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5G Time Synchronization

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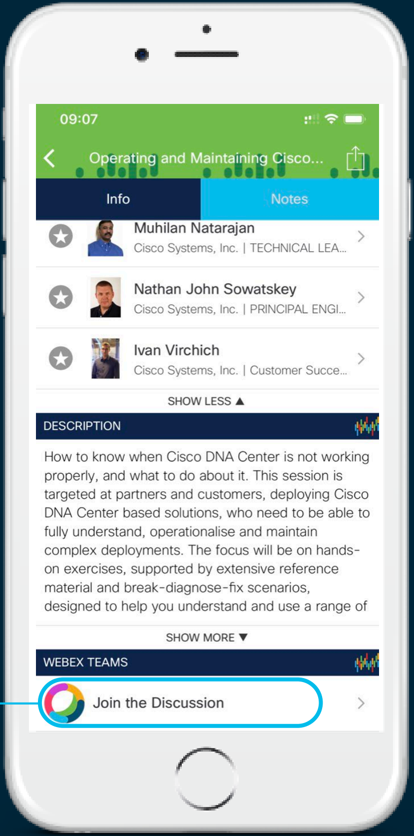


Agenda

- Synchronization In Telecommunication Networks
- Frequency & Phase Sync requirements in FDD vs TDD
- Timing Synchronization Standards
- 5G Time Synchronization Requirements
- Solution Options and Best Practices
- Summary

5G –

Where accurate timing is no longer an option…

but a requirement!!

Synchronization in Telecommunication Networks

Evolution of Time Synchronization

Synchronization
- Fundamental need for any Telecommunication

Analog to Digital Transition
- Synchronous protocols
- Bulk Data Transfer

Asynchronous Packet Switched network
- Better Bandwidth
- improved efficiency and
- Services flexibility

End to End IP
- Improved user experience – “Any service Any Where”
- Improved revenue with Multi-Services convergence

Synchronization Issues

Audio / Video Voice Communications

- Audible clicks
- Latency (echo)
- Dropped calls
- Corrupted Video
- Loss of Frame
- Audio Video mis-alignment

etc

Wireless Networks

- Seamless Handover
- Interference (eICIC)
- CoMP
- Carrier Aggregation
- Dual Connectivity
- Location Accuracy

Etc.

Application Impacted

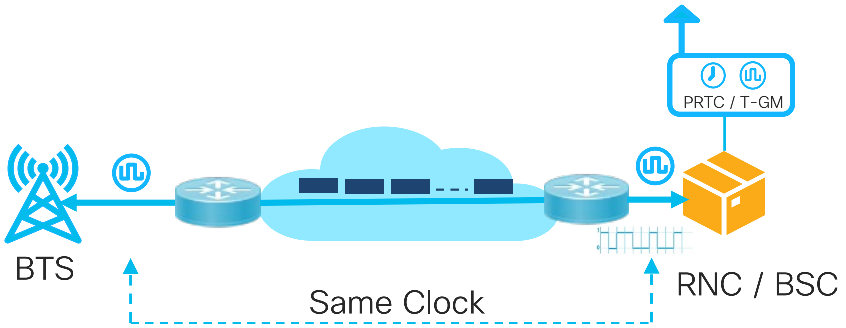
- Location Services
- Industrial Automation
- Smart grid
- IoT
- Network Monitoring

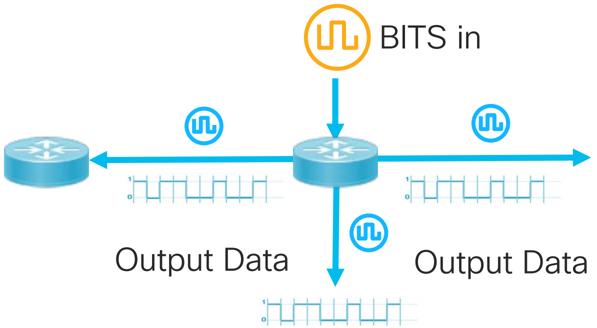
Etc.

Frequency & Phase Sync requirements in FDD vs TDD

Frequency Synchronization

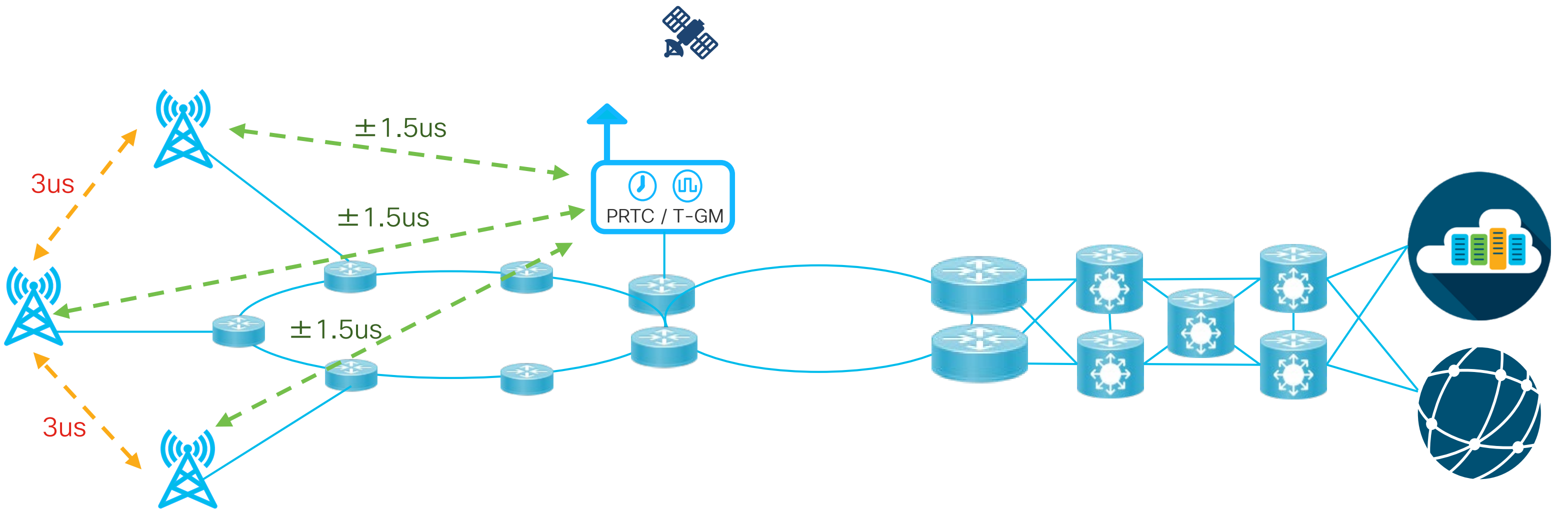
- Avoid Slips on TDM Interfaces (E1/T1, ...)
- Make Synchronous networks work (SONET/SDH)
- 2G, 3G, and 4G FDD Cellular Networks
  - Ensure radios transmit on correct frequency





RAN ... Radio Access Network; TDM ... Time Division Multiplexing; SONET ... Synchronous Optical Network; SDH ... Synchronous Digital Hierarchy

Phase Synchronization



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

Radio backhaul network: ±1.5µs from reference time

Frequency and Phase Sync Requirements

Application	Frequency		Phase		Note
	Backhaul	Air	Backhaul	Air	
LTE-FDD	±16 ppb	± 50 pbb	--	--	--
LTE-TDD	±16 ppb	± 50 pbb	±1.1μs ±4.1μs	±1.5μs ±5μs	< 3Km cell Radius > 3Km cell Radius
LTE-A / LTE-Pro	±50 pbb (Wide area) ±100 pbb (Local area) ±250 pbb (Home eNB)		≤ ±1.1μs	±1.5μs to 5μs	Depending on the application
LTE eMBMS	±16 ppb	± 50 pbb	≤ ±1.1μs	±1.5μs to 5μs	Inter-cell time difference

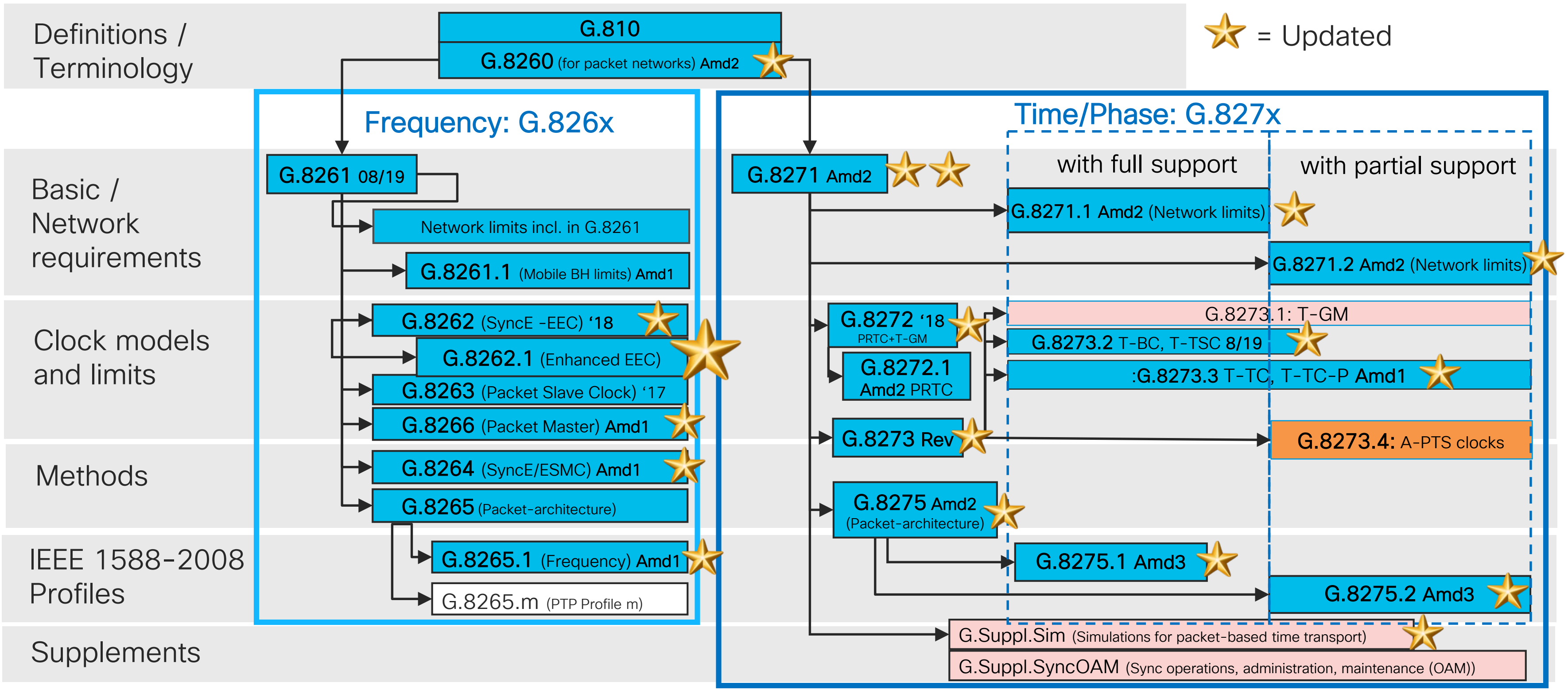
LTE-Advance	Type of Coordination	Phase	
		Backhaul	Air
eICIC	Enhanced inter-cell interference Coordination	≤ ±1.1μs	±1.5μs to 5μs
CoMP Moderate	UL coordinated scheduling DL coordinated scheduling	≤ ±1.1μs	±1.5μs to 5μs
CoMP Tight	DL coordinated beamforming	≤ ±1.1μs	±1.5μs
	DL non-coherent join transmission	≤ ±1.1μs	±1.5μs to 5μs
	UL Joint processing	≤ ±1.1μs	±1.5μs (±130ns)
	UL selection combining	≤ ±1.1μs	±1.5μs
	UL joint reception	≤ ±1.1μs	±1.5μs
MIMO	Tx diversity transmission at each Carrier frequency	65ns	±32.5ns

1 nano sec / sec = 1×10^{-9} (1 ppb)

Time Synchronization Standards

Standards: ITU-T SG15

Approved « In force »	Planned for 01/2020	Working Items	Future Working Items



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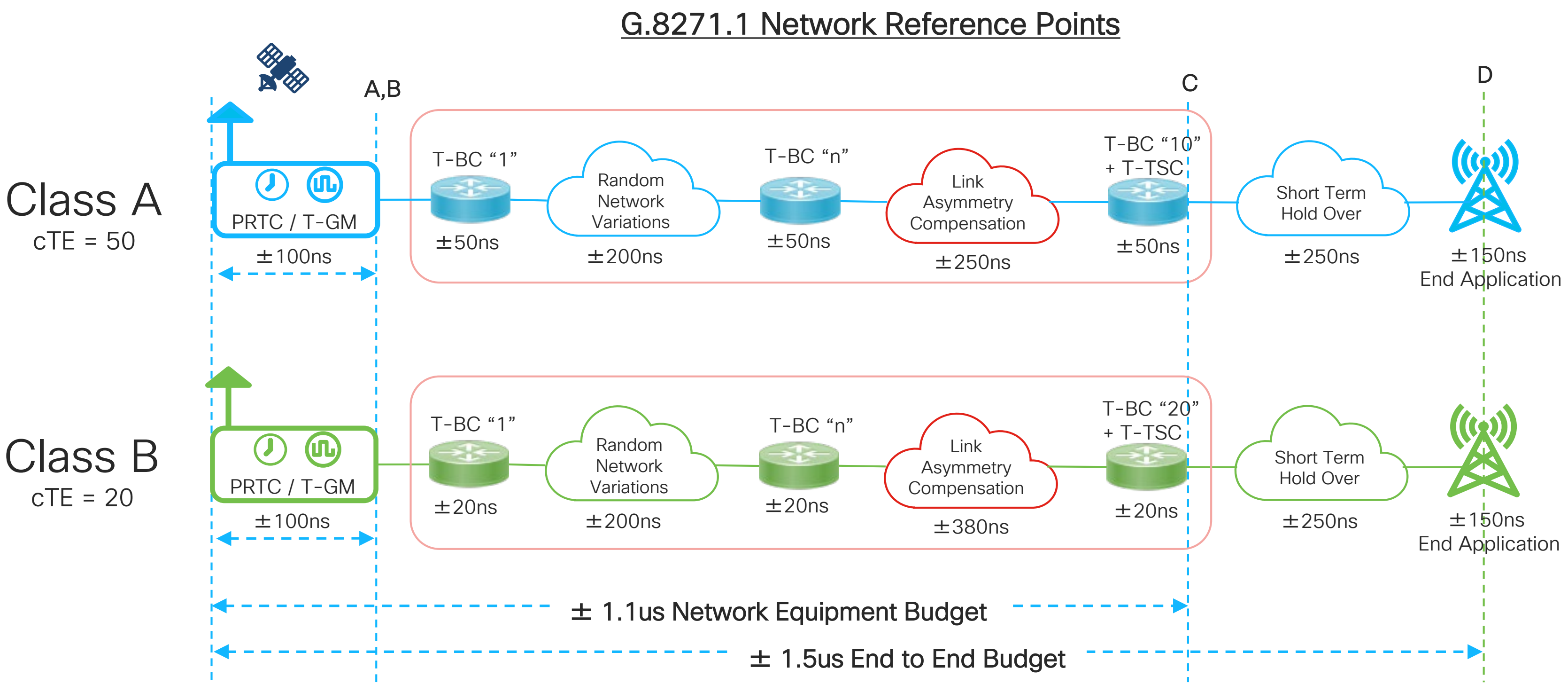
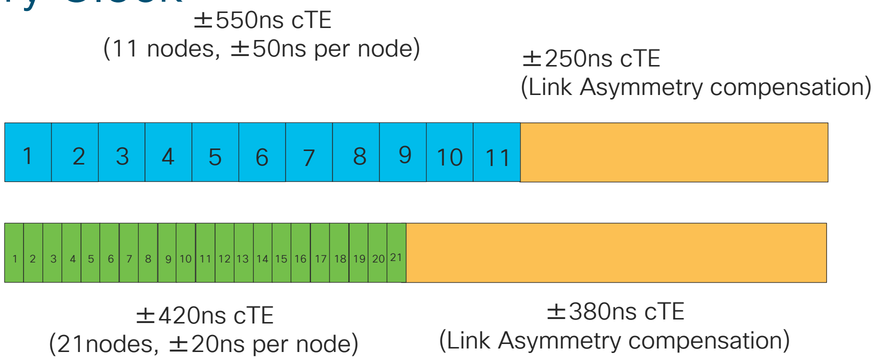
4G LTE / LTE-A Mobile Backhaul Budget



Phase Performance

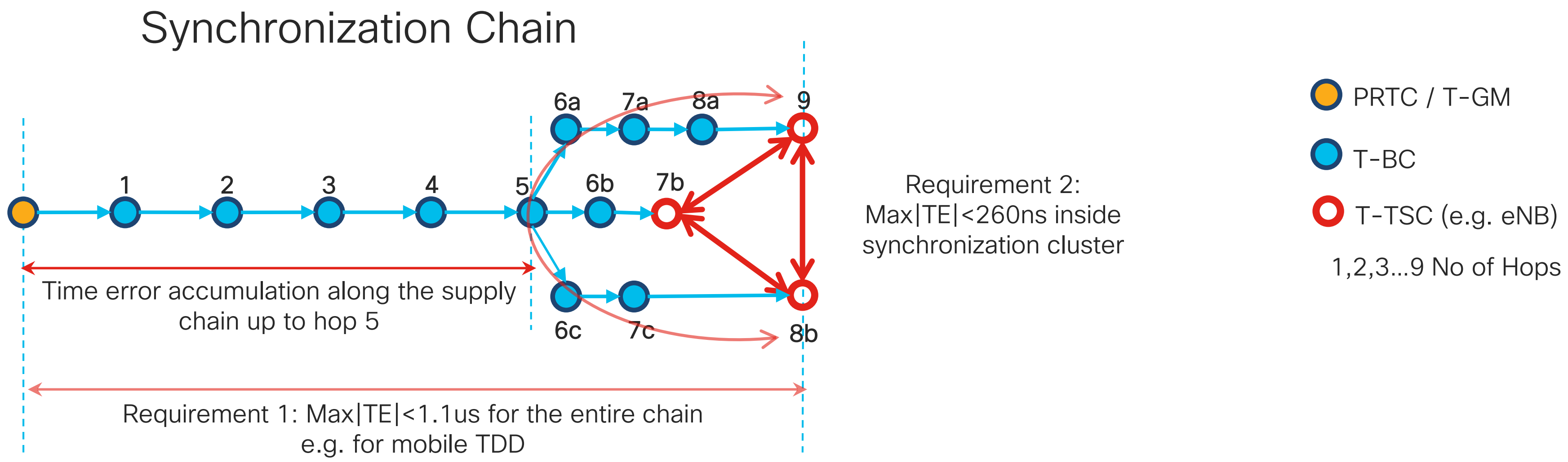
G.8273.2 Boundary Clock



Level	Max Total Time Error* max|TE|	Constant Time Error cTE	Dynamic Time Error** dTE
Class A (10 T-BC's + T-TSC)	100 ns	±50 ns	±40 ns
Class B (20 T-BC's + T-TSC)	70 ns	±20 ns	±40 ns

* Max|TE| includes all time error components (unfiltered)
** dTE is an MTIE limit over 1K (constant temp) or 10K (variable) seconds with low-pass filter (there is also a TDEV limit)

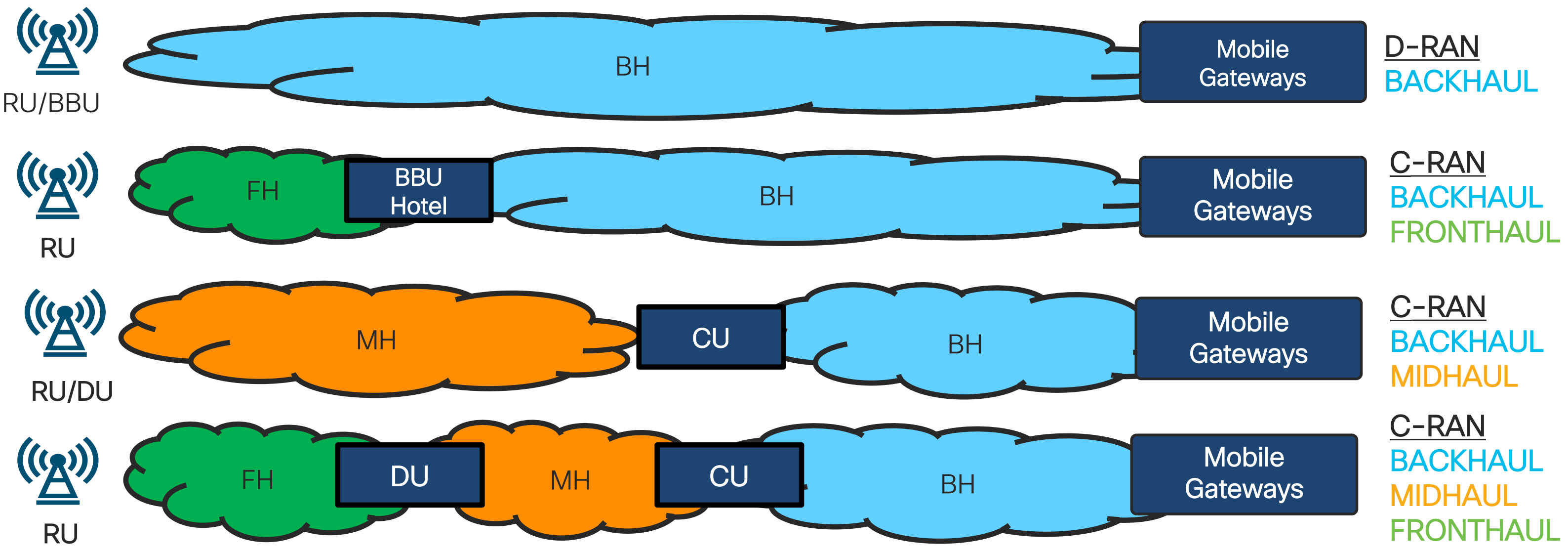
Absolute vs Relative Budget



- All nodes sync'd within the max|TE| of 1100nS
- Cluster below "5" also synced within max|TE| of <260nS RELATIVE to each other

5G Time Synchronization Requirements

RAN Evolution



Split Groups	Splits	Latency One Way	Bandwidth
Backhaul (S1 / Nx)	None	Service Dependent	~User bandwidth
Midhaul High Split (F1)	Option 2: PDCP-RLC	1- 5 milliseconds	~User bandwidth
Fronthaul	Option 7/8: PHY Hi- PHY Lo	100us / 150us / 500us	Very High

RAN Evolution vs Transport Timing

1. Fronthaul Requirements
   a. Jitter & Latency
   b. TSN
2. 5G RAN Applications
3. New Performance Definition
   a. Class C

Fronthaul Standards

CPRI
Common Public Radio Interface

- CPRI
(Common Public Radio Interface definition to connect RE & REC)

- eCPRI
(Next version of CPRI, connect eRE and eREC over packet based transport)

O-RAN ALLIANCE
xRAN

- Formed to standardize critical elements of proprietary RAN architectures

- Defines Open - eCPRI Specifications for vendor interoperability

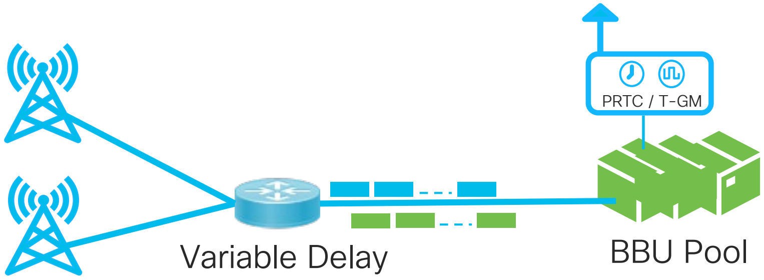
IEEE
Advancing Technology for Humanity

- 1914.1 ROE
- 1914.3 NGFI
(Defines encapsulation and mapping of Radio protocol over ethernet; including Fronthaul functional split definition)

- 802.1CM
(Specifies TSN profiles for Fronthaul)

Timing on Packet Fronthaul

CPRI protocol delivers Sync



How do we deliver Sync with CPRIoEthernet or eCPRI?

- CPRI timing built-in to synchronous protocol itself
  - PRTC delivers time up to BBU, BBU delivers it to RU over CPRI
- eCPRI or ROE requirement for timing same as before – but all the way to RRH/eRE
  - Much tighter than Backhaul or Midhaul timing requirements

What is 802.1CM?

- TSN features – making packets deterministic, most important are:
  - 802.1Q Amd. 26 Frame Pre-emption (was 802.1Qbu)
  - 802.3 Amd. 5 Interspersing Express Traffic (was 802.3br)

- 802.1CM takes TSN & applies it to Fronthaul (e.g. CPRIoPacket)
  - Splits CPRI traffic into separate IQ (radio bits) & Control/Mgmt (C&M)
  - Specifies the use of PTP for carrying timing information
    - Defines various budgets for absolute/relative timing error in the Fronthaul
  - Low latency requirement for IQ (radio) traffic (100uS between RE/REC)
  - 802.1CM defines two profiles for transport of Fronthaul traffic:
    - Profile A: Strict priority queuing (no frame pre-emption)
    - Profile B: Frame Preemption and Interspersing Express Traffic

Time Sensitive Networking 802.1CM

Ethernet for Fronthaul

- **Profile A**: Strict priority queuing (no frame pre-emption)
  - Radio data payload frame size max is 2000, C&M max is 1500 octets
  - IQ data traffic belongs to strict priority traffic class – strict priority algorithm
  - C&M data assigned to lower priority than IQ data
- **Profile B**: 802.1Qbu Frame Preemption
  - Pre-emption useful to avoid restrictions on the maximum frame size
  - Frame Preemption up to 25G links
  - IQ data traffic configured (*frame pre-emption status)* as "*express*"
  - C&M data assigned to lower priority than IQ data and set "*pre-emptable*"

802.1CM for Deterministic Latency

Mode	Radio Traffic	Enterprise Traffic
Strict Priority	Excellent Service Each Node: Moderate ENT queuing delay Each Node: Self-queuing delay	CIR met. SLAs may not guaranteed for Jitter and Delay.
Strict Priority + Preemption	Excellent Service Lowest Latency Each Node: Small ENT queuing delay Each Node: Self-queuing delay	CIR met. Latency / Jitter impact increased due to heavy preemption

	Fronthaul Max. Latency (us)			Fronthaul Frame Delay Variation (us)		
Scenario	1 node	2 node	3 node	1 node	2 node	3 node
SP	3.1	6.3	9.3	3.0	6.0	8.9
SP+P(Qbu*)	0.2	0.4	0.6	0.1	0.2	0.2

SP= Strict Priority
SP+P = Strict Priority + Frame Preemption

RAN Evolution
vs
Transport Timing

1. Fronthaul Requirements
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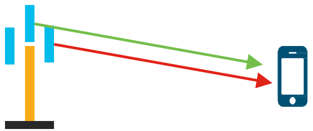
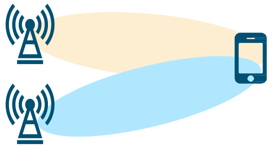
2. 5G RAN Applications
3. New Performance Definition
   a. Class C

eCPRI / ROE / NGFI Transport Requirements



Transmission Diversity
±32.5ns Phase Accuracy
Improves error performance
Data Rate or Capacity



Carrier Aggregation
±65ns Phase Accuracy
Higher Pick Date Rate
Better Load Balancing

Cordinated Multi Point
±130ns Phase Accuracy
Higher Pick Date Rate
Better Load Balancing

Category	Time Error Requirements at UNI |TE|			3GPP TAE requirements at antenna ports
	Case 1		Case 2	
	Case 1.1	Case 1.2		
A+	N.A.	N.A.	20 ns Relative	65 ns
A	N.A.	60 ns Relative	70 ns Relative	130 ns
B	100 ns Relative	190 ns Relative	200 ns Relative	260 ns
C	1100 ns Absolute		1100 ns Absolute	3 µs

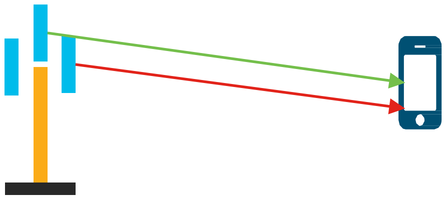
Case 1 = T-TSC is integrated in eRE

- Case 1.1 = integrated T-TSC requirements to T-TSC Class B
- Case 1.2 = enhanced integrated T-TSC requirement is total max |TE| is 15 ns

Case 2 = T-TSC is not integrated in eREs

* 3GPP TS 38.104, 38.133

Transmission Diversity



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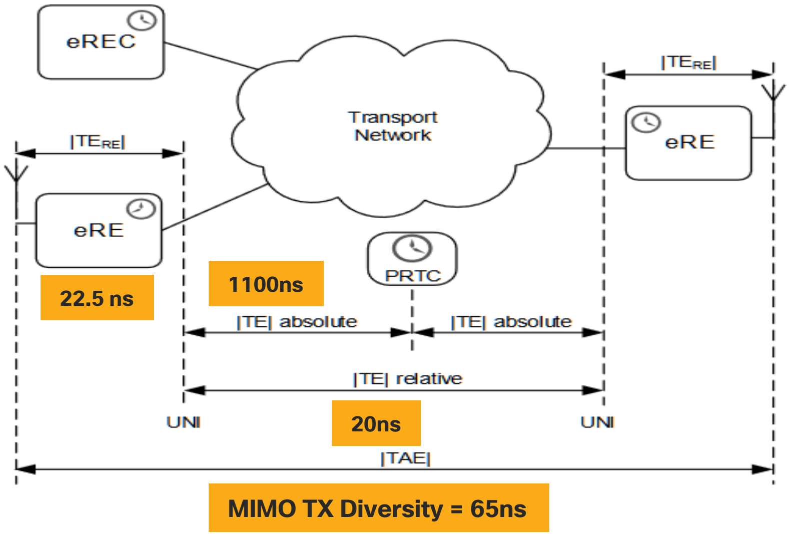

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	Case 1		Case 2	
	Case 1.1	Case 1.2		
A+	N.A.	N.A.	20 ns Relative	65 ns

Case 2 = T-TSC is not integrated in eREs

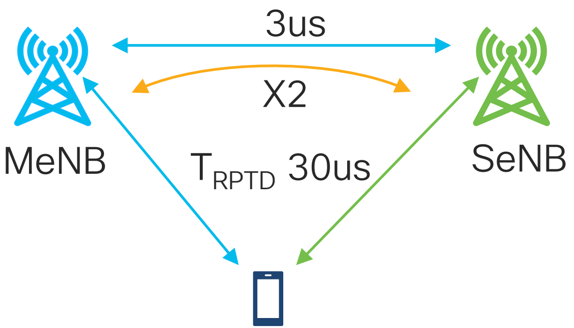
Example: Class A+ (T-TSC not integrated with eRE):

$|TE|_{Relative} <= TAE - 2xTE_{RE}$

65ns – 2x22.5ns

= 20ns

Dual Connectivity



UE with multiple Tx/Rx capability is configured to utilise radio resources provided by two distinct schedulers, located in two eNBs connected via a backhaul over the X2 interface

Synchronous ENDC Requirements

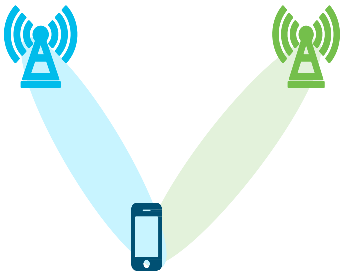
MRTD	Inter-band NR CA	Intra-Band non-conti NR
FR1	33us	3us (Co-located)
FR2	8us	3us (Co-located)
Between FR1 & FR2	TBD	

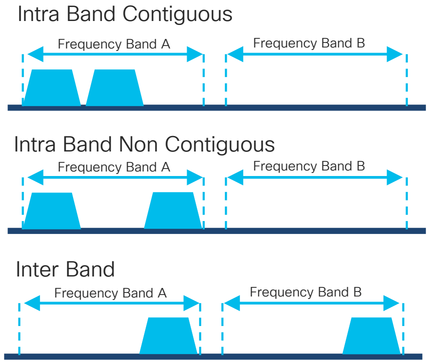
MTTD	Inter-band NR CA
FR1	35.21us
FR2	8.5us
Btw FR1 & FR2	TBD

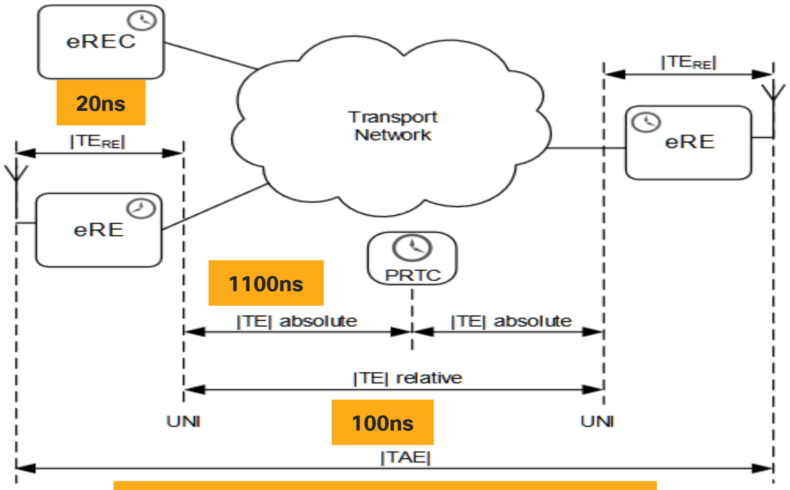
T_{RPTD} : Absolute propagation time difference between MN and SN which are serving the same UE = 30us (9Km)

MRTD : Maximum Received Timing Difference
MTTD : Maximum Transmitted Timing Difference

Carrier Aggregation







CA Intra Non-Contiguous, CA Inter = 260ns

Category	Time Error Requirements at UNI |TE|			3GPP TAE requirements at antenna ports
	Case 1		Case 2	
	Case 1.1	Case 1.2		
A	N.A.	60 ns Relative	70 ns Relative	130 ns
B	100 ns Relative	190 ns Relative	200 ns Relative	260 ns
C	1100 ns Absolute		1100 ns Absolute	3 µs

<u>Example case 1.1: Class B (T-TSC not integrated with eRE):</u>

$TE_{Relative} \le TAE - 2|cTE_{RE}| - 2|TE_{T\text{-}TSC}| - 2|dTE_{T\text{-}TSC}|$

$260ns - 2x20ns - 2x20ns - 2x40ns$

$= 100ns$

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Industrial Automation

clock accuracy level	Number of devices in one Communication group	Synchronisation requirement	Service area	Use case reference
1	Up to 300 device	< 1 µs	≤ 100 m^2	Factories of the Future 2.4 Factories of the Future 5.3 PMSE 1.2, Electric Power Distribution 4.1
2	Up to 10 UEs	< 10 µs	≤ 2500 m^2	PMSE 3.1
3	Up 500 UEs	< 20 µs	≤ 2500 m^2	PMSE 2.1

PMSE – Programme Making Special Events

3GPP TR 22.804 – for information
3GPP TR 22.821 – Feasibility Study

RAN Evolution
vs
Transport Timing

1. Fronthaul Requirements
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2. 5G RAN Applications

3. New Performance Definition
   a. Class C

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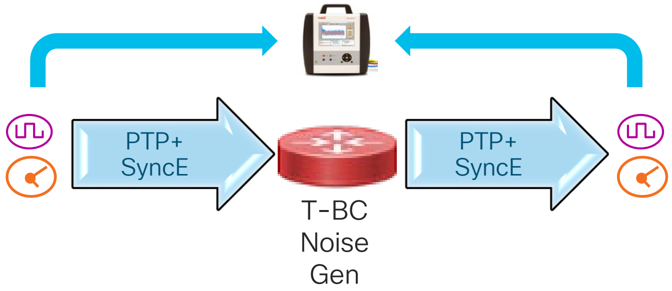
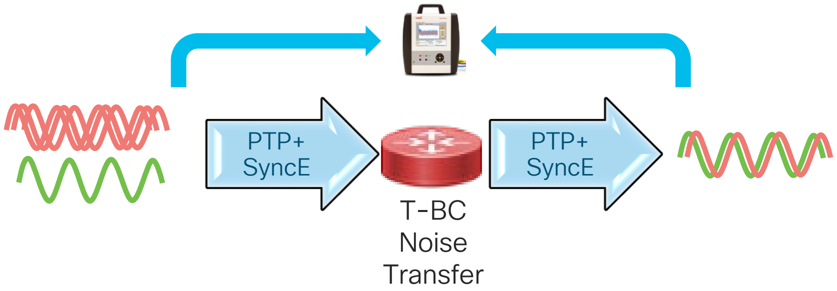
5G Phase Performance

G.8273.2 Boundary Clock

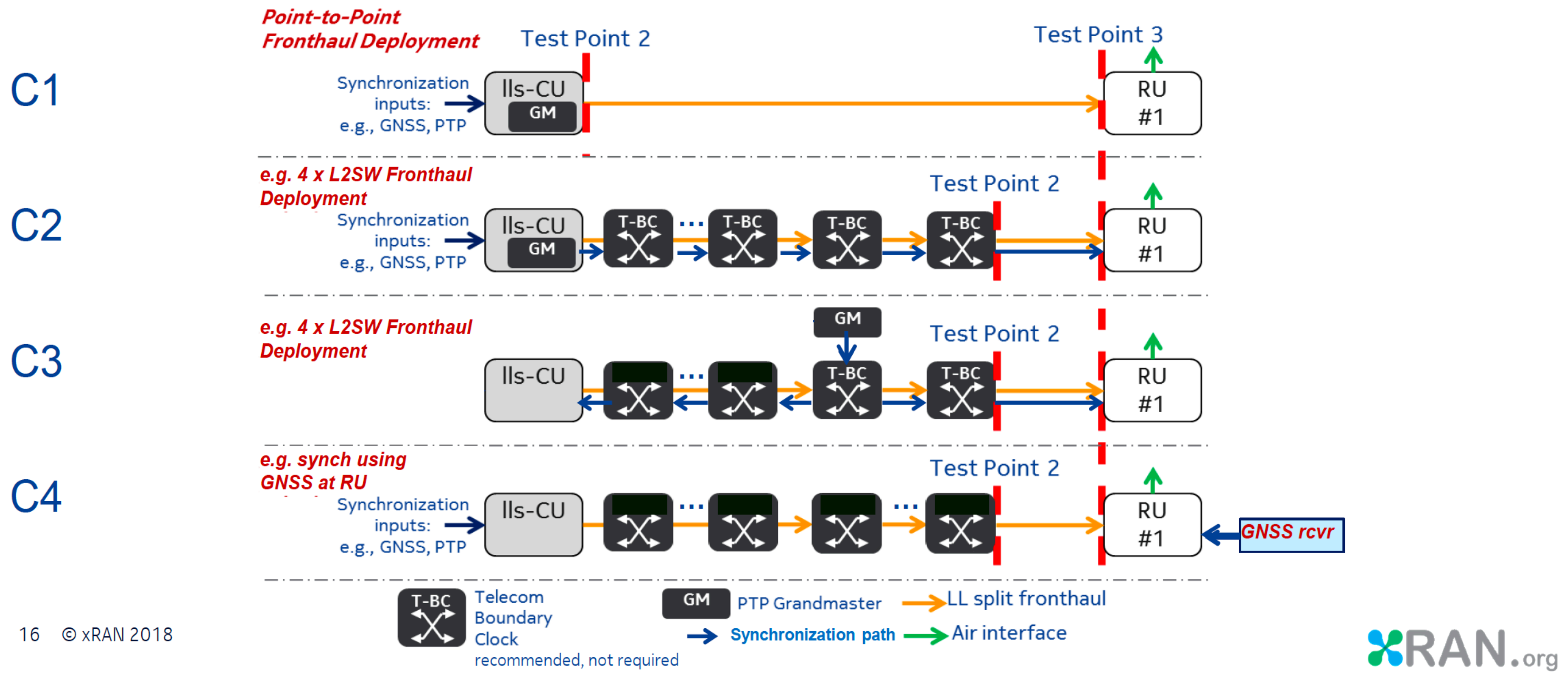
- Noise Generation: New Classes with ever tighter time error margins
- Meeting these limits involves hardware – it is not a software fix





Level	Max Total Time Error max|TE|	Constant Time Error cTE	Dynamic Time Error dTE
Class A (10 T-BC's)	100 ns	±50 ns	±40 ns
Class B (20 T-BC's)	70 ns	±20 ns	±40 ns
Class C (proposed*)	20 ns	10 ns	±20 ns

O-RAN Guidelines



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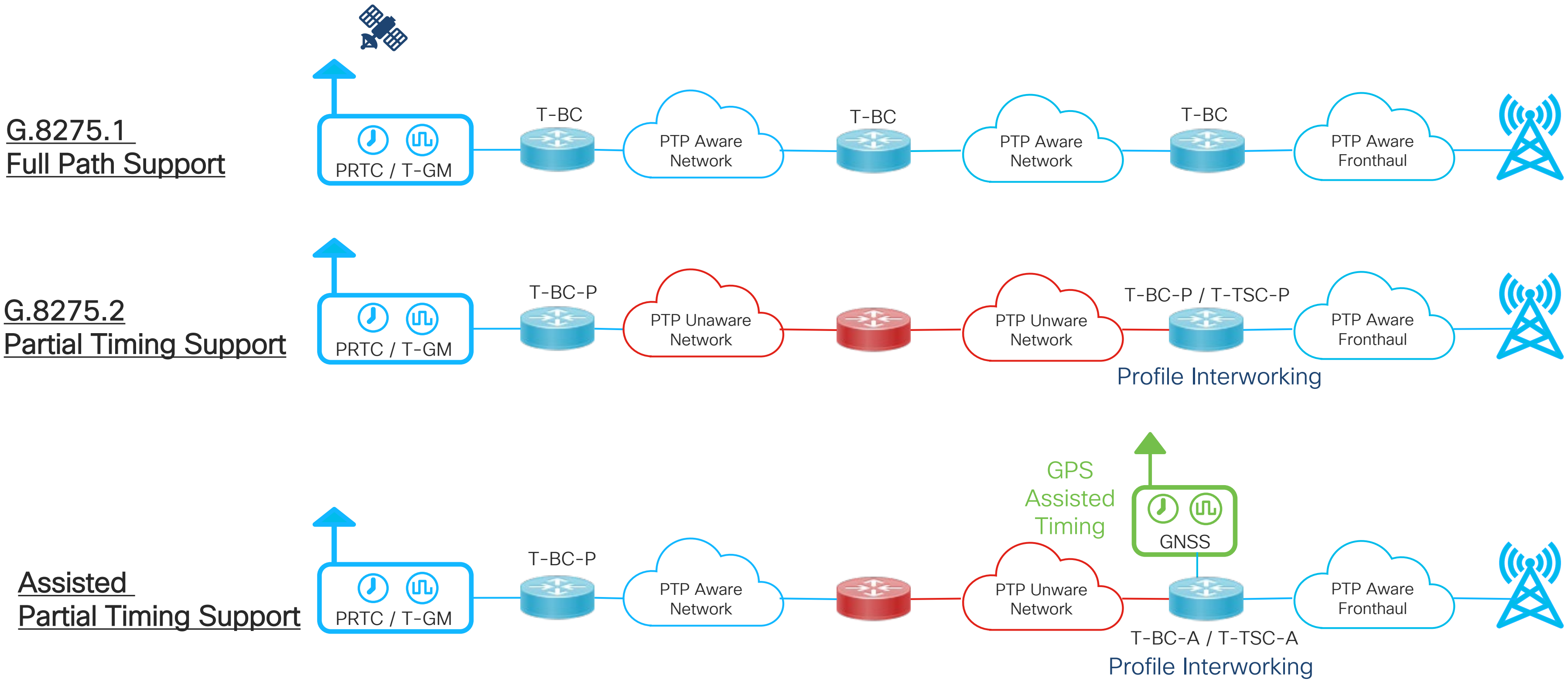
Solution Options and Best Practices

Solution Options

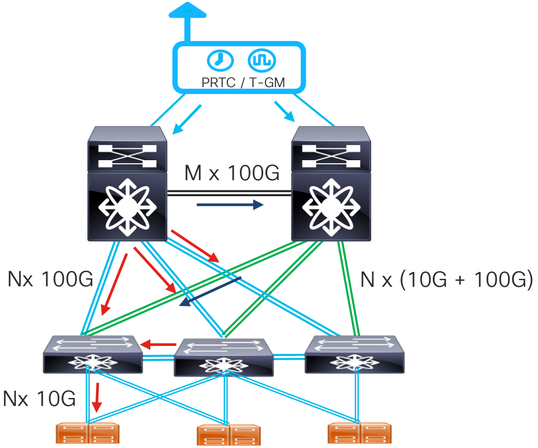


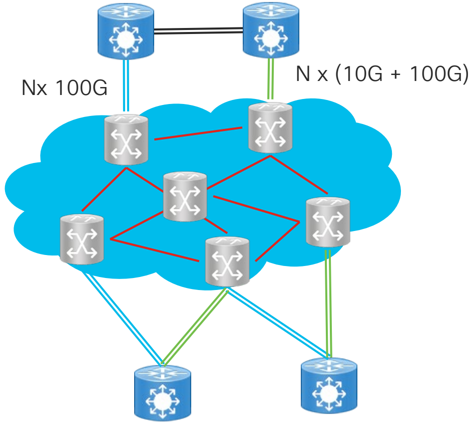
Key Deployment Challenges

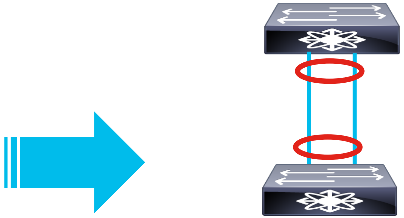
- Legacy Networks
  - doesn’t support – SyncE or PTP
- Network Path Asymmetry & Re-routing
- PTP over Bundle links
- Last Mile network is “Non-standard” transport or outsourced
- Migration issues

Non-standard = Network that doesn’t support accurate timing E.g. Microware, Cable, GPON etc.

PTP over Bundle links or ECMP Paths



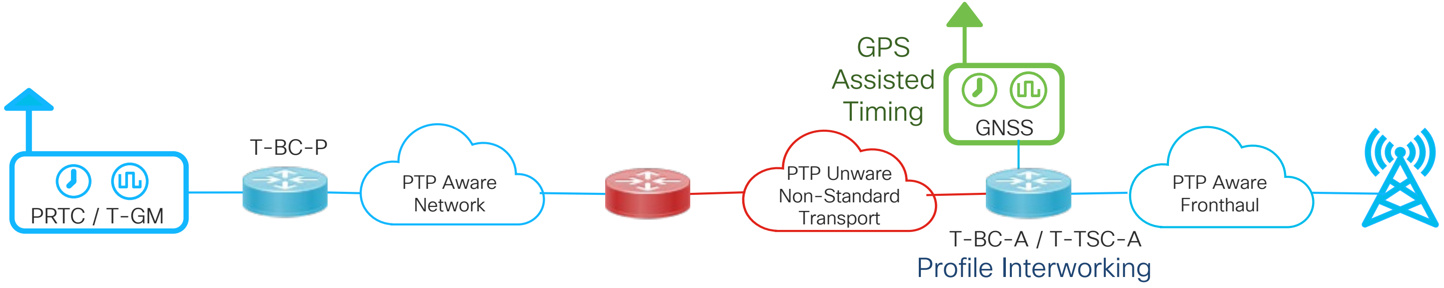




Solution is G.8275.1
(L2 Port based profile)

- Topology will surely have Asymmetry paths
- Hashing Algorithm may put packets in different paths
- Link failure will introduce phase offset

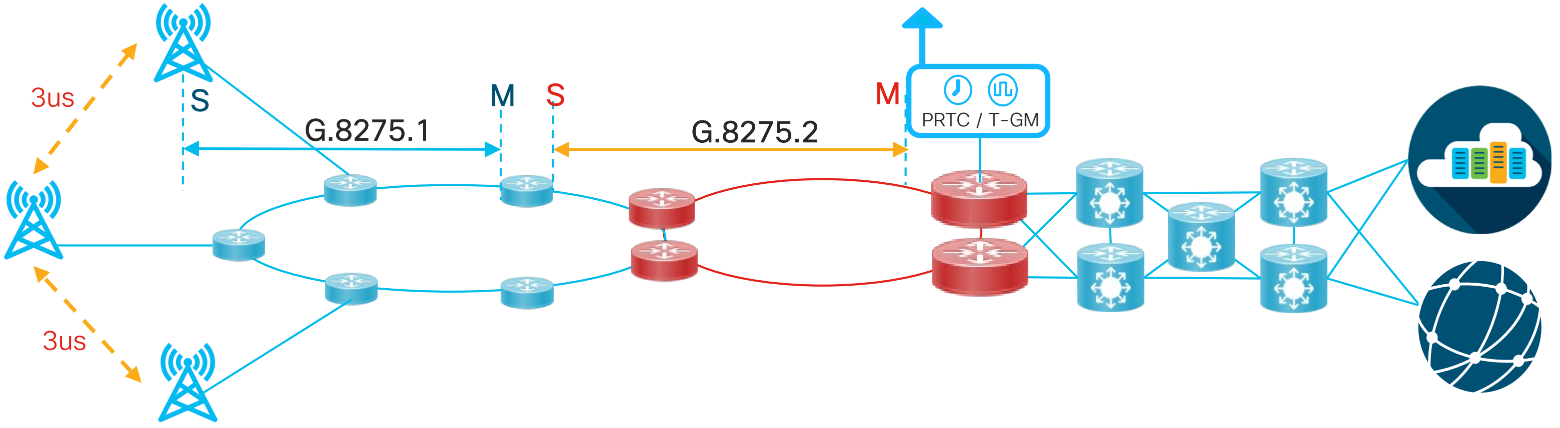
5G over Non-Standard Transport
APTS : Assisted Partial Timing Support



Non-standard Transport = Network that doesn't support accurate timing E.g. Microware, Cable, GPON etc.

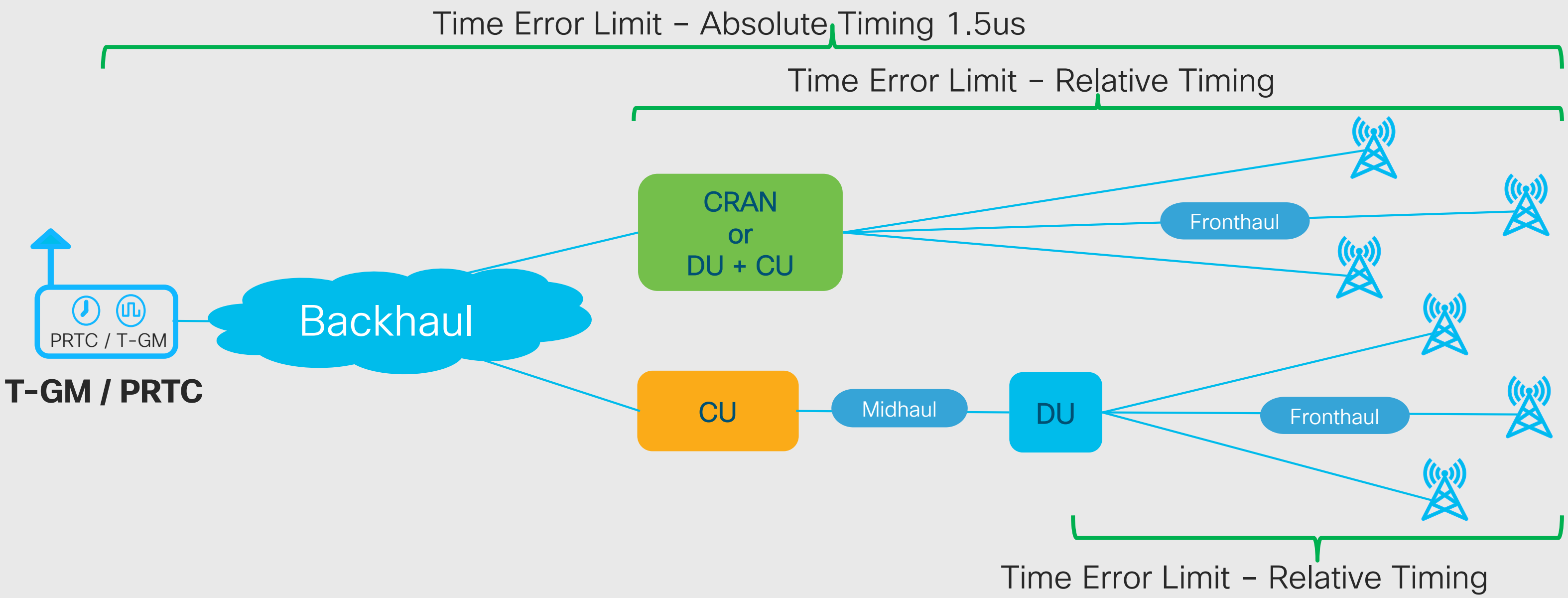
- Edge CSR measures Time stamps received from the network PTP flow with the local PRTC
- Compensate the error and Calibrate the PTP flow.
- In the event of Local PRTC failure, CSR uses calibrated PTP flow to keep the client aligned

Multi-profile or Profile Inter-working



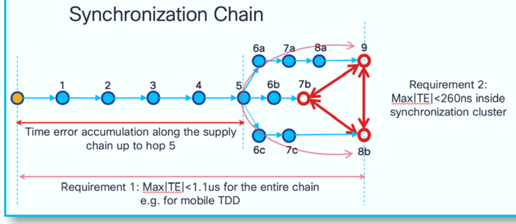
- Provides a migration path to roll out new profile on existing network
- Provides support to connect PTP aware and PTP unaware networks

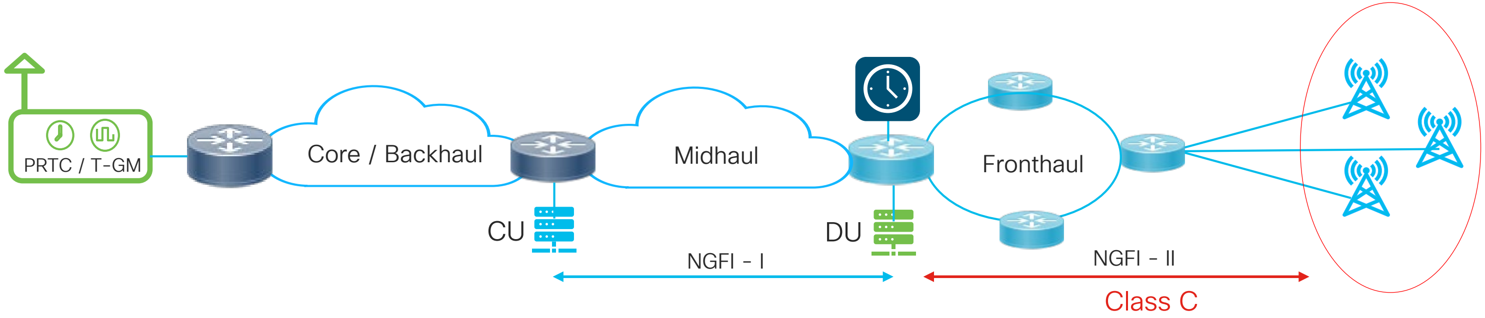
Design Fronthaul Synchronization

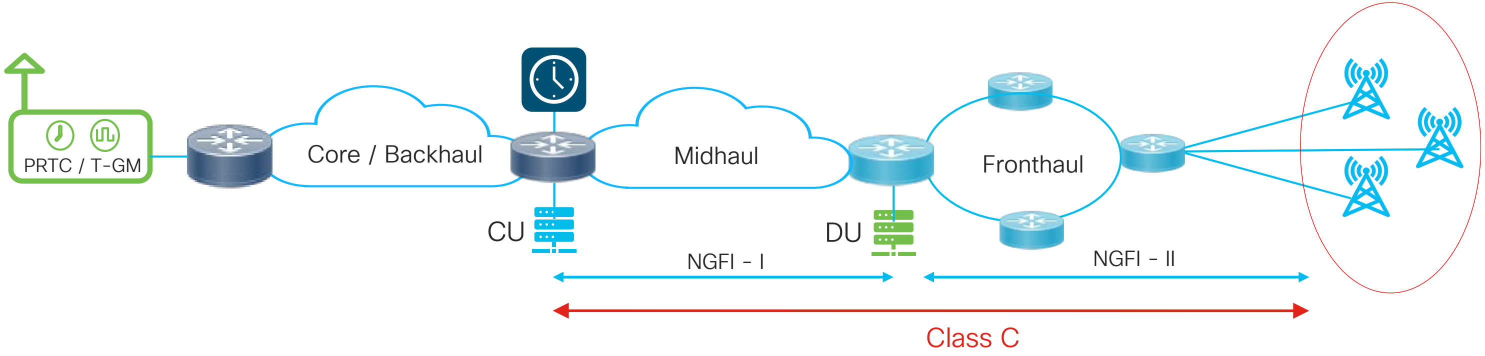


- Some customers will focus on tight “Absolute” Timing
- Some may focus on tight “Relative” timing
- Trade off is Cost vs Complexity and Operations

So What is Class C Timing For?





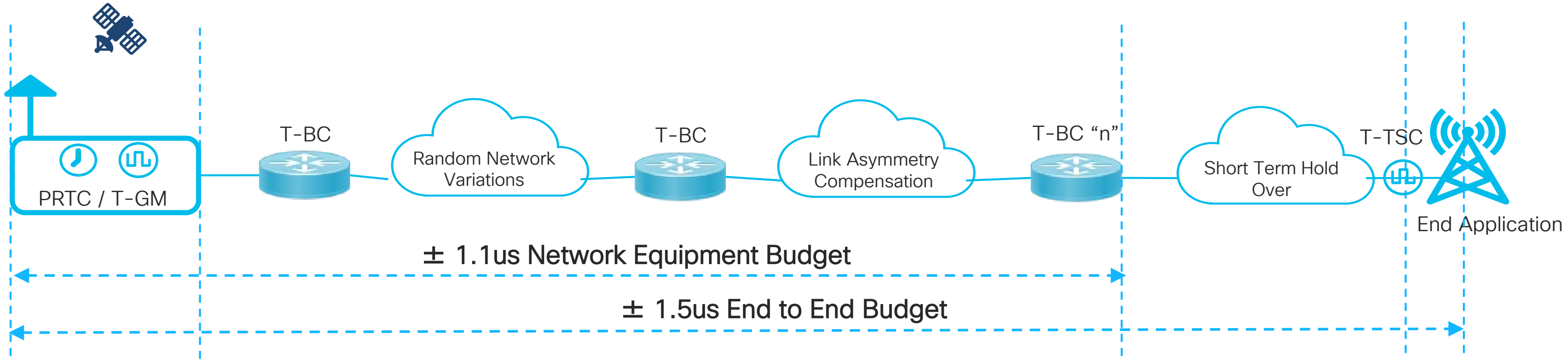


Learnings and Recommendations

- G.8275.1 – PTP Full Path support is the must have approach for successful 5G
- G.8275.1 is recommended for Bundle Interface and with Ring topologies
- Deploy GNSS / PRTC close to the client
- For PTP unaware networks, and / or G.8275.2 based deployments, it is recommended to deploy A-PTS for dynamic asymmetry correction
- Parallel PTP network could be an answer to bypass “legacy networks”

Summary

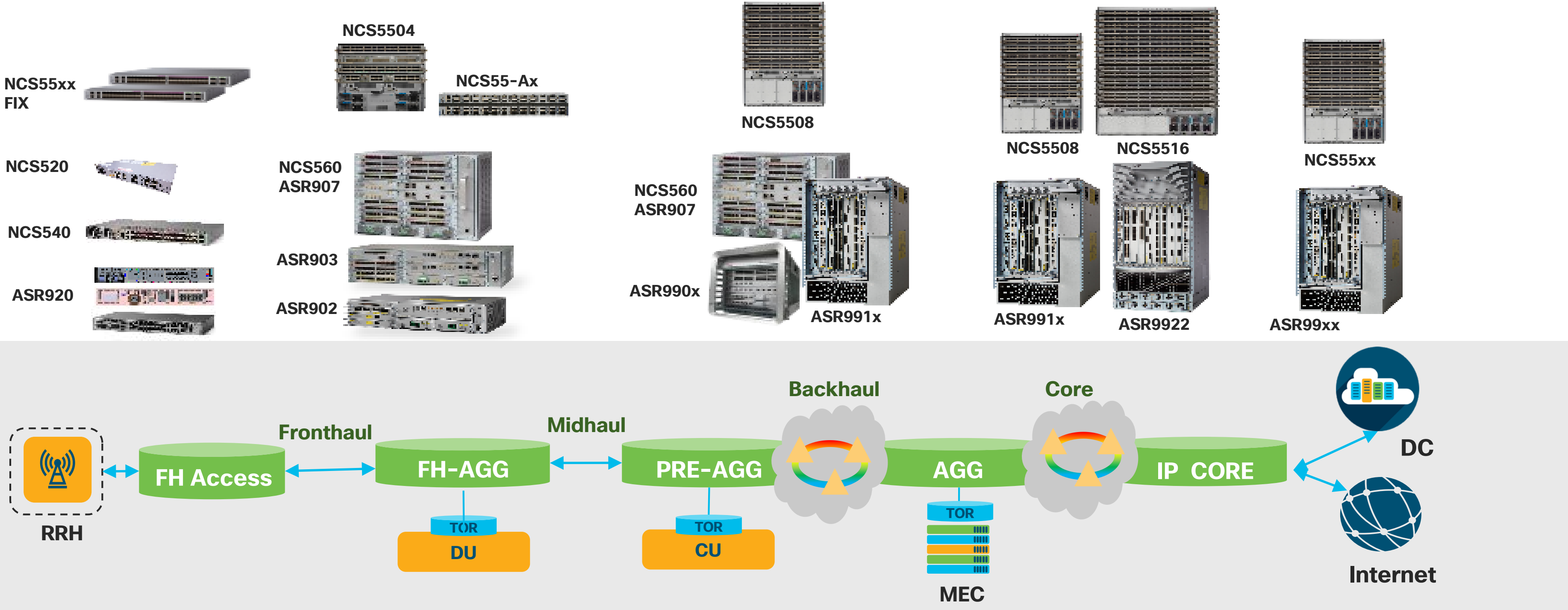
Time Synchronization Defines 5G



G.8272 Class B PRTC ~ 40ns G.8272.1 ePRTC ~30ns	G.8273.2 Class C T-BC ~ 10ns Class C T-TSC ~ 10ns	G.8273.2 Class C T-TSC ~ 10ns G.8273.2 / 802.1CM / eCPRI $\lvert TE_{RE} \rvert$ = 15ns or 20ns
G.811.1 ePRC ~30ns	G.8262.1 eEEC – 7ns MTIE, 1ns TDev	

Cisco Time Synchronization

Strong Feature Support and Roadmap

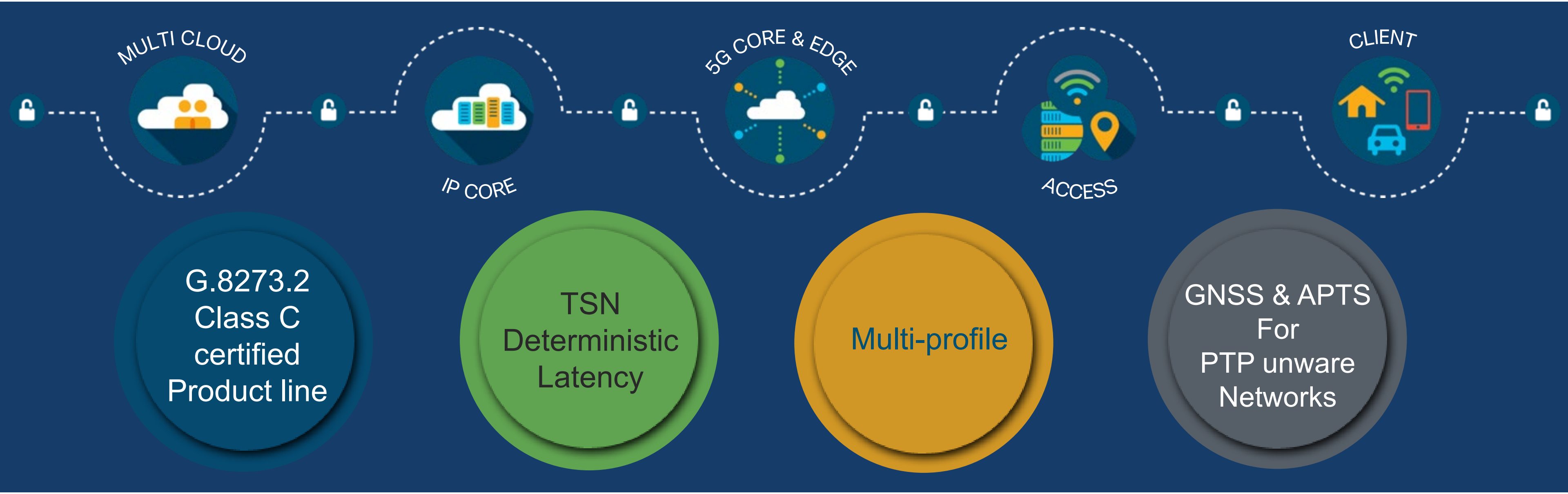


* SyncE, PTP 1588v2-2008, G.8265.1, G.8275.1, G.8273.2 Class C, G.8275.2, Multi-profile support , Asymmetry correction, GNSS

* Roadmap: eEEC, APTS

* Contact SPNS Product Marketing for more detail

Cisco enables Synchronization



Better Accuracy	5G Fronthaul Use Cases	Smooth Migration Path	Support for Legacy Transport

References and Further Information

- **BRKSPG-2557** 5G Synchronization - Design, testing and deploying Timing to support 5G rollouts - by Dennis Hagarty
  31st Jan 2020, Hall 8.1, CC8, Room 8.18/8.17

- 3GPP TR 38.104, TR 38.801, TR 38.214, TR 38.133
- 3GPP TR 28.204, TR 28.821
  http://www.3gpp.org/ftp/specs/archive

- IEEE 802.1CM
  https://1.ieee802.org/tsn/802-1cm/

- O-RAN Specifications
  https://www.o-ran.org/specifications

- eCPRI Specifications
  http://www.cpri.info/spec.html

- ITU-T Recommendations – ITU-T G.826x and G.827x Series
  https://www.itu.int/rec/T-REC-G/en

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