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Let’s go

The bridge to possible

Synchronizing 5G Mobile Networks

Network Based Timing

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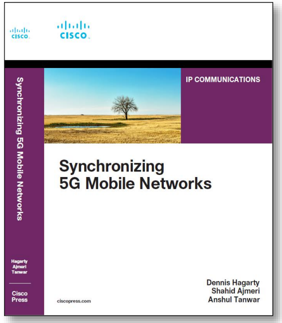
Agenda



- Introduction
- 5G synchronization standards
- 5G RAN timing solutions
- Deployment and best practices
- Troubleshooting and interoperability
- Latest developments
- Conclusion and further info

Key Abbreviations

APTS	Assisted Partial Timing Support
(a)BMCA	(alternate) Best ~~Master~~ Clock Algorithm
(a)BTCA	(alternate) Best TimeTransmitter Clock Algor.
CA	Carrier Aggregation
CoMP	Coordinated Multi-point
cTE	Constant Time Error
dTE	Dynamic Time Error
EEC	Ethernet Equipment Clock
eEEC	Enhanced EEC
ESMC	Ethernet Synchronization Message Channel
eSyncE	Enhanced SyncE
FDD	Frequency Domain Duplex
FTS	Full (on-path) Timing Support
GNSS	Global Navigation Satellite System
MITM	Man in the Middle
MTIE	Maximum Time Interval Error
O-CU	Open Centralized Unit

O-DU	Open Distributed Unit
O-RU	Open Radio Unit
PRC	Primary Reference (frequency) Clock
PRTC	Primary Reference Time Clock
PTP	Precision Time Protocol
PTS	Partial Timing Support
SyncE	Synchronous Ethernet
T-BC	Telecom Boundary Clock
T-GM	Telecom Grand Master
T-TC	Telecom Transparent Clock
T-TSC	Telecom Time ~~Slave~~ Synchronous Clock
TAE	Time Alignment Error
TDD	Time Domain Duplex
TDEV	Time Deviation
TE	Time Error
TSN	Time Sensitive Networking
UTC	Universal Coordinated Time

Introduction

5G Changed Sync in MAJOR way

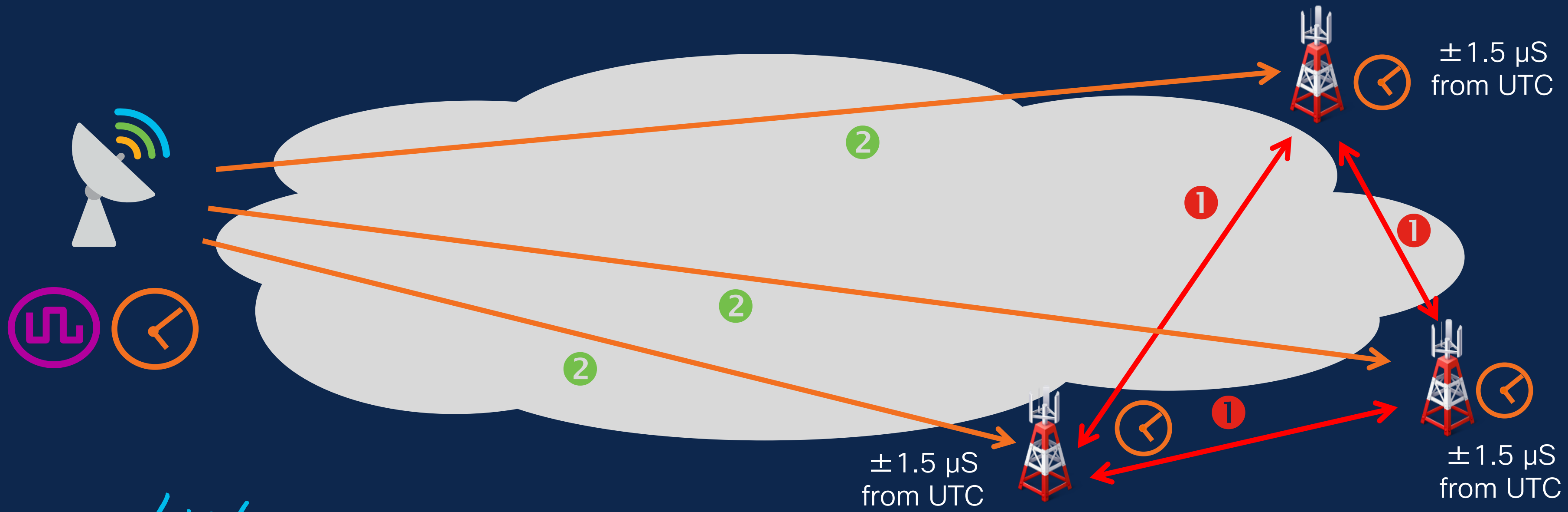
- Previous mobile networks used only frequency synchronization
  - Initially delivered using TDM and then later using SyncE/Ethernet and/or PTP
- Now PHASE also required for new TDD/5G radio services/features
- Implemented with GNSS locally or PTP + SyncE through transport network
- Phase/Time Sync uses Precision Time Protocol (PTP)/IEEE 1588
  - Accuracy of 10's – 100's of nanoseconds (10^{-9}) Time Error over 5–10 hops
  - Requires specialized hardware and careful network design
  - PTP/SyncE support included in increasing number of network transport systems
  - SyncE & PTP Telecom profiles supported across Cisco Service Provider products
  - Solutions have been standardized by the ITU-T and continue to evolve

Phase Synchronization for 5G

Common Reference Time

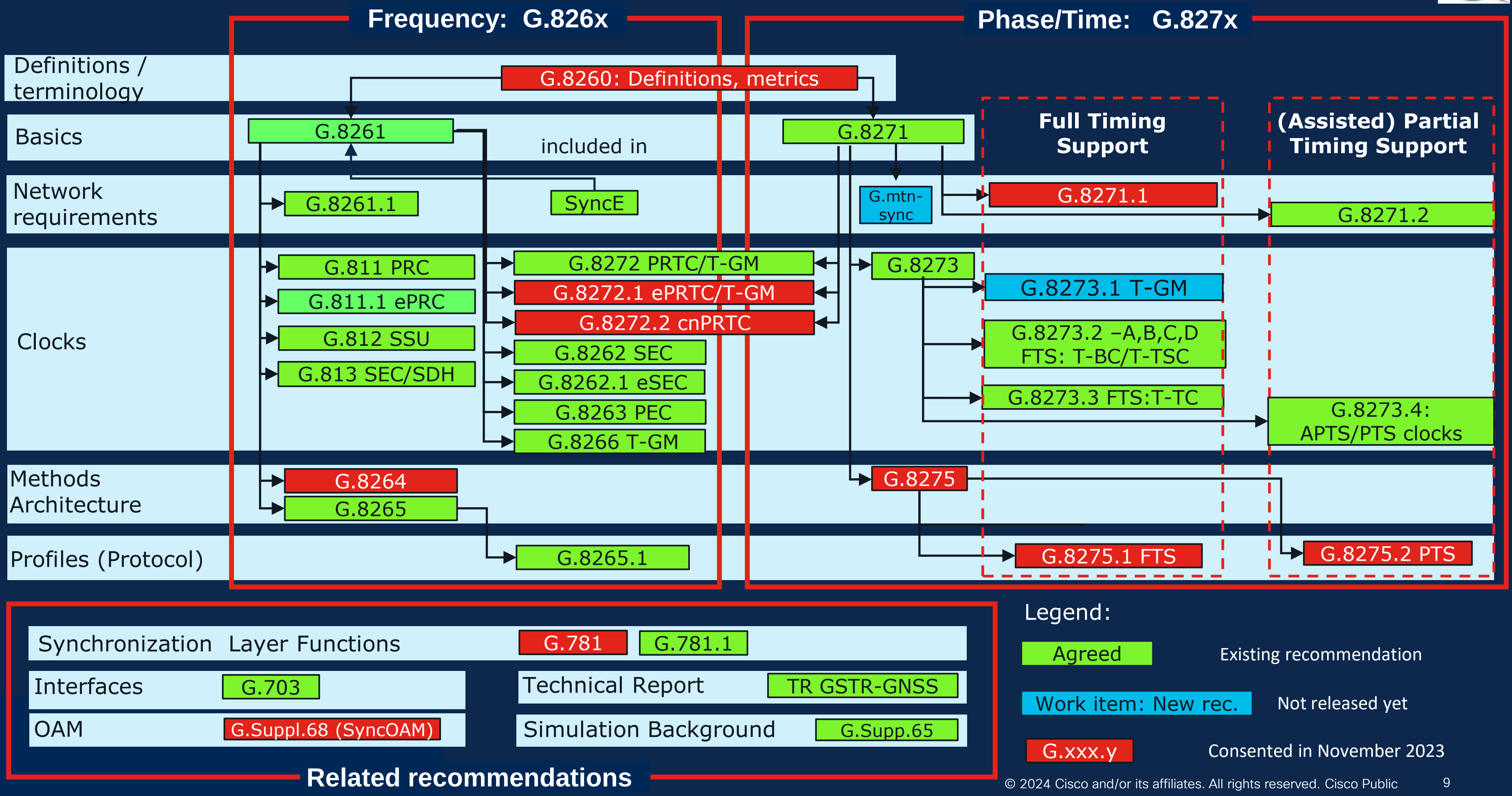
❶ Requirement (TDD, 5G radio co-ordination): 3 µs between base stations

❷ Implementation: ±1.5 µs from a common reference time (normally UTC time)

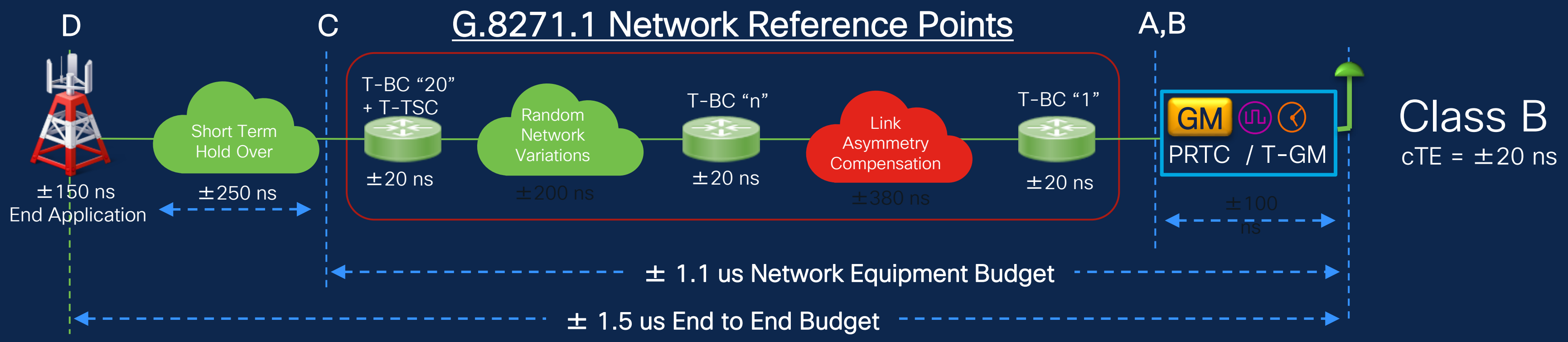


Synchronization Standards

ITU-T SG15 Question 13 Recommendations



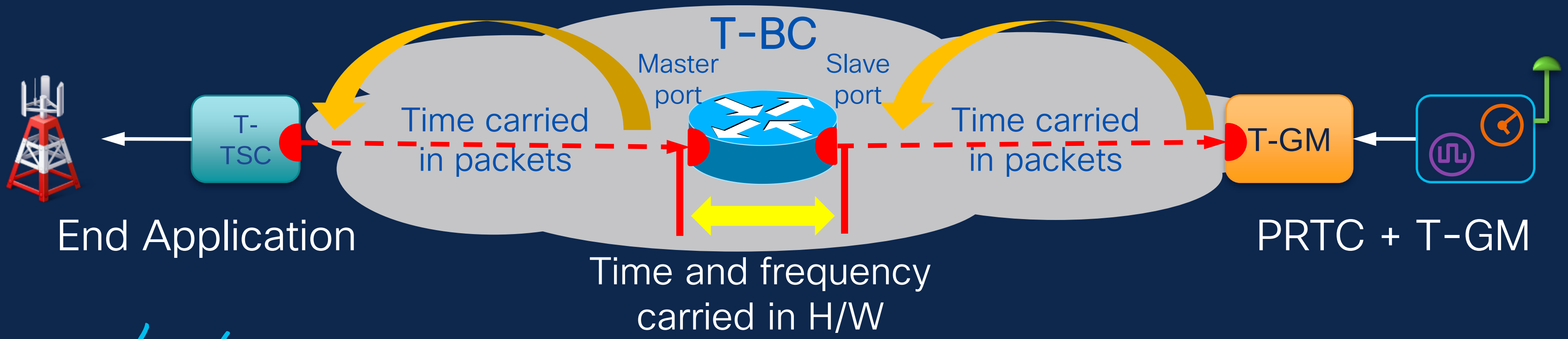
Allocating Timing Budget v Node Performance



Performance Class	Max Total Time Error max|TE|	Constant Time Error cTE	Dynamic Time Error dTE_L low pass
Class A	100 ns	±50 ns	±40 ns
Class B	70 ns	±20 ns	±40 ns
Class C	30 ns	±10 ns	±10 ns
Class D	5 ns (low pass)	For further study	For further study

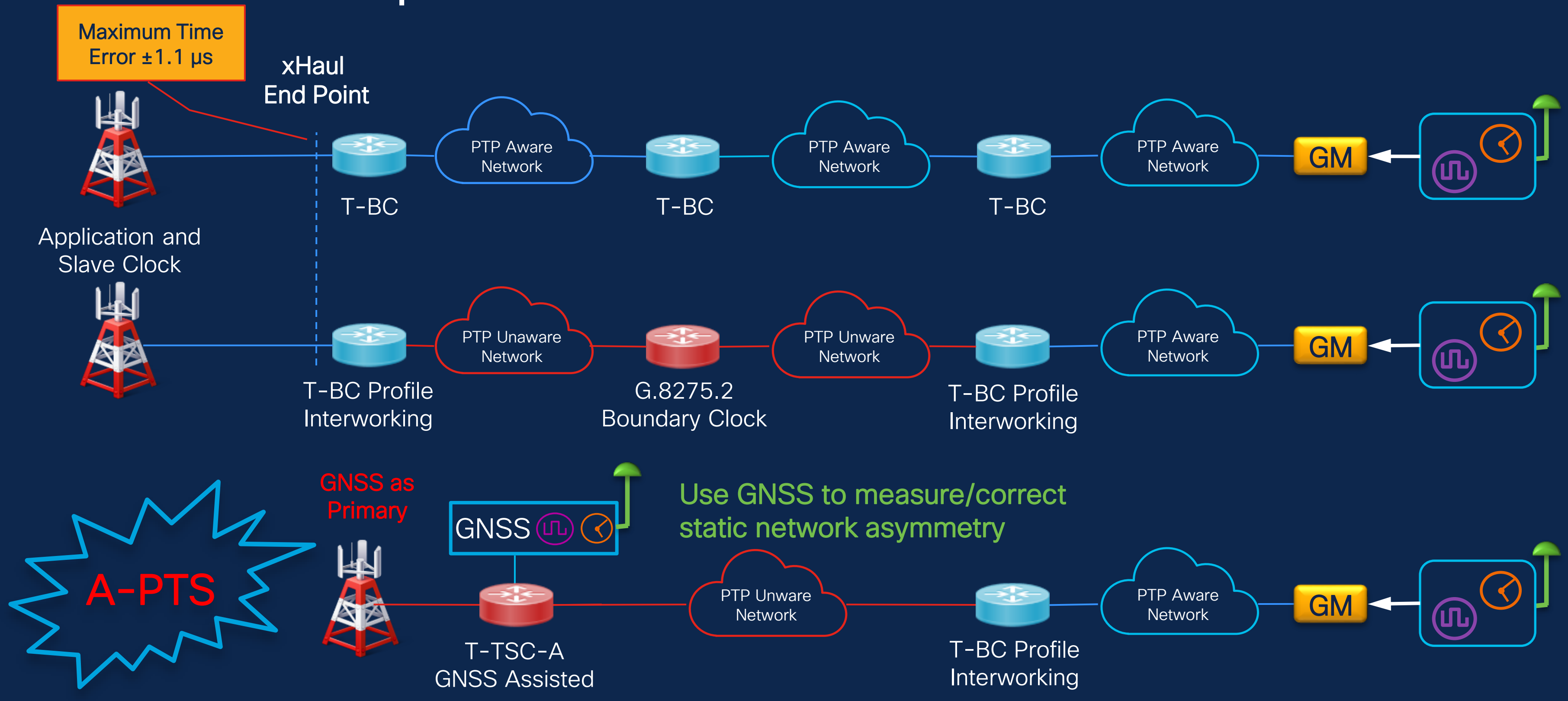
Define the Node/Clock Performance

- PTP aware nodes carry time in hardware
  - Properly implemented, they have predictable performance
  - It is easy to test/confirm this performance (standardized testing)
- Sync can cross more hops or meet a lower budget by using better clocks,
  - 5G Fronthaul can have much stricter requirements than the 1.5 µs end-to end



A-PTS = Assisted Partial Timing Support

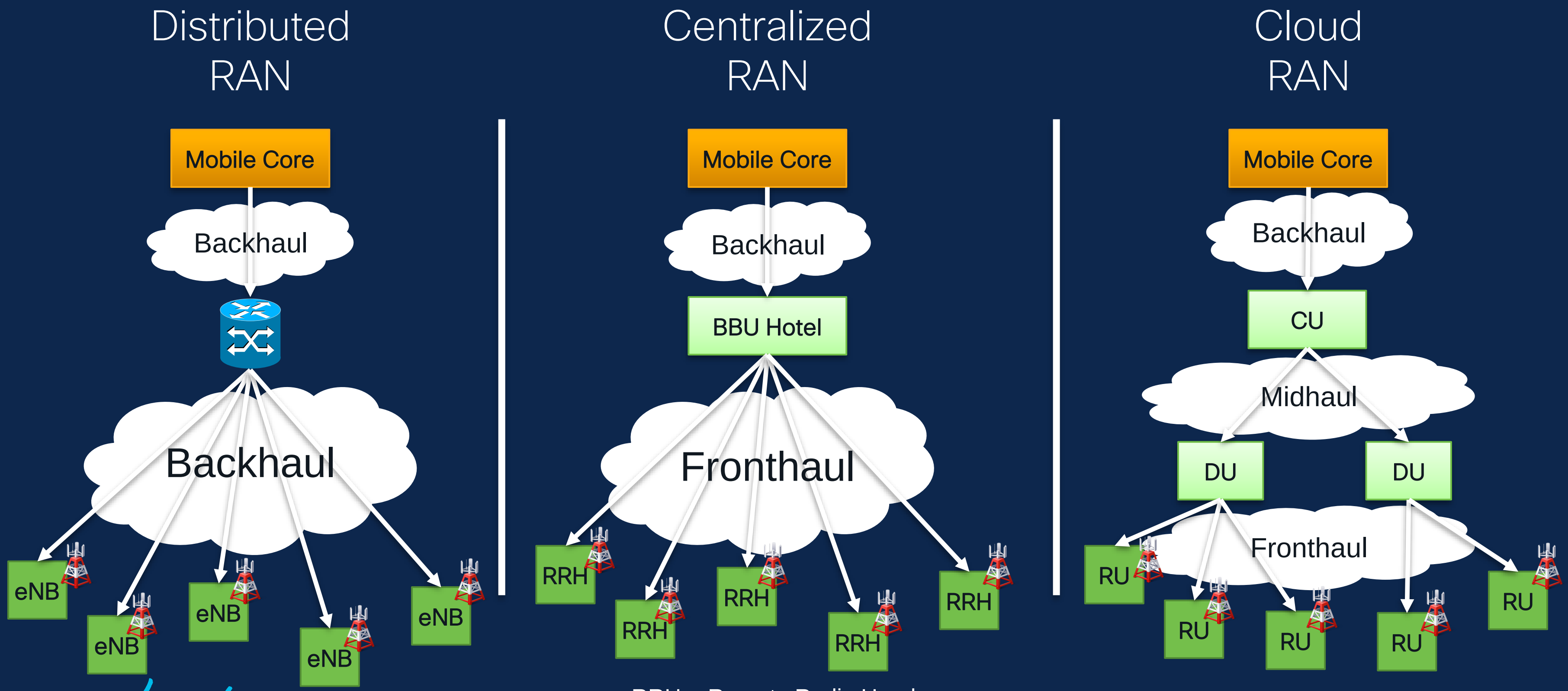
Solution Options



5G RAN Timing Solutions

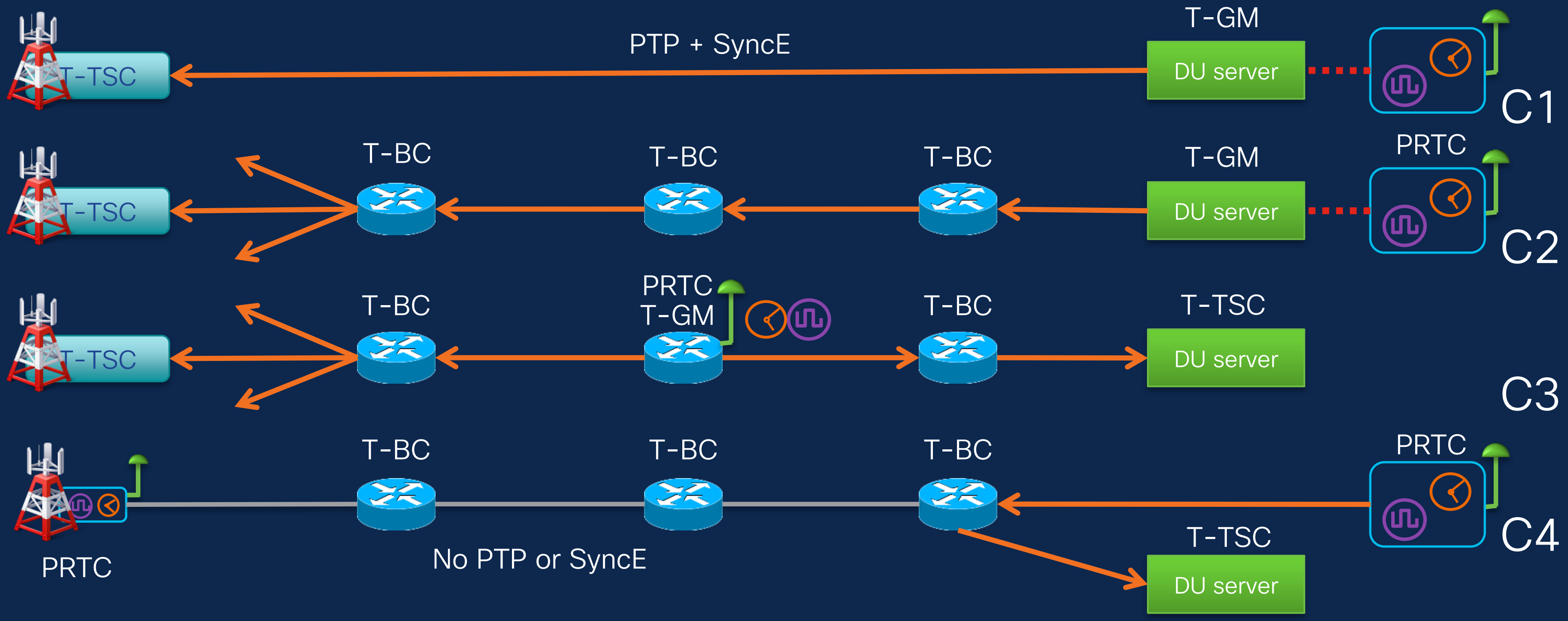
RAN Topologies

CU = Centralized Unit
DU = Distributed Unit
RU = Radio Unit



RRH = Remote Radio Head

O-RAN Fronthaul Deployment Options



Source: O-RAN-WG4.CUS.0-v08.01

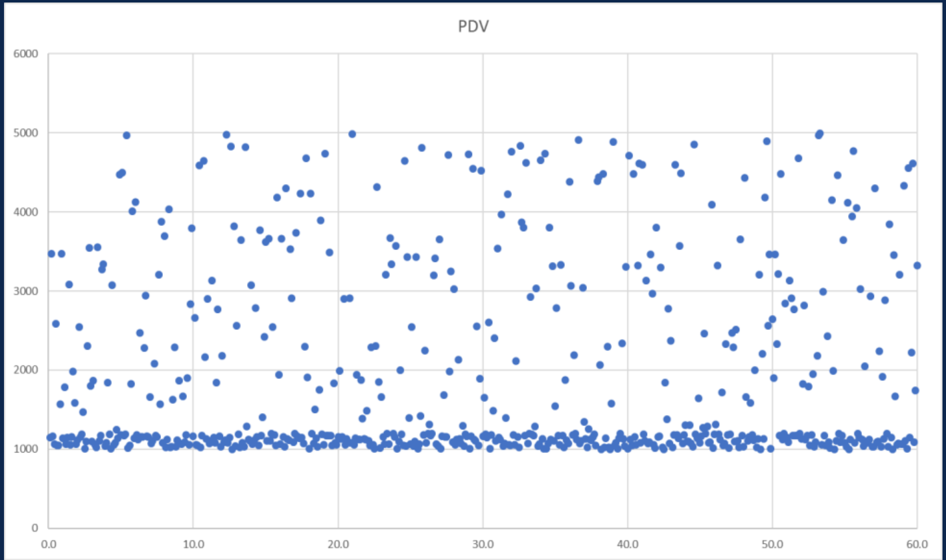
Deployment and Best Practices

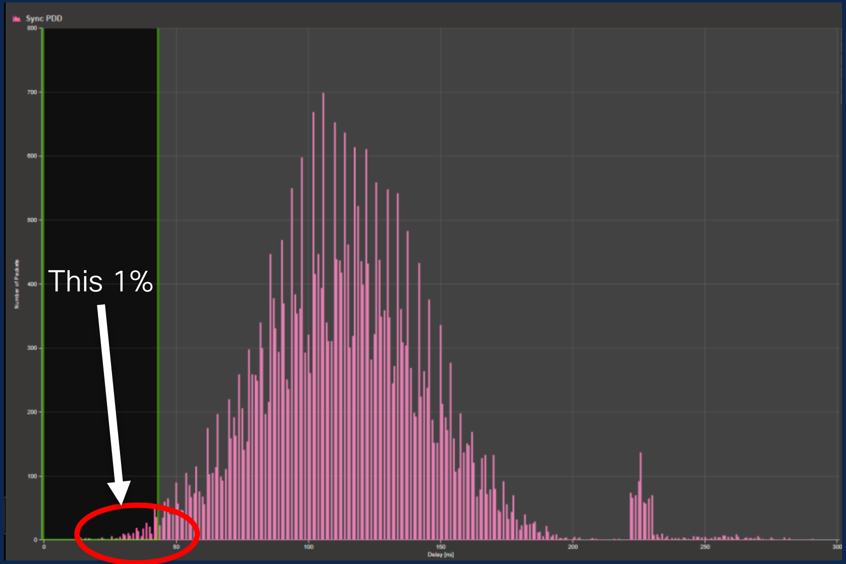
Network Design

- Phase Synchronization
  - Deploy G.8275.1 with physical frequency (SyncE/eSyncE)
  - Reduce PDV wherever possible (boundary clocks reset PDV back to zero)
  - Control asymmetry (routing, link, node, transport); boundary clocks limit asymmetry
  - Transport layer may have asymmetry problems that could require fixing
- Frequency Synchronization
  - If possible, use physical distribution (SyncE/eSyncE) not packet for frequency
  - G.8265.1 interoperates with SONET/SDH & SyncE (gaps with eESMC mapping)
  - Packet distribution goal: reduce PDV (minimize hops as it disallows aware nodes)
  - Asymmetry isn't an issue for frequency over packet

Reduce PDV

- Packet Delay Variation grows passing through unaware nodes:
  - Must have a “floor” (about 1 percent) of lucky packets arriving in minimum time
  - Accumulates with every unaware node – mostly “reset to zero” with T-BC’s



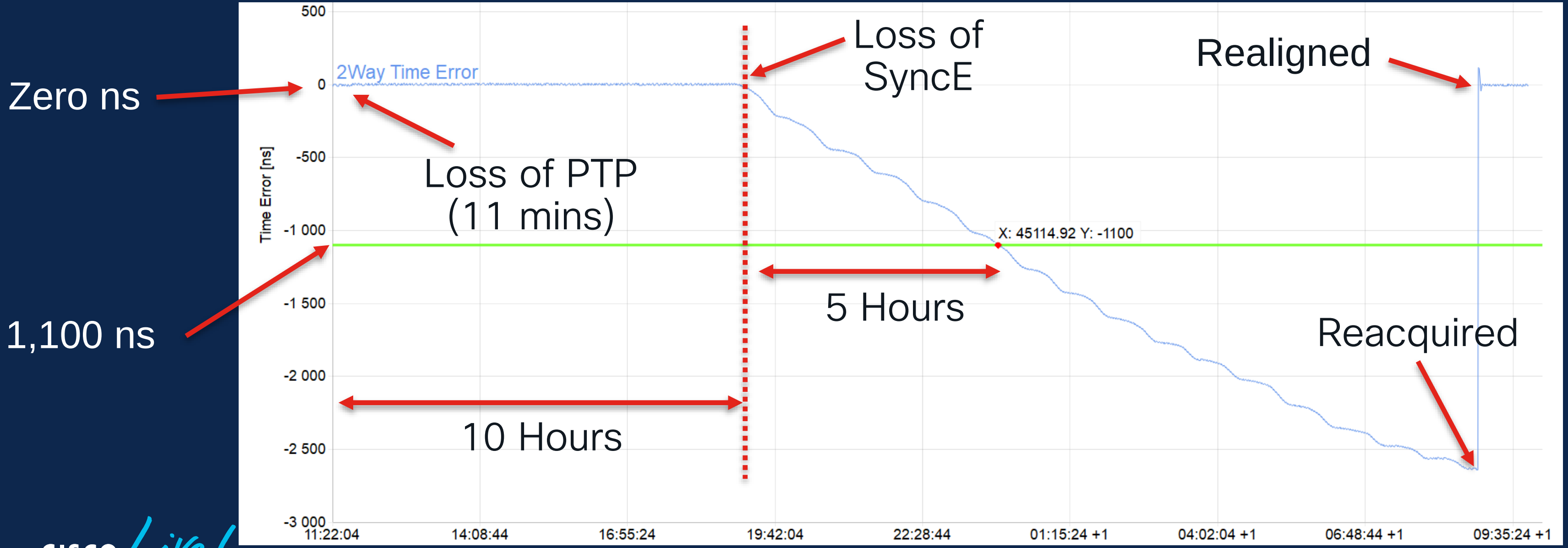


Reduce Asymmetry

- 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 μsecs of asymmetry = 1 μsec of time error
- Reducing asymmetry on unaware network is hard:
  - QoS cannot really solve the problem – but it helps
- Boundary clocks handle asymmetry inside the nodes
  - Assuming they are properly engineered and built
  - Must be cautious of asymmetry from advanced pluggable optics

Holdover: SyncE and non-SyncE

- Holdover: either oscillator only, or assisted with external frequency (SyncE)
- Relying on local oscillator: staying < 1.1µs only possible for several hours

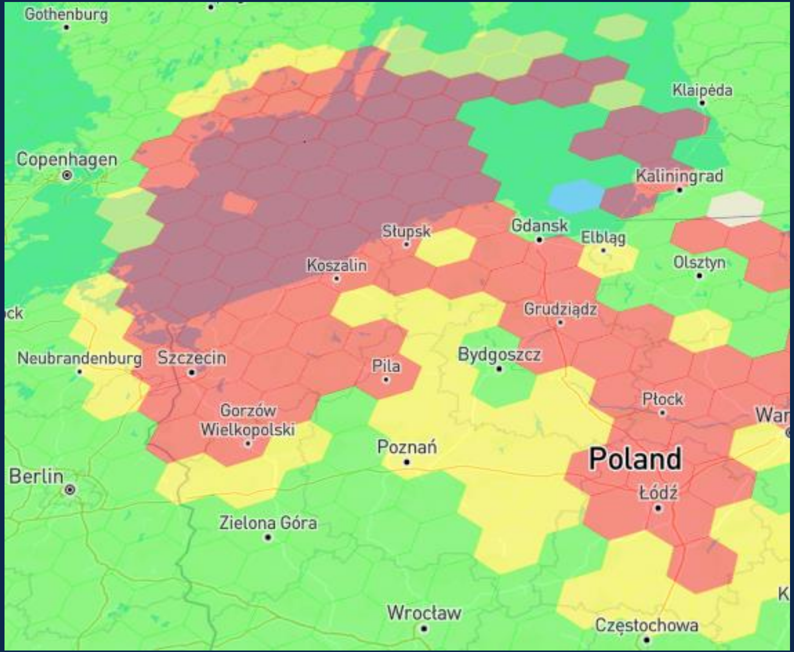


Deploying Satellite Systems

- Jamming and GNSS issues
  - Short term interruptions are ok (expected?) – but devices must support holdover
  - Jamming is not a matter of IF, but a matter of WHEN and HOW LONG?
  - Regulators are taking a hard look at organizations' reliance on GNSS time
- There are some solutions that help mitigate jamming/spoofing:
  - GNSS "Firewalls" from several vendors
  - "Anti-jam" antennas reject/attenuate false or overwhelming signals
  - Military-derived "active" CPRA (Controlled Radiation Pattern) Antennas
  - Geographical redundancy: separating receivers (also for weather events)
  - Robust holdover (especially with SyncE assistance)
  - Multi-band and multi-constellation can help but are no guarantee!!!

“Baltic Jammer”

- Jamming seems to coming from Russian enclave of Kaliningrad



- Likely Electronic Warfare unit
- Varies in power from day-to-day
- Covers much of the Baltic
- Denying GNSS to half of Poland
- Reaches almost to Berlin on some days
- Red spots show inaccurate fix in aircraft
- Image source: gpsjam.org for Jan 19th

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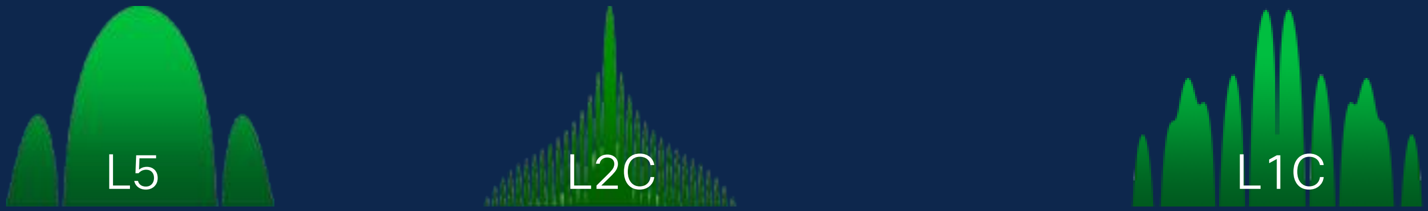
Deploying Satellite Systems

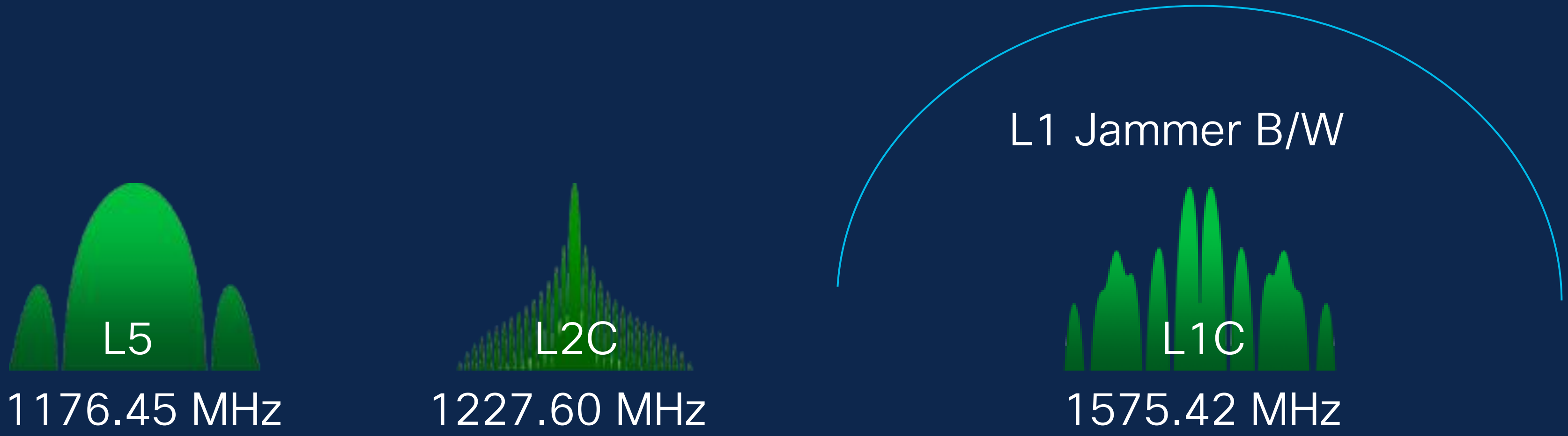
- Many GNSS transmit in several separate bands: for GPS, that’s L1, L2, L5
  - L1 is the default/legacy band for GPS, other bands were military only
  - Later generations of satellites have introduced civilian signals in L2 and then L5
  - L5 (aviation band) is a more robust, higher power and better performing signal
  - New L1C signal is coming to supplement the long-running L1 C/A



1176.45 MHz | 1227.60 MHz | 1575.42 MHz

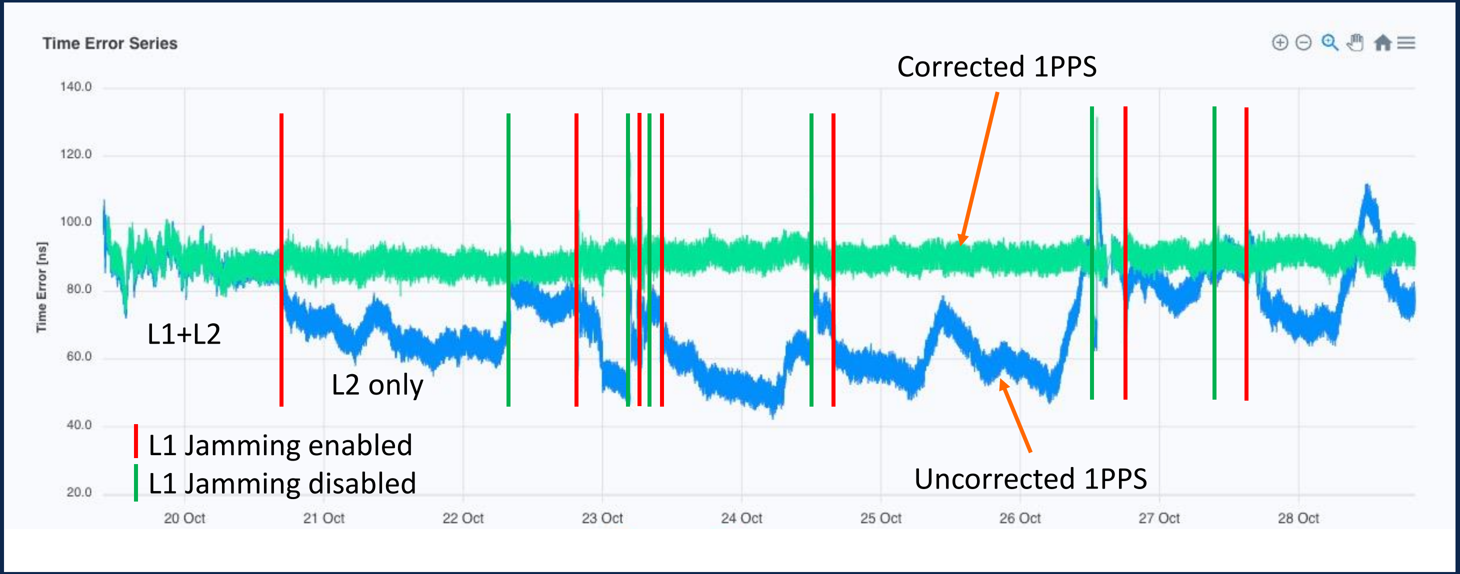
Deploying Satellite Systems

- Multiple bands can improve resistance to jamming/spoofing
- Spoofing multiple bands is hard, typically they spoof 1 band, jam others
- People working on techniques to improve resiliency (e.g. common view)



Deploying Satellite Systems

- Innovators producing ways to use multiple bands to improve performance
- “Common view” technique using authenticated data from remote source...



Source: Zdenek Chaloupka, Timing Solutions (Limited)

Enhanced SyncE (eSyncE and eESMC)

eSEC/eEEC = G.8262.1
ESMC/eESMC= G.8264

- eSyncE was introduced in new recommendation G.8262.1 (Jan 2019)
  - Improved performance: especially frequency wander on output
  - Increasingly rolled into components, network devices (esp. class C level T-BCs)
- Enhanced TLV in ESMC (Apr 2016 amend.) for new clock types & functionality
  - Allowed higher accuracy clock sources, time sources, and enhanced SyncE clocks
  - Added new TLV for "extended quality levels" such as PRTC, ePRTC, ePRC, eSEC/eEEC
  - Includes new clockIdentity TLV for source of the SyncE signal
  - Separate count of the SEC/EEC and eEEC/eSEC hops from the originating source
- Significant interoperability issues can arise in a mixed network:
  - Nodes that do not support enhanced TLV will drop it!!!

ESMC = Ethernet Synchronization Message Channel

Enhanced TLV from ESMC

- Supported across the –XR portfolio
  - Support for "enhanced" QL values (PRTC, eEEC, ePRC, ePRTC, EEC1, EEC2)
  - Introduces hop count and clock identity, like the PTP Announce message
  - No mechanism yet written into G.781 to use these fields to select a source
  - Frequency selection will choose HIGHER QL level before PRIORITY (eSyncE before SyncE)
  - Node not supporting enhanced TLV will drop it and "break the chain" of enhanced traceability
    - Next node supporting enhanced TLV will readd it (own clockIdentity, restart count with eEEC:1, EEC:1)
    - Next node supporting enhanced TLV sets mixed EEC/eEEC and sets partial chain flag

clockIdentity: Node1
Count of EEC clocks: 0
Count of eEEC clocks: 1
Mixed EEC/eEEC: No
Partial chain flag: No

clockIdentity: Node1
Count of EEC clocks: 1
Count of eEEC clocks: 1
Mixed EEC/eEEC: Yes
Partial chain flag: No

No enhanced TLV processing and so TLV not forwarded

clockIdentity: Node4
Count of EEC clocks: 1
Count of eEEC clocks: 1
Mixed EEC/eEEC: Yes
Partial chain flag: Yes

clockIdentity: Node4
Count of EEC clocks: 1
Count of eEEC clocks: 2
Mixed EEC/eEEC: Yes
Partial chain flag: Yes

Deploying Timing Summary

- Engineer a “timing solution” and not just solve a connectivity problem
  - Timing design is an end-to-end budgeting exercise
  - Remove as much asymmetry and PDV as possible
  - Be very cautious with PTPoIP
  - Not try to get too fancy with the packet design
- PTP aware networks limit the accumulation of PDV and time error
- Upgrade transport systems to be PTP and SyncE aware
- Deploy SyncE for stability/holdover, move to end-2-end enhanced SyncE
- Try to understand your GNSS vulnerability and have a backup strategy
- Work <u>with</u> the standard solutions rather than trying to “roll your own”

Troubleshooting

Steps-In Order

- Frequency Synchronization and ESMC state
- Status of the PTP interface and the PTP encapsulation
- Foreign master
  - Make sure the domains agree, clockClass, clockAccuracy
- Packet Counters
- Servo State and Timestamps
  - Ensure the FPGA devices have been upgraded to latest version
- Advertised clock

Frequency Synchronization and ESMC state

```
Router#show frequency synchronization interfaces brief
Flags:  > - Up                D - Down              S - Assigned for selection
        d - SSM Disabled      x - Peer timed out    i - Init state
        s - Output squelched
Fl   Interface                QLrcv QLuse Pri QLsnd Output driven by
==== ======================== ===== ===== === ===== ========================
>S   TenGigE0/0/0/10          PRC   PRC     5 DNU   TenGigE0/0/0/10
>S   TenGigE0/0/0/12          PRC   PRC    10 PRC   TenGigE0/0/0/10
```

Interface State and Encapsulation

```
Router#show ptp interface brief

Intf              Port         Port                    Line
Name              Number       State        Encap      State          Mechanism
--------------------------------------------------------------------------------
Te0/0/0/10        2            Slave        Ethernet   up             -
Te0/0/0/11        3            Passive      Ethernet   up             2-step DRRM
Te0/0/0/47        4            Initializing Ethernet   down           2-step DRRM
Hu0/2/0/0         6            Master       Ethernet   up             1-step DRRM
Hu0/1/0/0         1            Initializing IPv4       unknown        2-step DRRM
Hu0/4/0/0         5            Uncalibrated Ethernet   up             2-step DRRM
```

Foreign masters

```
Router#show ptp foreign-master best
Interface GigabitEthernet0/0/0/4 (PTP port number 5)
Ethernet, Address E85C.0A77.AC02, Multicast
Configured priority: None (128)
Configured clock class: None
Configured delay asymmetry: None
Qualified for 1 hour, 43 minutes, 59 seconds
Clock ID: e85c0afffe77ac8d    ← GM clockID
Received clock properties:
  Domain: 24, Priority1: 128, Priority2: 128, Class: 6
  Accuracy: 0x21, Offset scaled log variance: 0x4e5d
  Steps-removed: 1, Time source: GPS, Timescale: PTP   ← One T-BC in chain
  Frequency-traceable, Time-traceable
  Current UTC offset: 37 seconds (valid)
Parent properties:
  Clock ID: 8025fffe7e5480  ← clockID of parent (master port)
  Port number: 1
```

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Interface Packet Counts-Master End (1-step)

```
Router#show ptp packet-counters tenGigE 0/0/0/15

  Packets                       Sent       Received       Dropped
  ---------------------------------------------------------------
  Announce                       597              0             0
  Sync                          1193              0             0
  Follow-Up                        0              0             0
  Delay-Req                        0            306             0
  Delay-Resp                     306              0             0
  Pdelay-Req                       0              0             0
  Pdelay-Resp                      0              0             0
  Pdelay-Resp-Follow-Up            0              0             0
  Signaling                        0              0             0
  Management                       0              0             0
  Other                            0              0             0
```

Interface Packet Counts-Slave End (2-step)

```
Router#show ptp packet-counters tenGigE 0/0/0/14

  Packets                        Sent        Received        Dropped
  -------------------------------------------------------------------
  Announce                          0             608              0
  Sync                              0            1217              0
  Follow-Up                         0            1217              0
  Delay-Req                       594               0              0
  Delay-Resp                        0             594              0
  Pdelay-Req                        0               0              0
  Pdelay-Resp                       0               0              0
  Pdelay-Resp-Follow-Up             0               0              0
  Signaling                         0               0              0
  Management                        0               0              0
  Other                             0               0              0
```

Servo State and Timestamps-Good

```
Router#show ptp platform servo

Servo status: Running
Servo stat_index: 2
Device status: PHASE_LOCKED  ! FREQ_LOCKED when SyncE only is locked
Servo Mode: Hybrid
Servo log level: 0
Phase Alignment Accuracy: 1 ns
Sync timestamp updated: 1398061
Sync timestamp discarded: 0
Delay timestamp updated: 1409313
Delay timestamp discarded: 0
Last Received Timestamp T1: 1701864243.745991140 T2: 1701864243.745994674
                        T3: 1701864243.754582538 T4: 1701864243.754586075
Offset from master:  0 secs, 1 nsecs
Mean path delay : 0 secs, 3535 nsecs
```

Servo State and Timestamps-BAD!

```
Router#show ptp platform servo      ! T1, T4 from master, T2 and T3 from slave

Servo status: Running
Servo stat_index: 4
Device status: FREERUN
Servo Mode: Hybrid
Servo log level: 29696
Phase Alignment Accuracy: 1676072730853233567 ns
Sync timestamp updated: 3673087930
Sync timestamp discarded: 0
Delay timestamp updated: 367277020
Delay timestamp discarded: 0
Last Received Timestamp T1: 1701809073.714897160  T2: 83314.205745391
                        T3: 83314.212403270       T4: 1701809073.721661829
Offset from master: -1676072730 secs, 853234548 nsecs
Mean path delay   :  0 secs, 640 nsecs
```

FPGA Upgrades to latest version

```
Router#show hw-module fpd

Auto-upgrade:Disabled
Attribute codes: B golden, P protect, S secure
                                                                   FPD Versions
                                                                  ==============
Location   Card type             HWver FPD device       ATR Status   Running Programd  Reload Loc
-------------------------------------------------------------------------------------------------
0/RP0/CPU0 N540X-12Z16G-SYS-A    2.0   ADMConfig            UPGD FAIL  1.00     1.00          0/RP0
0/RP0/CPU0 N540X-12Z16G-SYS-A    2.0   IoFpga               NEED UPGD  1.43     2.07          0/RP0
0/RP0/CPU0 N540X-12Z16G-SYS-A    2.0   IoFpgaGolden     B   CURRENT             1.31          0/RP0
0/RP0/CPU0 N540X-12Z16G-SYS-A    2.0   Primary-BIOS      S  RLOAD REQ  1.19     1.33          0/RP0
0/RP0/CPU0 N540X-12Z16G-SYS-A    2.0   StdbyFpga         S  CURRENT    0.40     0.40          0/RP0
0/RP0/CPU0 N540X-12Z16G-SYS-A    2.0   StdbyFpgaGolden  BS  CURRENT    0.40     0.40          0/RP0
0/RP0/CPU0 N540X-12Z16G-SYS-A    2.0   TamFw             S  CURRENT    4.11     4.11          0/RP0
0/RP0/CPU0 N540X-12Z16G-SYS-A    2.0   TamFwGolden      BS  CURRENT    4.11     4.11          0/RP0
```

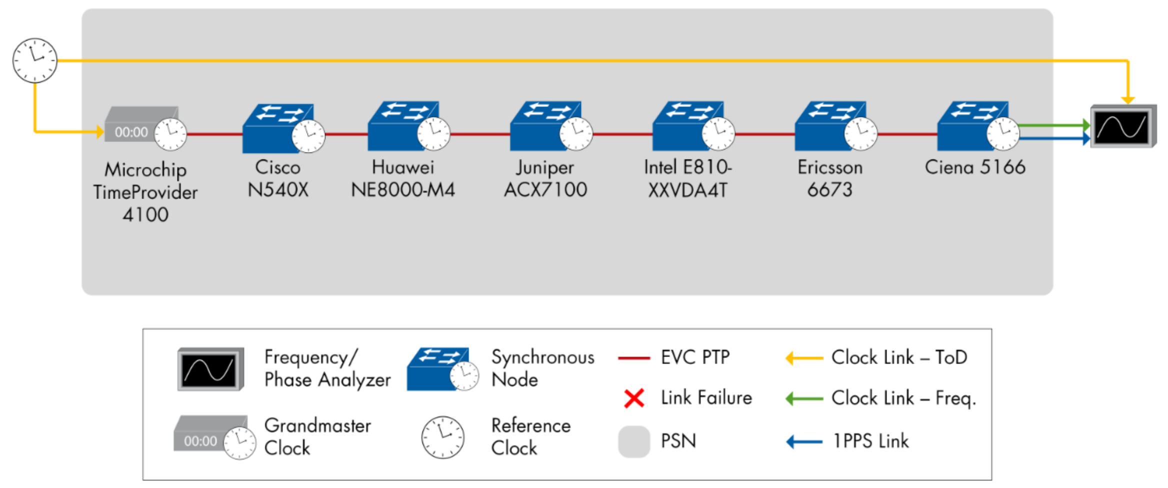
PTP Advertised Clock

```
RP/0/RP0/CPU0:CVCMHL0001A-CS000-PE001#show ptp advertised-clock
Fri Jan 19 03:58:54.829 UTC
Clock ID: 4c5d3cfffe4e5e00
Clock properties:
  Domain: 24, Priority1: 128, Priority2: 128, Class: 6
  Accuracy: 0x21, Offset scaled log variance: 0x4e5d ! ePRTC, ePRC has other values
  Time Source: GPS
  Timescale: PTP
  Frequency-traceable, Time-traceable
  Current UTC offset: 37 seconds (valid)
```

Interoperability

Multi-Vendor Interoperability

- Interop good, but latest ITU-T changes not up-to-date at same time
  - Staged at EANTC centre in Berlin, showcase: MPLS SD & AI Net World Congress
  - You can download 2023 report: https://eantc.de/events/mpls-sdn-interop-2023/



Multi-Vendor Interoperability

- Changes to the PTP Announce Message from G.8275.1
  - clockAccuracy and offsetScaledLogVariance need to carry ePRTC values
  - 1st version dropped Announce with outliers, now must accept all valid 1588 codes
- Addition of the “enhanced TLV” in the SyncE ESMC messages (G.8264)
  - Developed to allow ESMC to carry enhanced ePRTC quality level values
  - All platforms in the network must support these changes
  - Backwards compatibility is designed into the standards:
    - Nodes not supporting Enhanced TLV must ignore it
    - Some platforms (no names) drop the WHOLE ESMC message and not just the TLV
    - This breaks SyncE totally, not just the chain of enhanced TLV

Latest Developments

Inclusive Language

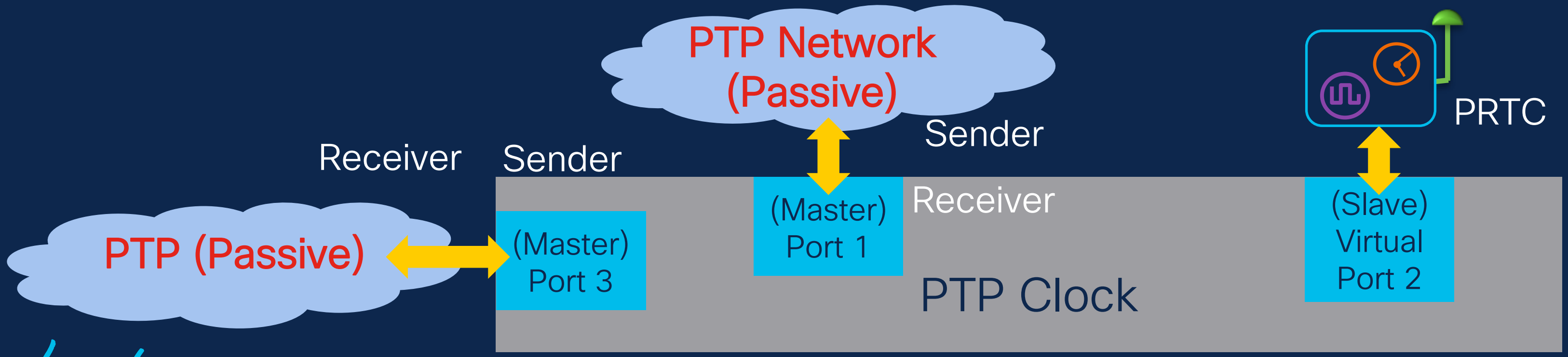
- IEEE introduced “optional” alternative terms for master/slave
  - Published IEEE Std 1588g-2022 to standardize them
    - “master” ➔ “timeTransmitter”; “slave” ➔ “timeReceiver”
    - “TT” for timeTransmitter, TimeTransmitter, and TIME_TRANSMITTER
    - “TR” for timeReceiver, TimeReceiver, and TIME_RECEIVER
    - “Grandmaster” remains “Grandmaster”
    - Folded into 1588-2019 as Amendment 2
- Note from new clause 4.4:
  “Replacing the terms “Master” and “Slave” will not affect PTP interoperability because the terms do not appear in PTP messages on the wire. However, interoperability of management mechanisms might be affected.”

Inclusive Language

- ITU-T will adopt new terms, but ONLY on future recommendations
  - T-TSC becomes Telecom-Time Synchronous Clock
  - Slave-only Ordinary Clock (SOOC) ➔ timeReceiver-only ordinary clock
  - Also affects the names of recommendations (e.g., G.8273.2)
  - Will take a while for all these changes to flow through the system
  - SyncE standards hardly affected, removed 1 or 2 slave references
- Too late to stop spread of many different terms in other areas
  - Client-server, leader-follower, etc.
- Playing havoc with data structures and YANG models
  - notTimeTransmitter and timeReceiverOnly from the port dataset
  - Two YANG models in Github covers original and alternative terminology

Monitoring and OAM

- Annex G (G.8275.1) added "Passive Port Monitoring"
  - Servo recovers time from non-slave ports to detect inconsistencies
  - Uses monitorReceiver, monitorSender & alternateMasterFlag fields
  - Also possible is network PTP monitoring via Virtual Port + GNSS
  - Coming to XR release in release 24.2.1 (end February/March)



Timing as a (National) Service

- Regulators demanding national critical infrastructure free of GNSS
- Defining a National Time Standard for UTC time
  - Many countries already do this, known as UTC(k)
  - But connectivity to clocks at national physics laboratories is limited
  - What many countries do NOT do, is to distribute it widely
- Now building national timing distribution networks
  - Build POPs for user orgs to connect to – how is this funded?
  - Operators pay to connect their own networks to the time POP
- National clock keeps low relative time error between operators

What's Happening in the Standards?

- ITU-T standards developments
  - May adopt optional features from 1588-2019 (such as Accuracy TLV)
  - Monitoring (OAM) and YANG models for Telecom Profiles (G.7721.1)
  - Increasing work on improving PTP security
- IEEE standards developments
  - 1588a Amend. 3: PTP enhancements for aBMCA with "Enhanced Accuracy TLV"
  - 1588e (MIB + YANG model for PTP) https://ieeexplore.ieee.org/document/10289672
  - Left-overs from 1588-2019 (e.g. P1588d: GDOI Key Exchange for Security)
  - IEEE P1952, Resilient Positioning, Navigation, and Timing User Equipment
- O-RAN standards development
  - Changes from the O-RAN specifications (for example, security work)

Conclusions

Conclusion

- Timing requires its own specific design for both PTP and SyncE
- Timing challenges coming up in more industries all the time
- 5G Fronthaul introduces additional complexity with relative time
- Lots of effort now going into transport system mitigation
- Deployment of enhanced SyncE in legacy networks
- GNSS independence/resilience increasingly a concern
  - Countries working on some form of national time network
- Security increasingly a problem being worked on

Resources: Past Cisco Live Sessions

5G Timing & Synchronization

- BRKSPG-3050 Synchronizing 5G Mobile Networks
  Event: 2023 Las Vegas

- BRKSPG-3050 Synchronizing 5G Mobile Networks
  Event: 2023 Amsterdam

- BRKSPM-3295 5G Timing & Synchronization Architectures
  Event: 2020 Barcelona

- BRKSPG-2557 5G Synchronization – Design, Testing and Deploying Timing to support 5G rollouts
  Event: 2020 Barcelona

Further Information: Conferences and Standards

- WSTS Workshop on Sync & Timing Systems, May 7-9, 2024, San Diego: https://wsts.atis.org/
- ITSF International Timing & Sync Forum, Nov 4-7, 2024, Seville, Spain: https://itsf2024.executiveindustryevents.com/Event/index.php
- ITU-T Study Group 15 Question 13: https://www.itu.int/en/ITU-T/studygroups/2022-2024/15/Pages/default.aspx
- Next ITU-T Sync Interim Meeting, 8-12 April 2024, Edinburgh UK: https://www.itu.int/en/ITU-T/studygroups/2022-2024/15/Pages/default.aspx
- Next ITU-T Sync Plenary Meeting, TBD – Early July 2024: https://www.itu.int/en/ITU-T/studygroups/2022-2024/15/Pages/default.aspx

Further Information on Budgeting Time Error

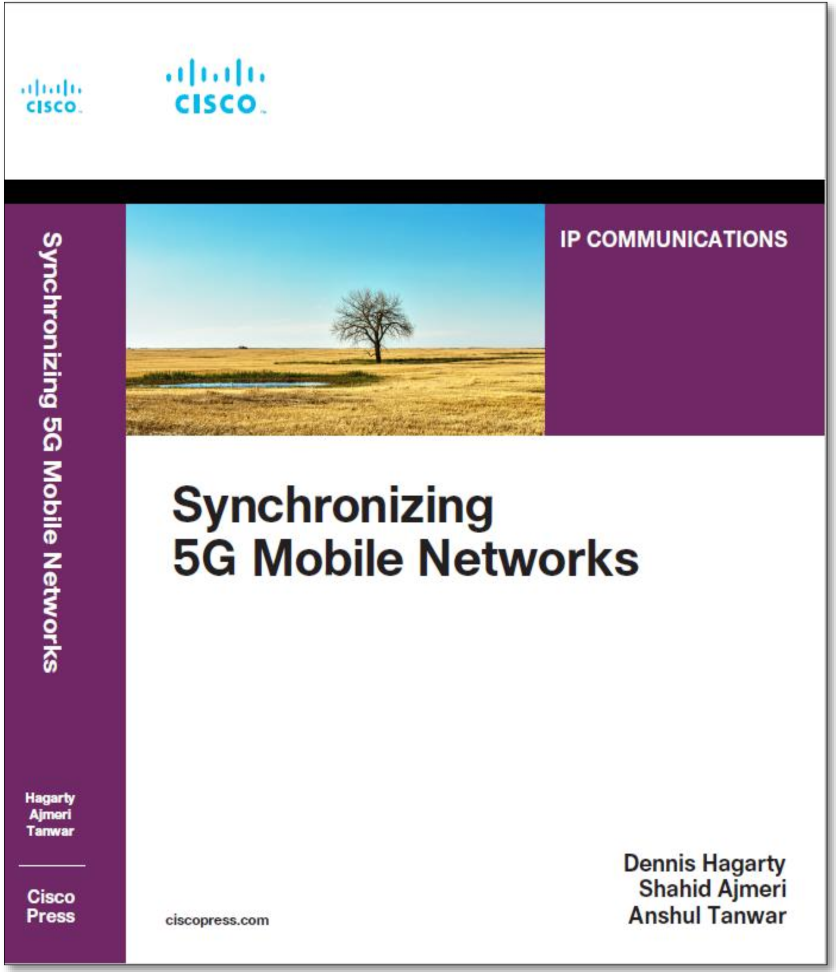
- Network models divide up the end-to-end budget
  - For LTE-A and 5G backhaul, this is ±1.1 μs/±1.5 μs
  - Assigns the budget to the different possible sources of time error
- G.8271.1: full timing support to the protocol level from the network (FTS)
  - Appendix IV "Constant and dynamic time error and error accumulation"
  - Appendix V "Example of design options" – budgeting max|TE|, dTE and cTE
- G.8271.2: partial timing support from the network (PTS)
- There are two Telecom Profiles defined, one for each use case
  - G.8275.1 for Full Timing Support (PTPoE multicast) "hop-by-hop"
  - G.8275.2 for Partial Timing Support (PTPoIP unicast)

Further Information

“Synchronizing 5G Mobile Networks”

https://www.ciscopress.com/store/synchronizing-5g-mobile-networks-9780136836254

Publisher: Cisco Press
eBook & Print
Published: June 2021



The bridge to possible

Thank you

Let's go