DRIVING DIGITAL TRANSFORMATION THROUGH IEEE 802.1 TSN TECHNOLOGY

IEEE TIME-SENSITIVE NETWORKING WEBINAR SERIES:

TSN TO THE FORE OF THE TRANSITION TO 5G WITH IEEE STD 802.1CM™

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MODERATED BY SRI CHANDRASEKARAN, SR DIRECTOR STANDARDS & TECHNOLOGY, IEEE SA

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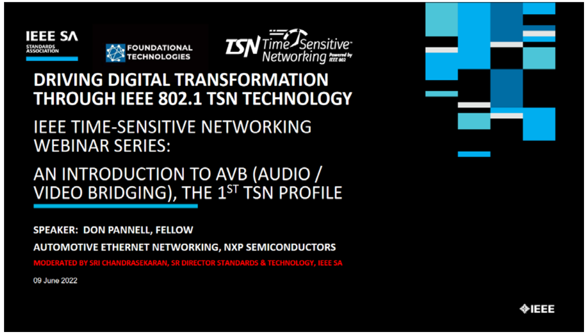

SPEAKER – JESSY ROUYER

Standardization Specialist, Network Infrastructure Business Group, Nokia

Jessy V Rouyer leads Ethernet transport networking standardization at Nokia.

His 22 years of experience in research, software development, and consultancy started with today's Bell Labs at Alcatel USA then Alcatel-Lucent USA and continue in the Optical Networks business within a product line management team focused on packet optical, synchronization, and services.

For two decades, he has contributed and held technical editor as well as leadership positions in IEEE SA, ITU-T, and MEF Forum. He became a MEF CECP. Following work on IEEE Std 802.1CM, he is currently YANG technical editor for IEEE P1914.3 revising Radio over Ethernet, and editor of ITU-T Recommendations central to Ethernet transport networking. He also serves as IEEE 802.1 Working Group Vice-Chair and Recording Secretary, and ITU-T SG15 Q10 Rapporteur.

Based in Texas, he holds over 20 granted patents and received his MSCS specializing in computer networks and systems from Université Henri Poincaré, France.

TSN to the fore of the transition to 5G with IEEE Std 802.1CM™

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OUTLINE

From 4G to 5G with TSN

Synchronization

Latency

Frame preemption

Fronthaul profiles

Bridge and end station requirements

Summary

Source: NSSDC

From 4G to 5G with TSN

From 4G to 5G

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4G → 4.5G → 5G

CA · CoMP · eICIC · MTC · mMIMO · V2X · ULL

4G

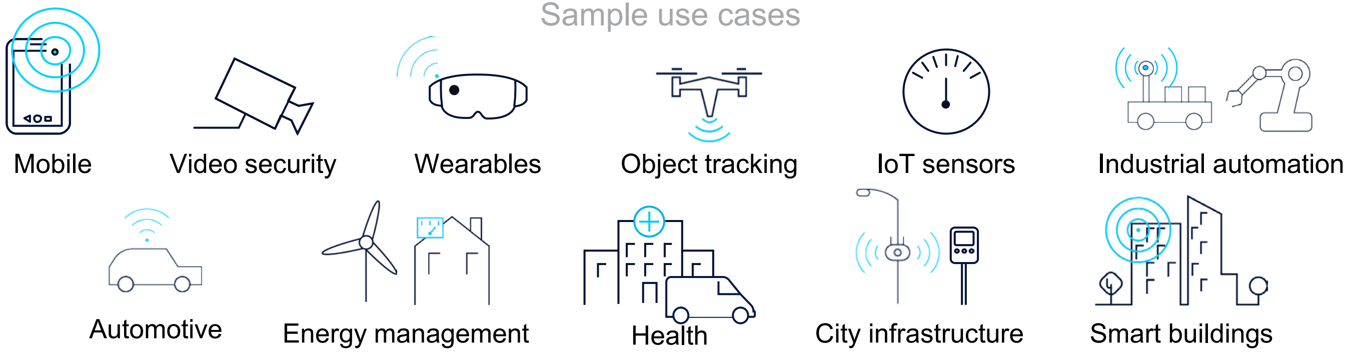
- MBB / higher bandwidth focus
- CPRI*
- Centralized RAN
- Site simplification
- Ethernet Backhaul

4G and 5G co-existence

5G

- eMBB, mMTC, uRLLC focus
- eCPRI**
- Cloud RAN
- Service driven optimization
- Ethernet Fronthaul

Sample use cases



* Common Public Radio Interface. ** eCPRI is not an acronym.

Radio Access Network evolution

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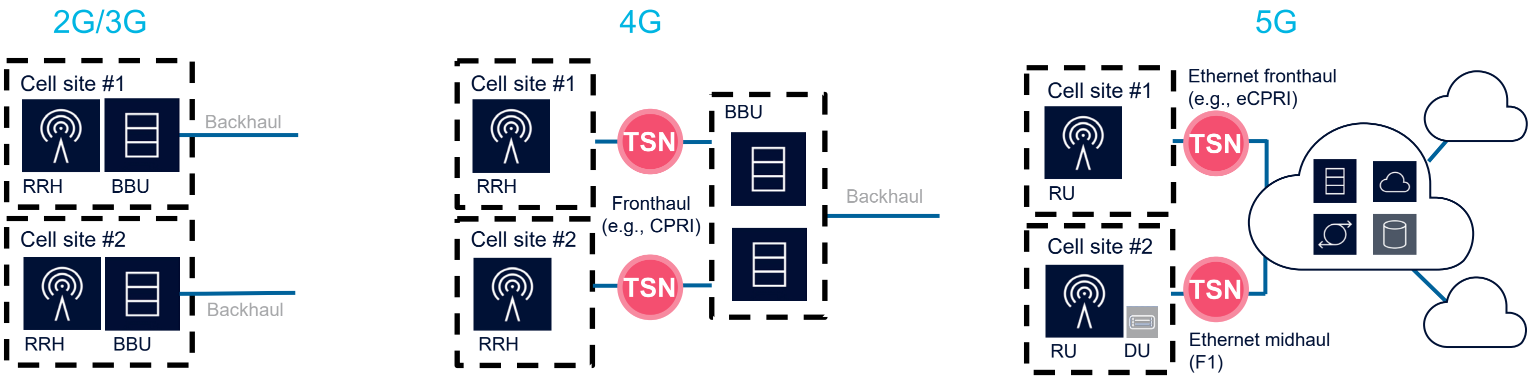

Performance gain

Distributed RAN
Radio and baseband functions collocated at cell site.

Centralized RAN
Radio functions located at cell site. Baseband functions centralized. Fronthaul based e.g., on CPRI.

Cloud RAN and beyond
Baseband functions split between radio site and the cloud. Ethernet fronthaul used to interconnect these functions.

Backhaul used for network interconnection

IEEE 802.1 Time-Sensitive Networking for Fronthaul

FOUNDATIONAL TECHNOLOGIES

IEEE Std 802.1CM™-2018
IEEE Standard for Local and metropolitan area networks – Time-Sensitive Networking for Fronthaul

Approved 7 May 2018
Published 8 June 2018

Also adopted as **ISO/IEC/IEEE 8802-1CM:2019** Telecommunications and information exchange between information technology systems — Requirements for local and metropolitan area networks — Part 1CM: Time-sensitive networking for fronthaul

Base

IEEE Std 802.1CMde™-2020
IEEE Standard for Local and metropolitan area networks – Time-Sensitive Networking for Fronthaul Amendment 1: Enhancements to Fronthaul Profiles to Support New Fronthaul Interface, Synchronization, and Syntonization Standards

Approved 4 June 2020
Published 16 October 2020

Forwarded for adoption to ISO/IEC/ JTC 1 SC 6

Amendment

This webinar assumes **base** IEEE Std 802.1CM as **amended** by IEEE Std 802.1CMde: "IEEE 802.1CM/de"

Collecting use cases and requirements

FOUNDATIONAL TECHNOLOGIES

3GPP

Specifies 4G and 5G technologies at large and attendant technical details, e.g., limits on the radio interface

CPRI Cooperation

Specifies CPRI, eCPRI, attendant technical details, and requirements for fronthaul networking, e.g., categories A, B, C

IEEE 1588

Specifies the Precision Time Protocol (PTP) for distributing time and frequency over a packet network

ITU-T Study Group 15 Question 13

Specifies PTP telecom profiles, network limits, clock requirements for PTP and Synchronous Ethernet (SyncE)

IEEE 802.1

Specifies profiles leveraging the TSN toolset and ITU-T Q13/15 Recommendations as well as attendant conformance statements to satisfy fronthaul networking use cases and requirements over a bridged IEEE 802.3™ Ethernet network

From Centralized RAN to Cloud RAN and beyond

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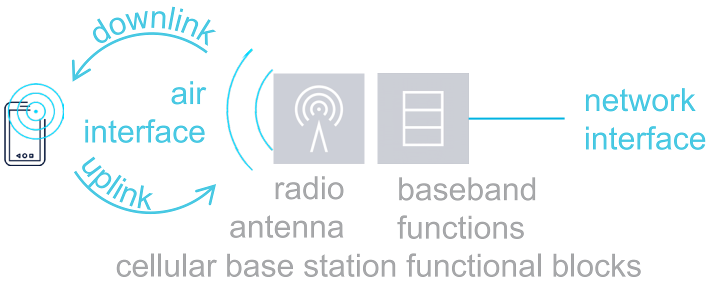
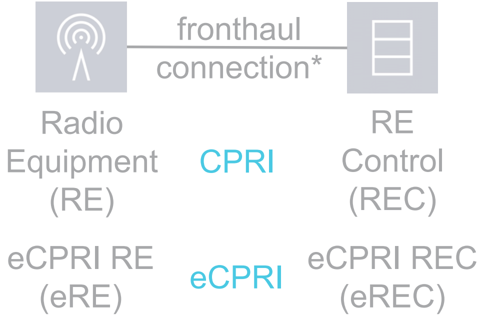
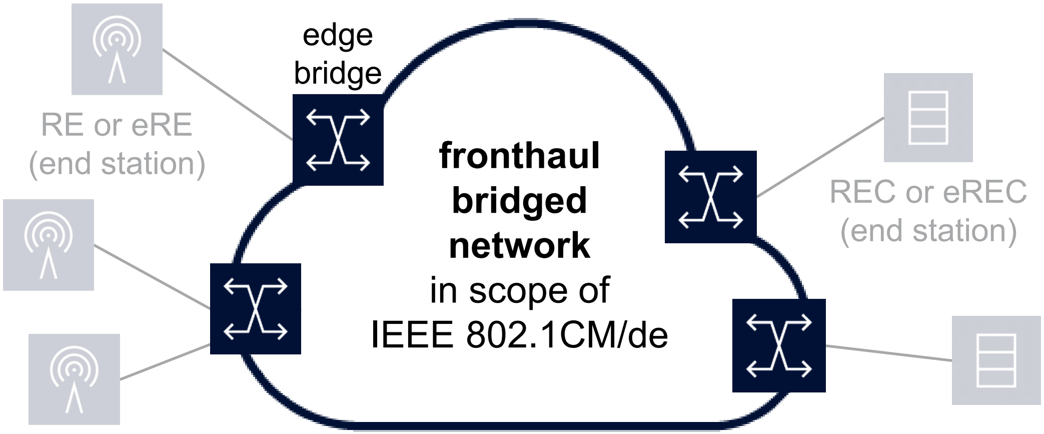






4G and 5G

- Evolved Universal Terrestrial Radio Access (E-UTRA)
- New Radio (NR) access technology for 5G

At least point-to-point connectivity using full-duplex point-to-point links

- Multipoint-to-multipoint or rooted-multipoint connectivity optional

Other traffic ok (if not impacting IEEE 802.1CM/de requirements)

Keep the fronthaul network as simple as possible
Leverage TSN and the ubiquity of Ethernet

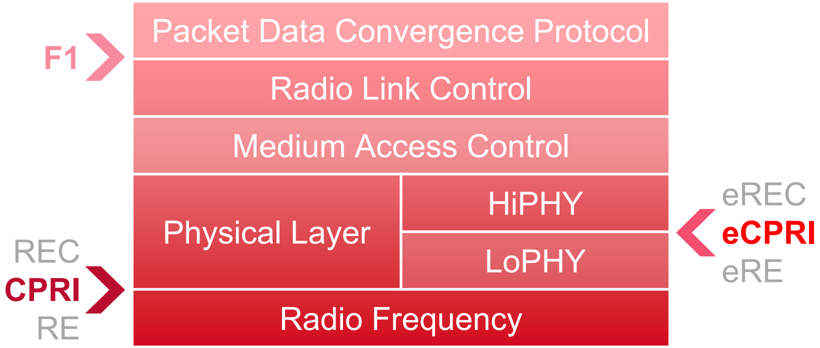
* CPRI specification allows multiple possibilities between end stations: single or multiple point-to-point links, star topology, ring topology.

Two requirement classes for CPRI and eCPRI transport

CPRI information flows or eCPRI Planes supported separately in the fronthaul bridged network

CPRI information flows	eCPRI Planes
IQ data: periodic CBR flow of user plane information in the form of In-phase and Quadrature modulation (IQ) data – IQ data flow packets fit in back-to-back "time windows"	**User Plane**: 3 information flows (User Data, Real-Time Control data, data for other eCPRI services) – "time windows" also used but some may be empty**
C&M data: exchanged between Control and Management (C&M) entities in functional blocks	**C&M Plane*****: includes C&M information exchanged between C&M entities in functional blocks
Synchronization data: for CPRI frame* and time alignment	**Synchronization Plane*****: provides frequency and time/phase synchronization to eREs and eRECs

Class 1 requirements focused on CPRI V7.0 (packetized over Ethernet)



Class 2 requirements focused on eCPRI V2.0 (natively packetized)

* I.e., the CPRI frame structure per CPRI specification; aligned with Orthogonal Frequency Division Multiplexing frame structure used by both E-UTRA and NR.
** Unused bandwidth in the bridged network can be used by fronthaul or other traffic. eCPRI User Data rates corresponding to the same end-user data rates are < than CPRI IQ data rates. *** No eCPRI-specific protocol.

Latency and loss requirements for Class 1 or for Class 2

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Class 1				Class 2			
CPRI information flow	**Max e2e* one-way latency (FILO)**	**Max e2e* FLR**		**eCPRI Plane**	**Latency class*** **	**Max e2e* one-way latency (FILO)**	**Max e2e* FLR**
IQ data	100 μs	10^{-7}	High** Priority Fronthaul (HPF)	User Plane (fast)	High100	100 μs	10^{-7}
					High200	200 μs	
					High500	250 μs	
N/A	N/A	N/A	Medium** Priority Fronthaul (MPF)	User Plane (slow)		1 ms	
				C&M Plane (fast)		1 ms	10^{-7}
C&M data (not as time critical as IQ data)	none	10^{-6}	Low** Priority Fronthaul (LPF)	C&M Plane (slow) (most C&M Plane traffic)		100 ms	10^{-6}
Synchronization data	none	none		Synchronization Plane		none	none

Allows full E-UTRA/NR performance

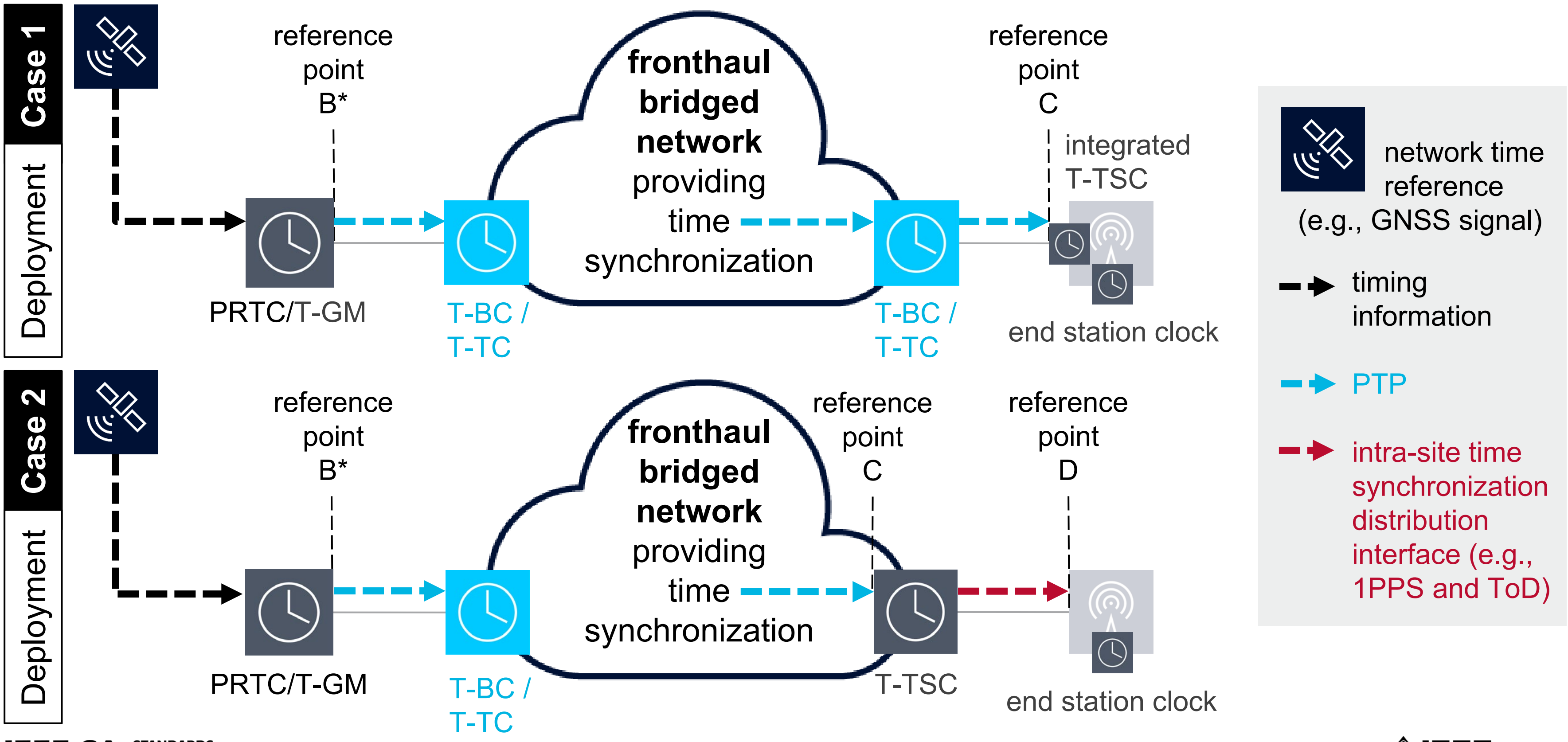
* From an edge port connected to an eRE/RE to another edge port connected to an eREC/REC.

** By reference to the 'CoS Name' in Table 1 of the Requirements for the eCPRI Transport Network V1.2.

*** Table 1A of the Requirements for the eCPRI Transport Network V1.2 lists High25 with a max latency of 25 μs for ultra-low latency performance, which is mostly but not exclusively for direct point-to-point fronthaul connections.

Synchronization

In-scope ITU-T G.8271.1 deployment cases



* Reference point A from Figure 7-1 of ITU-T G.8271.1 is within the PRTC/T-GM.

Time sync requirements for Classes 1 and 2

Case 1

T-TSC integrated in eRE/RE*

Case 1.1

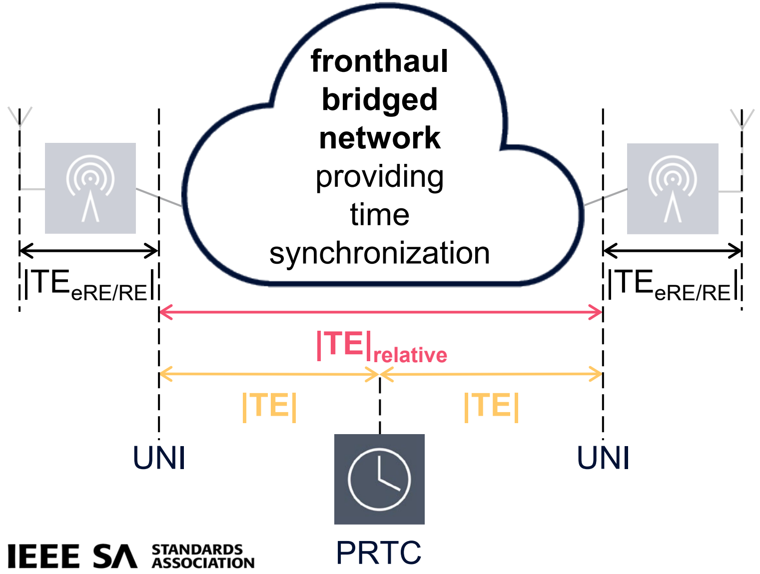
integrated T-TSC's performance ≈ performance of a standalone ITU-T G.8273.2 Class B T-TSC

Case 1.2

integrated T-TSC's max|TE| contribution = 15 ns

Case 2

T-TSC standalone at edge port



B	**Case 1.1:** $\max|TE|_{relative} = 260 - 2 \times |TE_{eRE/RE}| - 2 \times |TE_{T\text{-}TSC}|$ **Case 1.2:** $\max|TE|_{relative} = 260 - 2 \times |TE_{eRE/RE}| - 2 \times |TE_{T\text{-}TSC}|$ **Case 2:** $\max|TE|_{relative} = 260 - 2 \times |TE_{eRE/RE}|$
A	**Case 1.2:** $\max|TE|_{relative} = 130 - 2 \times |TE_{eRE/RE}| - 2 \times |TE_{T\text{-}TSC}|$ **Case 2:** $\max|TE|_{relative} = 130 - 2 \times |TE_{eRE/RE}|$

3 timing Categories (A, B, C) for different 3GPP features

	Max |TE| (ns)			Max TAE (ns)	Example 3GPP feature for which the Category is relevant
	Case 1.1	Case 1.2	Case 2		
A	Remaining budget examples	60 relative	70 relative	130	Carrier aggregation radio access technologies (used between two cooperating eRE/REs)
B	100 relative	190 relative	200 relative	260	
	$|TE_{eRE/RE}| = 20$ $|TE_{T\text{-}TSC}| = 60$	$|TE_{eRE/RE}| = 20$ $|TE_{T\text{-}TSC}| = 15$	$|TE_{eRE/RE}| = 30$ $|TE_{T\text{-}TSC}| = 15$		
C	1100			3000	E-UTRA time division duplex radio access technology

$|TE_{T\text{-}TSC}|$ = 15 ≈ ITU-T G.8273.2 Class C T-TSC

$|TE_{T\text{-}TSC}|$ = 60 ≈ ITU-T G.8273.2 Class B T-TSC

* The eRE/RE has both eRE/RE internal TE and integrated T-TSC TE time budgets; the combined TE is what matters: no dedicated requirement in either Case 1.1 or Case 2.2 for these two TEs.

Frequency sync requirements for Classes 1 and 2

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Based on 3GPP TS 36.104

eRE/RE needs to recover a timing signal that meets applicable sync requirements on the radio interface

±50 ppb
on the short term of a 1 ms observation window

air interface

network interface

±16 ppb
on the long term*

PTP and (optionally) SyncE may be used by eRE/RE only if it can filter network noise so that:

total of all frequency errors < **±50 ppb**

Frequency sync recovery	Applicable requirements at eRE/RE input
ITU-T G.8262 SyncE	SyncE network limits in 9.2.1 of ITU-T G.8261 (08/2019)
ITU-T G.8262.1 eSyncE	
Directly by PTP signal	Performance requirements of applicable PTP profile with ref. point C at eRE/RE input

ITU-T G.8271.1, G.8273.2, G.8273.3, G.8275.1 assume PTP + SyncE combination, show no frequency sync requirement

PTP can carry time and frequency: e.g., ±1 µs met in phase ➔ ±16 ppb met in frequency on the long term

- E.g., interface can keep ±1 µs for indefinite time ➔ **±16 ppb** could be recovered when input is averaged over periods > 1000/16 s
- ITU-T G.8261.1 assumes **±16 ppb** as the network limit for mobile applications ➔ a network that can meet ±16 ppb is suitable

* Long-term period depends on the time constant of the phase-locked loop.

Network sync methods to meet sync requirements

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Method	Example(s)	Description
Packet timing	PTP	Performance dependent on deployment approach. Four main approaches: ❶ P2P sync distribution from remote common master (no intervening packet switching) • Two-way protocol used for time alignment • eRE/REs in need of time / phase alignment need not be co-located • Performance dependent on link characteristics due to distance to remote master – Asymmetry in optical transmission due to use of different wavelengths ❷ Co-located common master at the eRE/RE… ❸ Timing distribution to eRE/REs cluster from nearest common master / BC… ❹ General deployment per appropriate PTP profile…
PHY frequency sync	SyncE*	Per ITU-T G.8261, G.8262, G.8262.1, G.8264. ITU-T G.8275.1-based networks (ITU-T G.8273.2 clocks) assume SyncE support of PTP operations; usable by an end station for frequency sync and/or PTP operations support.
GNSS or RNSS at eRE/REs	BDS, Galileo, GLONASS, GPS, IRNSS, QZSS	Expected accuracy in typical installations: ≈ 100 ns under normal operations** ▪ ITU-T G.8272 PRTC specification: 100 ns ▪ ITU-T G.8272.1 ePRTC specification: 30 ns for ePRTC in a central location
Others	Radio Base Synchronization methods with target accuracy in µs range	

* PTP may recover time and frequency sync → SyncE use optional. ** Holdover or redundancy usable to address GNSS signal loss to meet performance objectives during such loss.

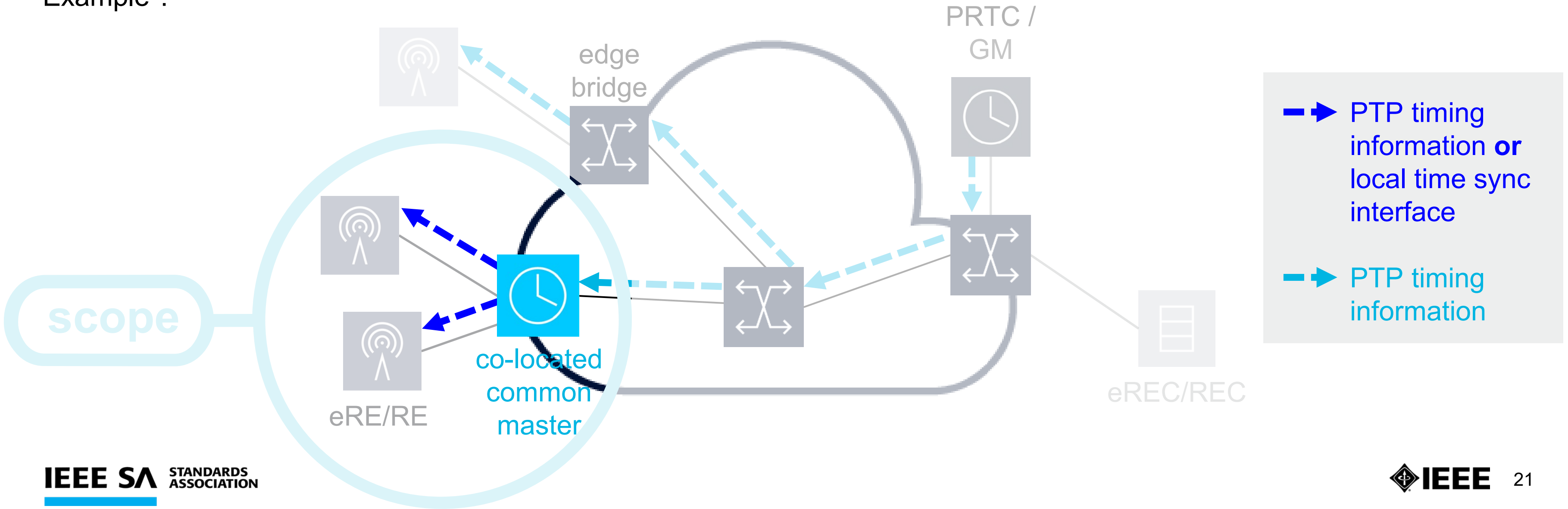
Co-located common master at eRE/RE

Packet timing performance approach 2

Co-location of eRE/REs and common master that can have access to a PRTC (“PRTC traceable master”)

Significantly less concerns related to the link connecting the master compared to approach 1

Example*:



* Figures in this presentation as in IEEE 802.1CM/de illustrate rather than provide deployment guidance. IEEE 802.1CM/de requirements are what matter.

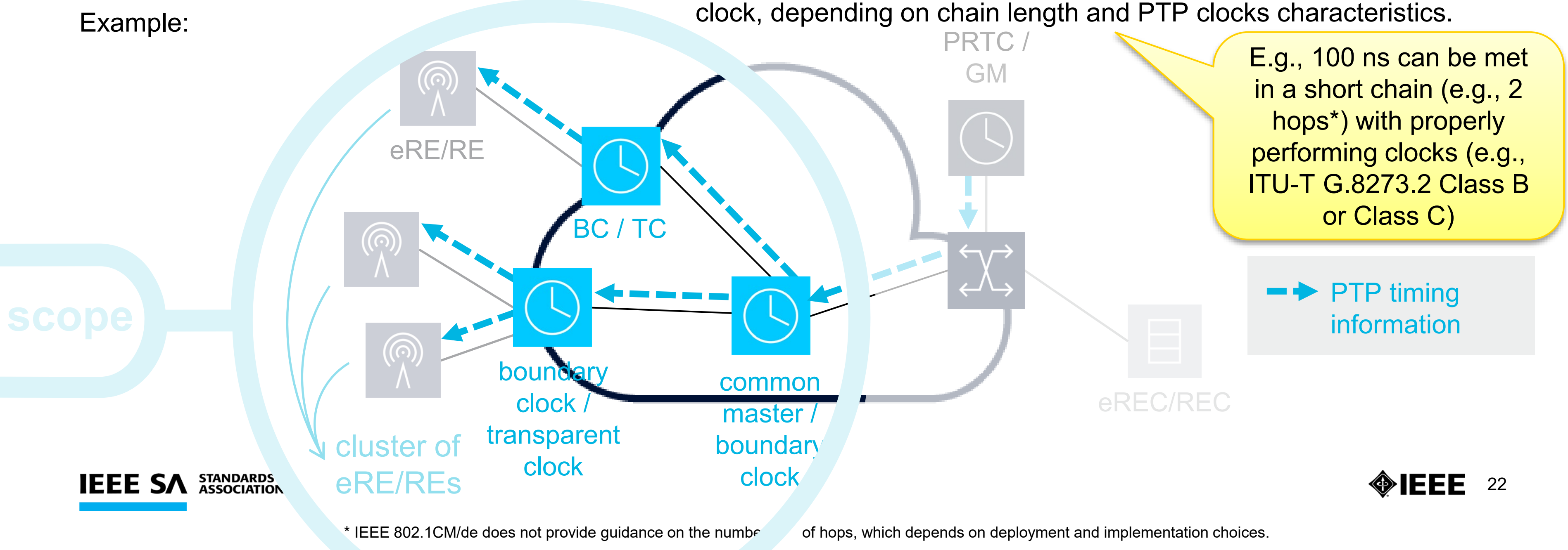
Distribution to cluster from nearest common clock

Packet timing performance approach 3

Relative phase deviation can be calculated starting at nearest common clock master / boundary clock

Allows for a relatively short synchronization chain: target performance in terms of max absolute TE, relative to common clock, depending on chain length and PTP clocks characteristics.

Example:



* IEEE 802.1CM/de does not provide guidance on the number of hops, which depends on deployment and implementation choices.

General deployment per appropriate PTP profile

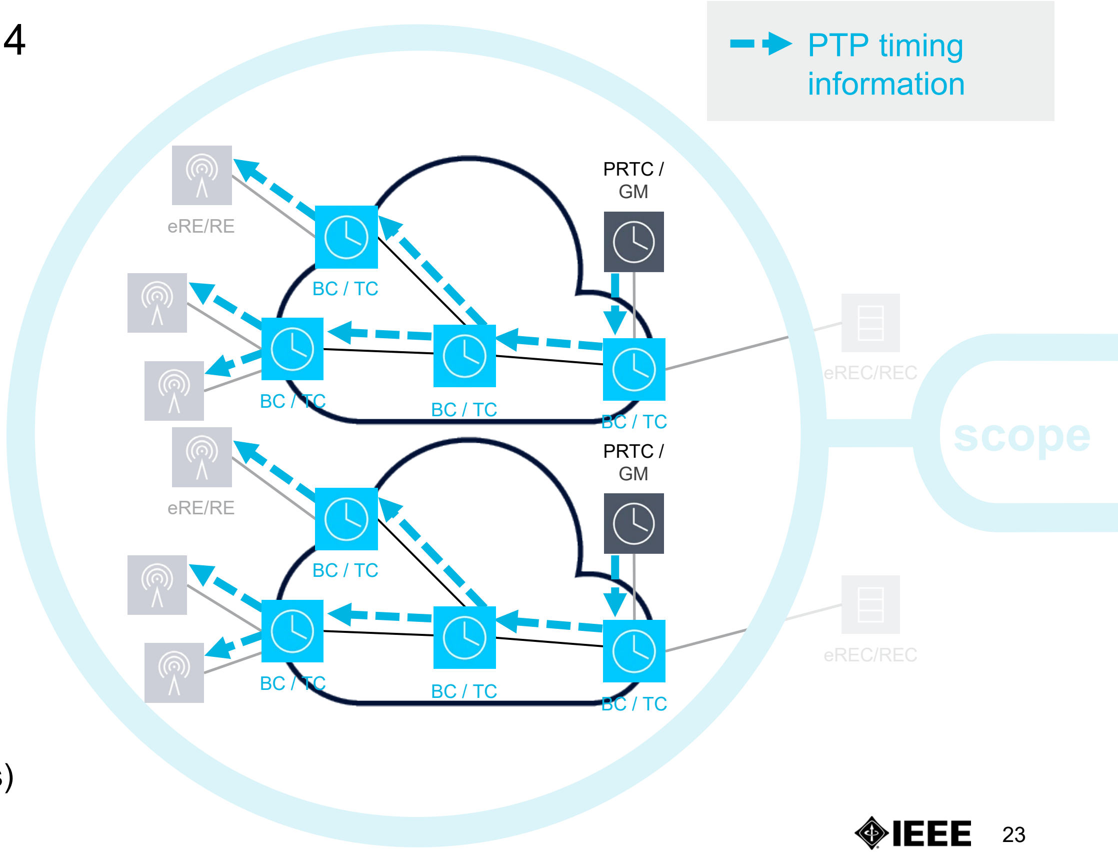
Packet timing performance approach 4

Appropriate PTP profile

Example:

- Combination of:
  - ITU-T G.8275 time sync architecture
  - ITU-T G.8275.1 PTP telecom profile with Full Timing Support (FTS)
  - ITU-T G.8271.1 network characteristics
  - ITU-T G.8273.2 T-BC / ITU-T G.8273.3 T-TC
- Target performance* in terms of max absolute TE relative to an internationally-recognized time reference:

  1.1 μs at eRE/RE input to meet
  1.5 μs at eRE/ RE output
  (including some budget for
  synchronization network rearrangements)



* Timing transport could be via ITU-T G.8275.2 Partial (rather than Full) Timing Support though the performance achievable over a PTS network is generally not up to IEEE 802.1CM/de fronthaul synchronization requirements.

Putting it all together: synchronization solutions

Category			Network sync method usable to meet Category requirements	
A	B	C	Packet timing	❶ Point-to-point synchronization distribution from remote common master ▪ Uses ITU-T G.8275.1 T-profile and SyncE per ITU-T G.8261, G.8262, G.8262.1, G.8264 ▪ For Category A requirements: • Accurate control of the link propagation delay asymmetries (e.g., from using different wavelengths in optical transmission) required in the ns range • ITU-T G.8271 assumes co-located deployments (e.g., antennas on same roof)
A	B	C	Packet timing	❷ Co-located common master at the eRE/RE ▪ Uses ITU-T G.8275.1 T-profile and SyncE per ITU-T G.8261, G.8262, G.8262.1, G.8264 ▪ Co-located eRE/REs needed to meet Categories A and B requirements
	B	C	Packet timing	❸ Timing distribution to eRE/REs cluster from nearest common master / BC
		C	Packet timing	❹ General deployment per appropriate PTP profile
	B	C	GNSS or RNSS at eRE/REs	No requirement on fronthaul bridged network* ▪ To meet Category B requirements, eRE/REs implement GNSS per ITU-T G.8272: • GNSS-based PRTC performance influenced by e.g., antenna installation, cabling
		C	Others	No requirement on fronthaul bridged network*

* Requirements do however apply to bridges and end stations.

Impact of network ownership on synchronization

Two cases depending on Mobile Network Operator (MNO) and bridged / Transport Network Operator (TNO):

- **Same operator for mobile and bridged networks (MNO = TNO) ➔** full control of the network topology possible
  - For example: PRTC and/or PTP GM could be co-located with the eREC/REC ➔ full control of the location in the sync chain of the nearest common clock possible, which can be relevant for approach ❸ (Timing distribution to eRE/REs cluster from nearest common master / BC)
- **Different operators for mobile and bridged networks*** **(MNO(s) ≠ TNO)**:
  - Generally, accurate time sync reference and SyncE cannot be carried transparently
    - When timing master MNO-owned, and reference timing signals carried over the bridged network
  - **Re: time sync**:
    - Boundary clocks operate in a single PTP domain
    - Transparent clocks can carry time sync across the bridged network: requires careful consideration / SLA
  - **Re: frequency sync:**
    - SyncE layer traceable to a single clock
    - SyncE cannot be carried transparently over a bridged network
  - Time and/or frequency **SYNCaaS** (MEF 22.3) may be offered, based on SLA, by TNO to MNO
    - Approach ❸ not necessarily applicable: MNO generally has no visibility of the bridged network topology

* If the bridged network and mobile network operators are different, then multiple mobile networks can use the same bridged network.

Latency

Latency theory

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Worst-case latency of a bridge for gold flows (periodic CBR data flows at highest-priority Traffic Class, TC, e.g., IQ data):

$$t_{MaxBridge} = t_{SF} + t_{SelfQueuing} + t_{Queuing} + t_{MaxGoldFrameSize+Pre+SFD+IPG}$$

Store-and-forward delay of the bridge (not including worst-case delay from any input queuing): implementation-specific

Transmission time at a given port rate of one max size frame of a gold flow (MaxGoldFrameSize) with Preamble (Pre), Start Frame Delimiter (SFD) and following Inter Packet Gap (IPG)

Self-queuing delay resulting from other frames (if any) in the same TC (including any fan-in delay)

Queuing delay resulting from both:

- Another frame just selected for transmission
- Any frames in higher-priority TC queued up for transmission (none for gold flows at highest-priority TC*)

Worst-case queuing delay for gold flows = transmission time of a max size lower-priority frame (MaxLoFrameSize) including Pre, SFD and IPG = $t_{MaxLoFrameSize+Pre+SFD+IPG}$

Worst-case latency for a single hop, i.e., last bit in at bridge A to last bit in at bridge B: $t_{Hop} = t_{MaxBridge} + t_{Propagation}$

LAN propagation delay proportional to the length of the A-B link

- E.g., ~ 5 μs/km of fiber

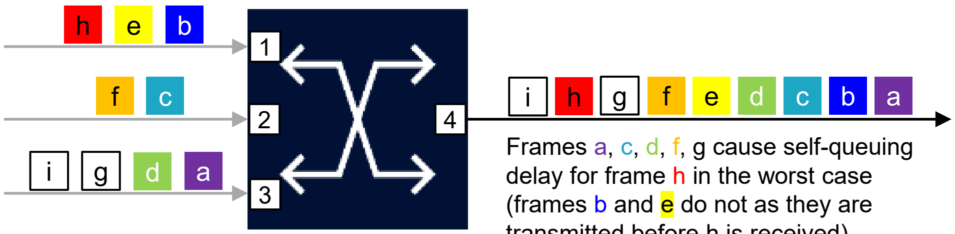
Worst-case e2e latency: $t_e = \sum t_{MaxBridge} + \sum t_{Propagation}$

*Any traffic at the same or higher priority than gold flows contributes to the worst-case self-queuing or queuing delay and must be accounted.

Self-queuing and fan-in delays

$t_{SelfQueuing}$ = delay of a frame due to other frames belonging to the same TC

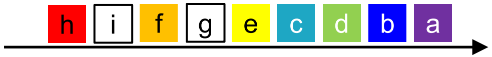
Self-queuing delay with time ordering preserved among ports:



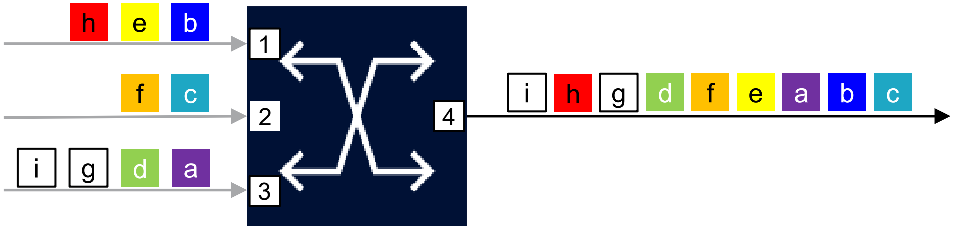
Frames a, c, d, f, g cause self-queuing delay for frame h in the worst case (frames b and e do not as they are transmitted before h is received)

- Periodic CBR flows: same TC and time window
- Frames i and g in the same flow
- Other frames in their own flows
- Bursty arrivals around the same time
- Frames received in alphabetical order
- 10 Gbit/s data rate on all ports

Without order preservation, one more frame (i) can cause self-queuing delay for frame h:



Fan-in = frames in same TC and destined to same egress port arrive at different ingress ports almost at the same time
Fan-in (for frames b, c, a but also for frames e, f, d, and for frames h and g) delay with frames received first transmitted first:



- Account for fan-in situations as part of self-queuing rather than handling them separately when calculating the worst-case self-queuing delay

Worst-case self-queuing delay

Worst-case self-queuing delay of egress port p for gold flows received at ingress port j:

$$t^{j,p}_{\text{SelfQueuing}} = t_{\text{MaxGoldFrameSize+Pre+SFD+IPG}} \times \sum_{\substack{i=1 \\ i \neq j}}^{N_p} \sum_{k=1}^{F_{i,p}} G_k^{i,p}$$

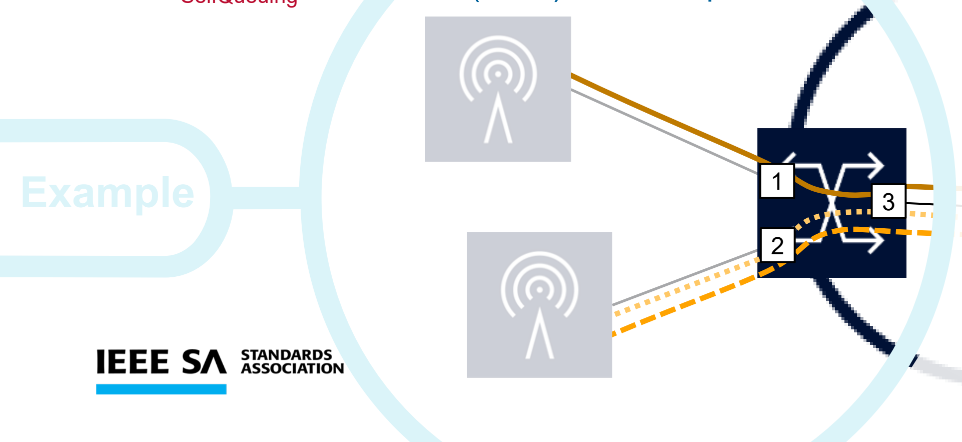
N_p = number of ingress ports that can receive interfering frames of gold flows transmitted by egress port p

$F_{i,p}$ = number of gold flows supported between ingress port i and egress port p

$G_k^{i,p}$ = max number (often 1) of frames of gold flow k between ingress port i and egress port p that can be grouped together in a single time window before they are received by the ingress edge port of the bridged network

Three gold flows: **1** received on port 1
1 + **1** received on port 2

- Ingress port 1, egress port 3
- 1522-octet C-tagged frames (1.5 ko payload) + 20-octet Pre+SFD+IPG on 10 Gbit/s ports (including low-priority flows – not shown)
- $t_{\text{MaxGoldFrameSize+Pre+SFD+IPG}} = 1542 \times 8 / 10^{10} = t_{\text{MaxLoFrameSize+Pre+SFD+IFG}} = t_{\text{Queuing}} = 1.2336\ \mu s$
- $t^{j,p}_{\text{SelfQueuing}} = 1.2336 \times (1 + 1) = 2.4672\ \mu s$



$t_{\text{MaxBridge}} = t_{\text{SF}}$ of 5 µs
+ $t_{\text{SelfQueueing}}$ of 2.4672 µs
+ t_{Queueing} of 1.2336 µs
+ $t_{\text{MaxGoldFrameSize+Pre+SFD+IFG}}$ of 1.2336 µs
= **9.9344 µs** << a stringent **100 µs** budget

Frame preemption

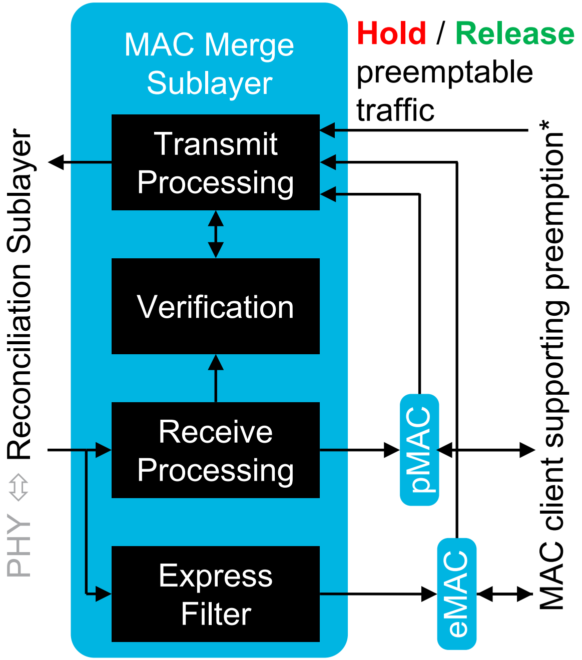
Interspersed Express Traffic & Frame Preemption

IEEE Std 802.3br™-2016 / IEEE Std 802.3™-2022 Interspersed Express Traffic

- Intersperses 1+ express frame(s) between preemptable frames or their fragments
- Optional MAC Merge sublayer (MMS) + express (eMAC) and preemptable (pMAC) full-duplex MACs ➔ new hardware
- Link local, disabled by default: enabled if link partner discovered to support IET
  - IEEE Std 802.1AB™ LLDP used to discover capability (no negotiation)
- MMS transmits mPackets once active (after optional verification) otherwise packets
- Requires MAC Control's PAUSE be disabled – partners need not be synchronized

IEEE Std 802.1Qbu™-2016 / IEEE Std 802.1Q™-2018 Frame Preemption

- IEEE Std 802.1Q™ forwarding process optionally supports frame preemption
- Configurable per port (*framePreemptionStatusTable* to mark each priority value as express (default) or preemptable) where it controls IET Transmit Processing:
  - **Hold** / preempt pMAC transmission if eMAC packet waiting
    - Preempt only if: 60+ octets of preemptable frame have been transmitted, and 64+ octets (including 4-octet FCS) remain to be transmitted
  - **Release** pMAC transmission if no eMAC packet waiting



* Optional MAC Control functionality not shown

Deterministically bounding fronthaul traffic latency

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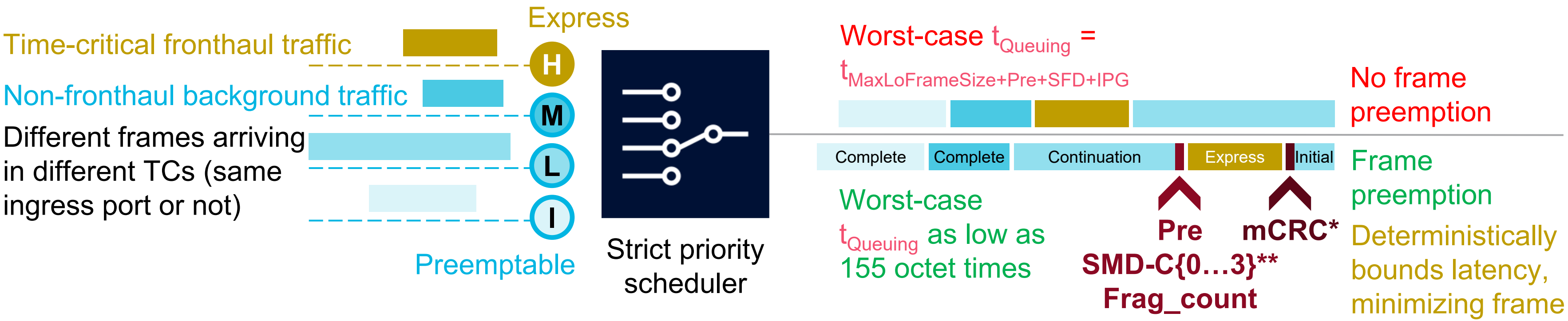

Frame preemption can take place following activation but is not instantaneous

- *addFragSize* (settable to 0, 1, 2, or 3) × 64 octets = min number of octets required in non-final fragments by receiver
- Preemptable frame preempted only once at least 64 × (1 + *addFragSize*) - 4 of its octets transmitted
  - Preemption at worst (1240 + 512 × *addFragSize*) bit times after a **Hold** request, i.e., as low as 155 octet times
- Express frame transmitted only after initial fragment's mCRC and IPG

Express frames or frames smaller than 124 octets carrying PTP messages: not preempted

Latency reduction benefit decreases as bridge port data rate increases

Preemption decreases the effect of non-fronthaul traffic on fronthaul traffic

*MAC merge packet (mPacket) Cyclic Redundancy Check ** Start mPacket Delimiter-Continuation

Fronthaul Profiles

Setting the stage for frontHaul profiles

Class 1	Class 2	
IQ data	User Plane (fast)	**HPF (gold flows)**
	User Plane (slow) C&M Plane (fast)	**MPF**
C&M data	C&M Plane (slow)	**LPF**

Profiles require **compliant end stations** (eRE/RE and eREC/REC) transmitting and receiving priority- or VLAN-tagged frames

- Same or different VLANs can support flows with different requirements
  - No impact on frame latency from VLAN choice
  - Flows with different ingress priority configured to be assigned with different TCs in the bridged network

Profiles require **compliant bridges** interconnected only with:

- Full-duplex point-to-point links
  - Never a bottleneck: data rates large enough* for the desired fronthaul data traffic including HPF, MPF, LPF

Fronthaul bridged network designed, configured, operated to:

- Address the criteria specified for the profile supported
- Achieve synchronization targets if it provides synchronization
- Avoid fronthaul data traffic overloading the network during normal operation

* E.g., the transmission rate of a bridge port aggregating fronthaul data information flows is > than the bandwidth required by the received HPF data traffic and not < than that of any port whose fronthaul data traffic is aggregated.

Fronthaul profiles to meet Classes 1 & 2 requirements

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What?	Profile A	Profile B: same as Profile A but…
Functions used	▪ IEEE 802.1Q bridging, no advanced TSN function ▪ Strict priority Transmission Selection Algorithm	Applies frame preemption on non-fronthaul traffic to decrease its effects on fronthaul traffic
Frame* size	For fronthaul and non-fronthaul traffic: 1500 octets max data payload, 2000 octets Max Frame Size	Lifts Profile A restrictions for non-fronthaul traffic (no MFS) without influencing FH traffic latency
TCs in the bridged network	▪ HPF: highest priority** + strict priority (TSA = 0) ▪ MPF: priority (preferably next one) below HPF's ▪ LPF: priority (preferably next one) below MPF's	Frame preemption enabled with smallest possible fragment size (i.e., 64 o) at each port supporting H/M/LPF traffic (whose priorities are express)
Meeting latency targets	Design topology and configure forwarding paths for worst-case e2e latency for HPF data, limiting the number of hops and total links length per latency theory and depending on specifics of actual deployment ▪ MaxGoldFrameSize = MFS of HPF data ▪ MaxLoFrameSize*** = max(frame size for all other flows with lower priority than HPF data) ▪ MEF 10.4 ingress BWP on H/M/LPF: M/LPF not starved, excess LPF ok – can share tokens from H/M ▪ Egress buffers sized to avoid HPF data overflowing to next time window	Frame preemption ➔ queuing delay caused by non-fronthaul traffic as low as 155 octet times
Meeting FLR targets	▪ Configure/operate bridged network to meet latency targets and avoid FH traffic loss due to congestion ▪ P(frame loss due to bit errors during transmission on an Ethernet link) << FLR tolerance requirements	

Synchronization solutions apply to both Profiles A and B

* Not including Pre, SFD, IPG. ** Traffic like that used for maintenance outside normal network operation can be set at the same or higher priority. *** Inconsequential if HPF data has highest priority and links are not bottlenecks.

Bridge and end station requirements

IEEE 802.1CM/de mandatory requirements

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Bridge (of a fronthaul bridged network) mandatory requirements – support:

- IEEE 802.1Q VLAN Bridge component mandatory requirements and the use of 1+ VID though:
  - No RSTP support mandate – Instead: active topology enforcement mechanism
  - No MVRP support mandate – Instead: fully engineered
- On each port: shared VLAN learning and at least “Admit All frames” Acceptable Frame Type
- Full duplex 1+ Gbit/s IEEE 802.3 MAC ports supporting 2000-octet max size MAC PDUs
- Strict priority transmission selection algorithm at each port for each of 3+ traffic classes
- Flow metering (MEF 10.4 token bucket bandwidth profile algorithm) without token sharing
- Disabling IEEE 802.3 MAC control PAUSE and IEEE Std 802.1Qbb™ / IEEE 802.1Q Priority-based Flow Control, if implemented, at ports and priorities supporting fronthaul traffic
  - Such flow control protocols may negatively impact latency for fronthaul traffic
- Not asserting Low Power Idle on Energy Efficient Ethernet-supporting ports also supporting fronthaul traffic

Bridge claiming Profile A compliance – support all of the above

End station (eRE, RE, eREC, REC) mandatory requirements – support:

- Priority-tagged or VLAN-tagged frames on all ports
- 3+ traffic classes on all ports

Profile Conformance Statement (PCS) proforma

IEEE 802.1CM/de optional requirements

Bridge optional requirements – support:

- Flow metering (MEF 10.4 token bucket bandwidth profile algorithm) with token sharing
- Profile B: if supported, requires supporting bridge mandatory requirements + frame preemption and IET
- Synchronization via the bridged network: if supported, requires supporting
  - Untagged frames on all ports*
  - PTP telecom profile with FTS (ITU-T G.8275.1) and 1+ of T-BC (Class A, B, or C – ITU-T G.8273.2), T-TC (ITU-T G.8273.3), or GM functionality and either PRTC or ePRTC (ITU-T G.8272 or G.8272.1)
  - SyncE functions including Ethernet Synchronization Messaging Channel (ESMC) per ITU-T G.8264, and related ITU-T G.8262 SyncE or ITU-T G.8262.1 enhanced SyncE equipment clock specification

End station optional requirements – support:

- Time synchronization via the bridged network: if supported and if end station terminates PTP, requires supporting:
  - Untagged frames on all ports
  - PTP telecom profile with FTS (ITU-T G.8275.1) + the functionality of 1+ related clocks allowing time and frequency sync requirements for Classes 1 and 2 to be met
    - E.g., functionality of TSC (ITU-T G.8273.2), PRTC**, or PRTC & T-GM (ITU-T G.8272)
- SyncE functions including ESMC per ITU-T G.8264, and related ITU-T G.8262 SyncE or ITU-T G.8262.1 enhanced SyncE equipment clock specification

PCS proforma

* Can be used for packet timing method and physical layer frequency sync. **ITU-T G.8275.1 not required if PRTC time sync delivered via 1 PPS without PTP.

Summary

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In a nutshell

- IEEE 802.1CM/de TSN for Fronthaul specifies two TSN profiles A and B, profile B using frame preemption
- CPRI Cooperation / IEEE 802.1 collaboration with input from ITU-T SG15 Q13 itself profiling IEEE 1588 PTP
- Requirements provided by CPRI Cooperation leveraging 3GPP requirements
- Class 1 (for CPRI V7.0) and Class 2 (for eCPRI V2.0) requirements for latency, loss, time, frequency
- Several sync solutions (PTP telecom profile-based) for 3 timing Categories (A, B, C) for different 3GPP features
- Detailed formulas to help deterministically pre-determine worst-case latency (fully engineered solution)
- Frame preemption to decrease the effect of non-fronthaul traffic on fronthaul traffic
- Comprehensive set of bridge and end station requirements along with Profile Conformance Statement proforma

Next

- ISO/IEC/IEEE 8802-1CM:2019/Amd.1 relatively soon
- IEEE Std 802.1CM-2018 revision by 7 May 2028 or earlier – 3GPP Release 18+?

First TSN profile of the TSN era

IEEE 802.1CM/de, a blueprint for further TSN profiles leveraging the TSN toolset

The IEEE 802.1 Working Group was awarded the 2020 IEEE SA Emerging Technology Award

> *"For the development of IEEE Std 802.1CM™-2018 Time-Sensitive Networking for Fronthaul, the first IEEE standard to connect a cellular network's radio equipment to its remote controller via a packet network, in particular, over a bridged IEEE 802.3™ Ethernet network."*

IEEE SA Beyond Standards blog post

> *"How Time-Sensitive Networking Benefits Fronthaul Transport"*

UPCOMING WEBINARS

Industrial Automation – IEC/IEEE 60802
Automotive Ethernet – IEEE P802.1DG
Aerospace Ethernet – IEEE P802.1DP / SAE AS6675

THANK YOU

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IEEE 802.1: http://www.ieee802.org/1

Foundational Technologies: https://standards.ieee.org/practices/foundational/index.html

Standards Home Page: https://tandards.ieee.org

Abbreviations

Term	Expansion	Term	Expansion	Term	Expansion
CA	Carrier Aggregation	GPS	Global Positioning System	PTS	Partial Timing Support
1PPS	1 Pulse Per Second	HiPHY	High PHY	QZSS	Quasi-Zenith Satellite System
3GPP	3rd Generation Partnership Project	HPF	High Priority Fronthaul	RAN	Radio Access Network
BBU	Baseband Unit	IET	Interspersing Express Traffic	RE	Radio Equipment
BC	Boundary Clock	IoT	Internet of Things	REC	Radio Equipment Control
BDS	BeiDou Navigation Satellite System	IPG	Inter Packet Gap	RNSS	Regional Network Satellite Service
BWP	Bandwidth Profile	IQ	In-phase and Quadrature modulation	RRH	Remote Radio Head
C&M	Control and Management	IRNSS	Indian Regional Navigation Satellite System	RSTP	Rapid Spanning Tree Protocol
CBR	Constant Bit Rate	LLDP	Link Layer Discovery Protocol	RU	Remote Unit
CoMP	Coordinated Multipoint	LoPHY	Low PHY	SFD	Start Frame Delimiter
CoS	Class of Service	LPF	Low Priority Fronthaul	SLA	Service Level Agreement
CPRI	Common Public Radio Interface	MAC	Medium Access Control	SMD-C	Start mPacket Delimiter-Continuation
DU	Distributed Unit	MBB	Mobile Broadband	SYNCaaS	Synchronization as a Service
e2e	edge port-to-edge port or end-to-end	mCRC	MAC merge packet Cyclic Redundancy Check	SyncE	Synchronous Ethernet
eICIC	enhanced Inter Cell Interference Coordination	MFS	Maximum Frame Size	T-BC	Telecom Boundary Clock
eMAC	express MAC	mMTC	massive Machine-Type Communications	TC	Traffic Class or Transparent Clock
eMBB	enhanced Mobile Broadband	mMIMO	massive Multiple-Input and Multiple-Output	TE	Time Error
ePRTC	enhanced Primary Reference Time Clock	MMS	MAC Merge Sublayer	T-GM	Telecom Grand Master
eRE	eCPRI Radio Equipment	MNO	Mobile Network Operator	TNO	Transport Network Operator
eREC	eCPRI Radio Equipment Control	MPF	Medium Priority Fronthaul	ToD	Time of Day
ESMC	Ethernet Synchronization Message Channel	MTC	Machine-Type Communications	TSA	Transmission Selection Algorithm
E-UTRA	Evolved Universal Terrestrial Radio Access	MVRP	Multiple VLAN Registration Protocol	T-TC	Telecom Transparent Clock
FCS	Frame Check Sequence	NR	New Radio access technology (for 5G)	T-TSC	Telecom Time Slave Clock
FH	Fronthaul	P2P	Point-to-Point	ULL	Ultra-Low Latency
FILO	First In Last Out	PDU	Protocol Data Unit	uRLLC	ultra-Reliable Low-Latency Communications
FLR	Frame Loss Ratio	PHY	Physical Layer	V2X	Vehicle-to-everything
FTS	Full Timing Support	pMAC	preemptable MAC	VID	VLAN Identifier
GLONASS	Global Navigation Satellite System	Pre	Preamble	VLAN	Virtual Local Area Network
GM	Grand Master	PRTC	Primary Reference Time Clock		
GNSS	Global Navigation Satellite System	PTP	Precision Time Protocol		