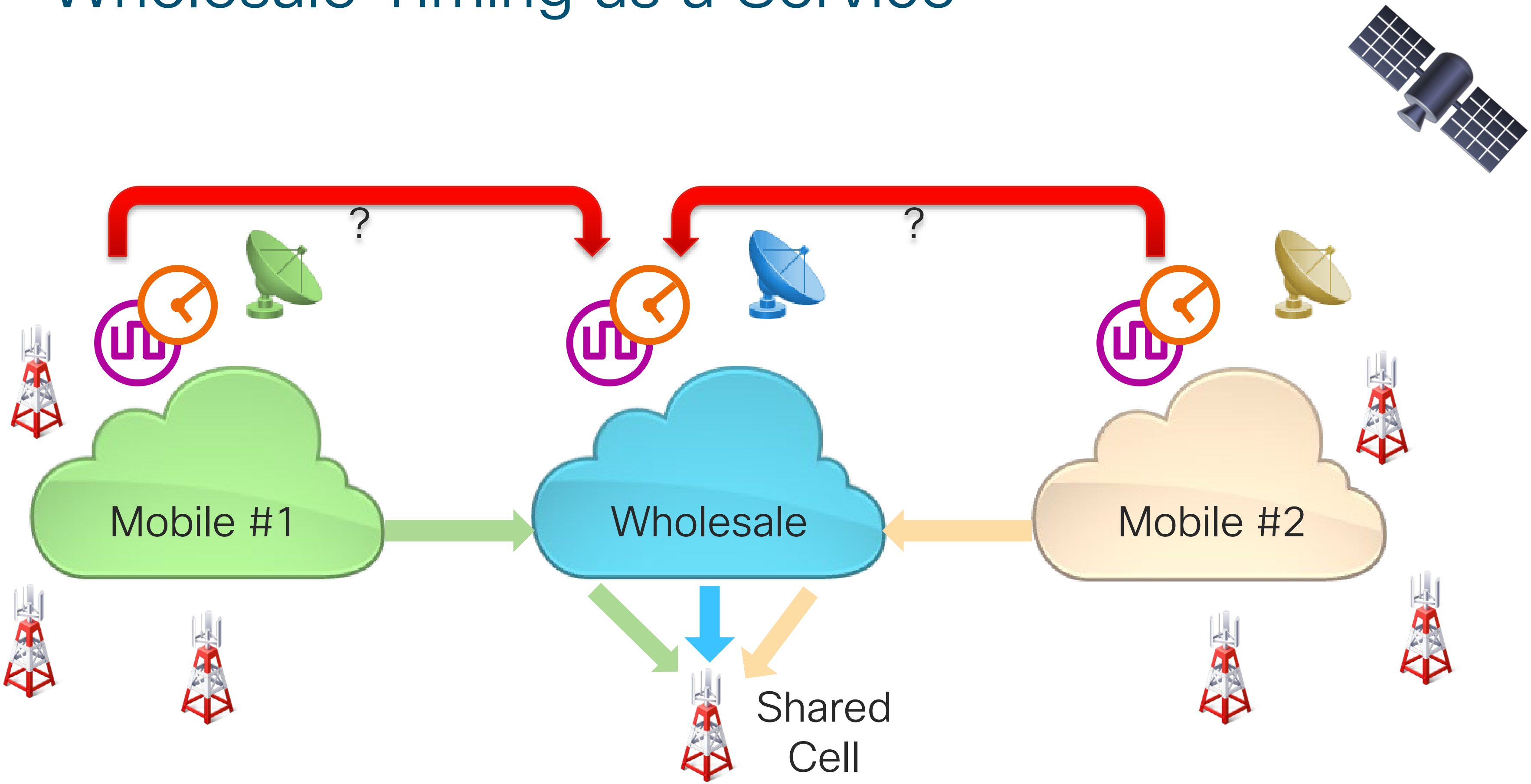
- “Smart” optical devices include buffering and/or complex processing
  - Buffering can be static and symmetrical, commonly it is neither
  - Complex processing can introduce variable delay after the timestamping
- Both introduce PDV/Jitter and commonly asymmetry, into the PTP signal
- Solution: The transport must become “PTP aware” and compensate
- In optical devices, this means using an Optical Service Channel for PTP

Third Party Networks

Carrying Synch over external networks is difficult

- T-BC Boundary clock can only be in a single "clock domain"
- Carriage of PTPoIP (G.8275.2) is possible, but unaware
- No simple solution (some are looking at this now):
  - Make sure all the mobile networks are closely aligned (e.g. to GPS UTC)
  - Wholesale SP can then provide their own clock aligned with GPS UTC
  - For Timing as a Service – can also monitor the clock at interconnect point
  - Easiest is to deploy GNSS (e.g. GPS) solution everywhere
    - Clever design required to ensure redundancy against GNSS outages
    - GNSS may not be good enough for Fronthaul timing requirements!!!

Wholesale Timing as a Service



Summary

- Engineering timing network to accurately carry phase is easier if:
  - PTP aware networks
  - Combination of SyncE with PTP
  - Use “PTP aware” transport
  - Work <u>with</u> the standards rather than trying to “roll your own”
  - Engineer a “timing solution” and not just solve a connectivity problem
    - It’s an end-to-end budgeting exercise
    - Remove as much asymmetry and PDV as possible
  - Not try to get too fancy

Further Information

- ITSF International Timing & Sync Forum, Nov 2-5 2020, Düsseldorf :
  https://itsf2020.executiveindustryevents.com/Event/home
- WSTS Workshop on Sync & Timing Systems, May 11-14 2020, Seattle
  http://www.atis.org/wsts/
- ATIS White Paper: "GPS Vulnerability"
  https://access.atis.org/apps/group_public/download.php/36304/ATIS-0900005.pdf
- ITU_T Study Group 15 Question 13:
  htts://www.itu.int/en/ITU-T/studygroups/2017-2020/15/Pages/q13.aspx

  Current ITU_T Sync Plenary Meeting (27 Jan – 7 Feb 2020, Geneva, CH)

  Next ITU_T Sync Interim Meeting (4 May '20, Seattle)

Further Information

- Calnex Solutions information on Timing Testing
  https://www.calnexsol.com/en/solutions-en/education/techlib/timing-and-sync-lab
- Cablelabs Timing with/without Remote PHY
  https://specification-search.cablelabs.com/docsis-timing-interface-specification
  https://specification-search.cablelabs.com/CM-SP-R-DTI

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