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Providing 5G-Quality Synchronization with Optical Timing Channel-enabled vPRTC in Real-world Networks

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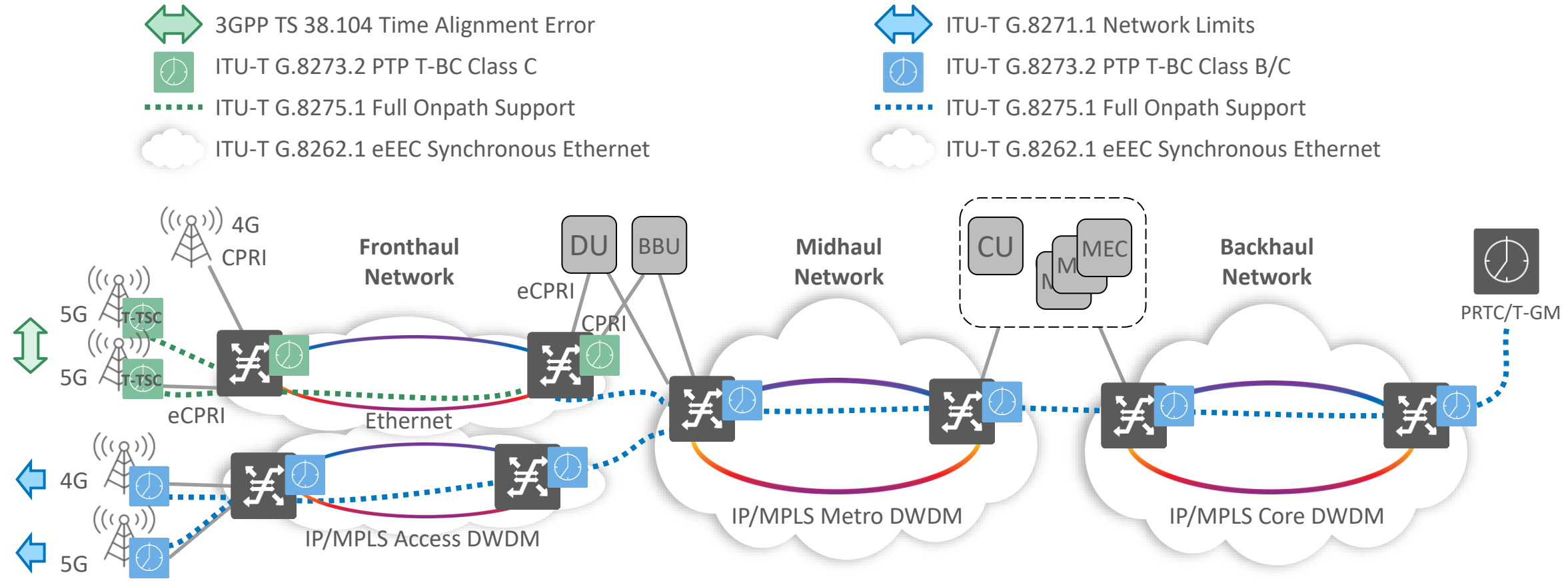
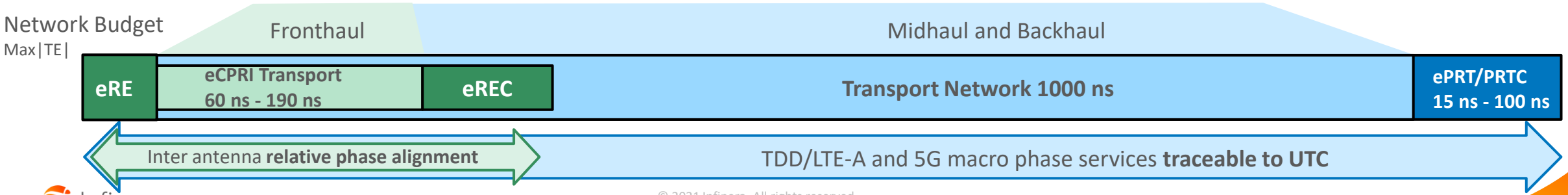
5G Drives High-accuracy Synchronization Requirements





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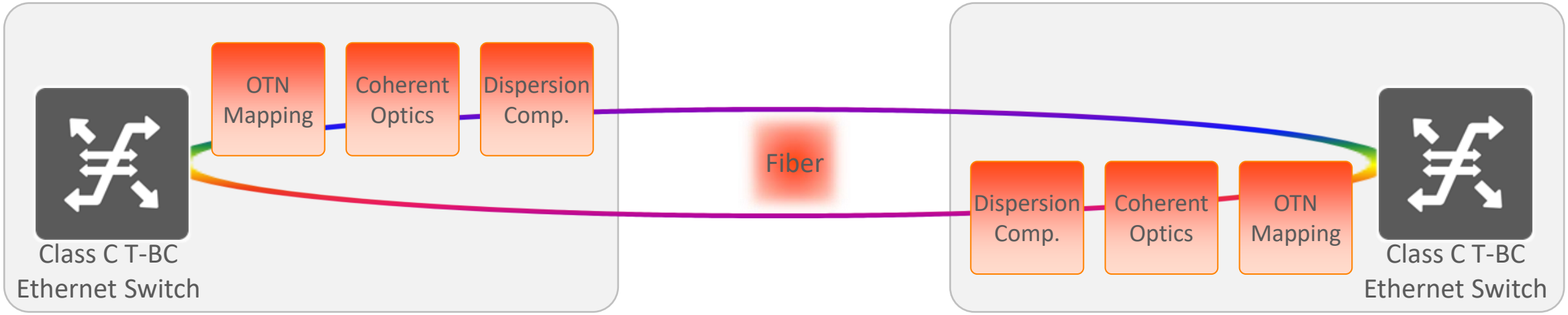
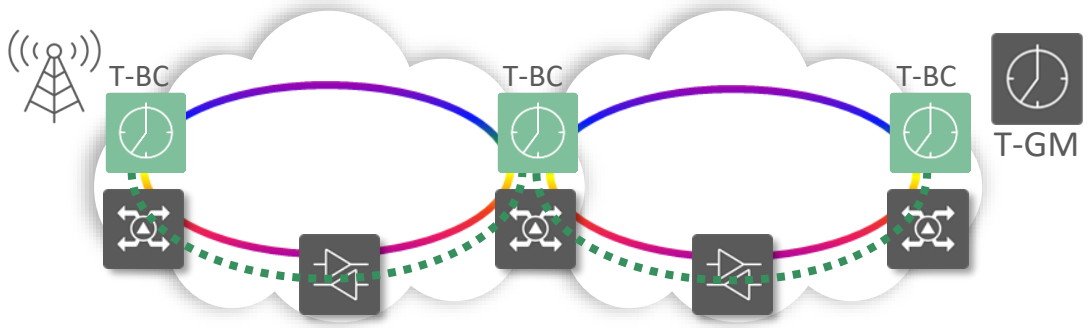
Example Causes of Asymmetry in Optical Transport



Contributor	Fiber	Dispersion Compensation	Coherent Optics	OTN Mapping	IP Routing and Ethernet Switching
Source	Asymmetry in fiber lengths, jumper cables, etc. 2.5 ns/m	Random asymmetry in DCF used in each direction	FIFO buffers in DSP Varies on restarts	Deep FIFO buffers in OTN mapping Varies on restarts	Traffic/buffering asymmetry and timestamping inaccuracy
Impact	Large but static	Very large but static	Varying and random	Large and random	Tight requirements to control impact
Range	Fixed cTE of ±5 to 1000+ ns	Fixed cTE of ±5 to 20,000 ns	Random cTE of ±20 to 130 ns on restart	Random cTE of ±20 to 1000 ns on restart	Class A/B/C specifications Max(TE) of 30 to 100 ns cTE of 10 to 50 ns dTE (low-pass filtered) of 10 to 40 ns

Sychronization Distribution Strategies for 5G

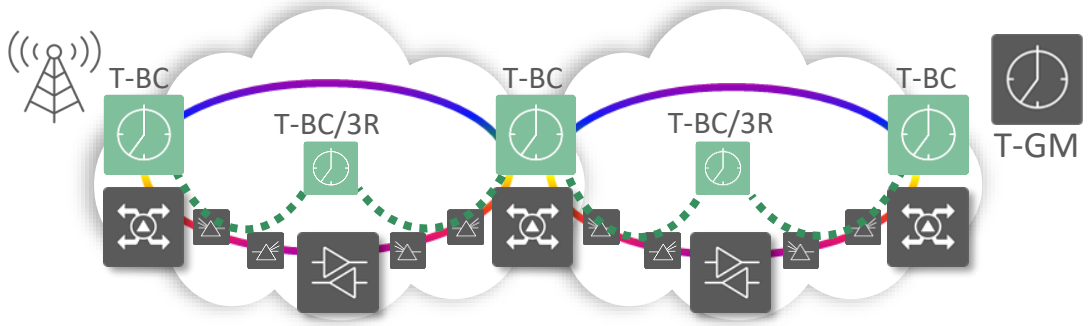
1. In-band Delivery



In-band delivery of synchronization

- Transponder synchronization performance
- Coherent synchronization performance
- High-performance PTP 1588 and SyncE delivery

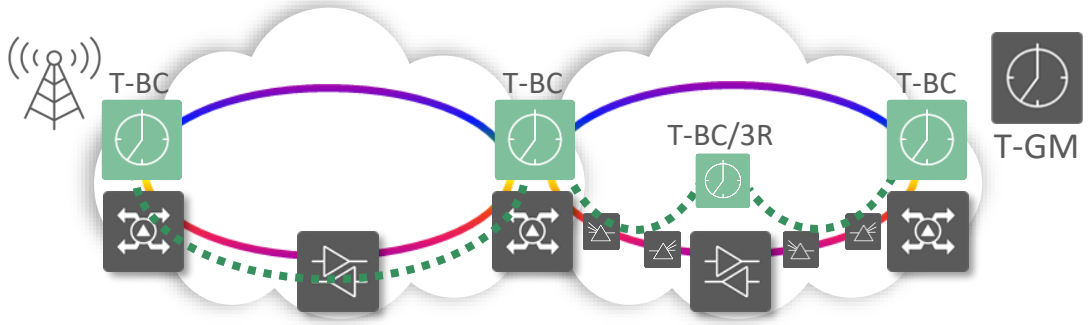
2. Optical Timing Channel



Out-of-band delivery of synchronization

- Very high-performance PTP 1588 and SyncE
- Single-fiber CWDM and O/E/L-band overlay
- OTC network elements:
  - T-BC Class D boundary clocks
  - Optical 3R regeneration

3. Hybrid Sync Distribution



Hybrid use of in-band and OTC mechanisms

- Interoperable and interchangeable
- All high-performance 1588 PTP, not proprietary
- Use the appropriate solution for the best fit
  - In-band delivery perfect for metro-access
  - OTC widely used as core distribution

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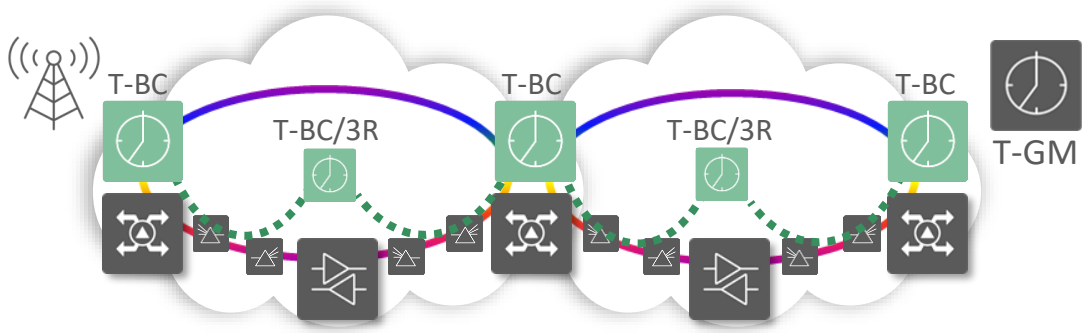
Infinera's OTC2.0 Solution



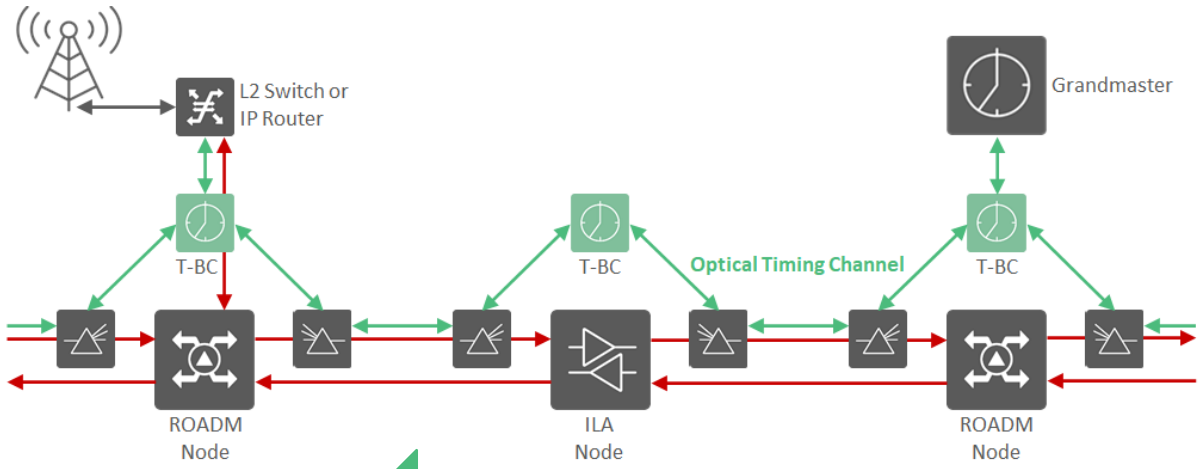
Infinera or third-party optical line system

OTC2.0 combines industry-leading sync capabilities from Microchip with Infinera's in-depth sync-over-DWDM knowledge and capabilities

KEY ATTRIBUTES/FEATURES:

- Supports nanosecond-level 5G sync distribution in challenging transport networks
- Market-leading and ***field-proven*** Class D sync distribution performance over transport networks
- Highly reliable and robust timing distribution with advanced resiliency mechanisms
- Extensive range of sync features and functionality
- Broad range of optical layer capabilities:
  - Infinera and third-party optical line systems
  - Brownfield and greenfield applications
- Broad range of supported network architectures and timing service delivery

Building High-Performance Optical Timing Channels



SYNC LAYER CONSIDERATIONS:

- High performance boundary clock operation
- vPRTC / Timing cloud architecture
- Demanding performance/feature requirements:
  - Class D cTE within ± 5 ns, max. |TE| <5 ns
  - Hop-by-hop local clock recovery, OCXO holdover
  - Resiliency mechanisms
  - GNSS/Grandmaster options
- Supporting optical layer interoperability:
  - BiDi single fiber working optics
  - Large (up to 6) number of degrees/directions

Optical Layer Foundation

OPTICAL LAYER CONSIDERATIONS:

- Fiber topology and resiliency – Ring, Linear, Tree, Mesh
- Analogue domain – many factors to balance:
  - Managing fiber effects – asymmetry, non-linear effects, dispersion etc.
  - Optical add/drop – ROADM / Fixed add/drop
  - Amplification options – EDFA / Raman
  - Bandwidth – C Band / C+L Bands
- Optical Timing Channel Toolkit:
  - Timing channel options – O/E/L-band
  - Sync/Retiming options – High performance T-BC, Integrated T-BC (Router) or optical 3R

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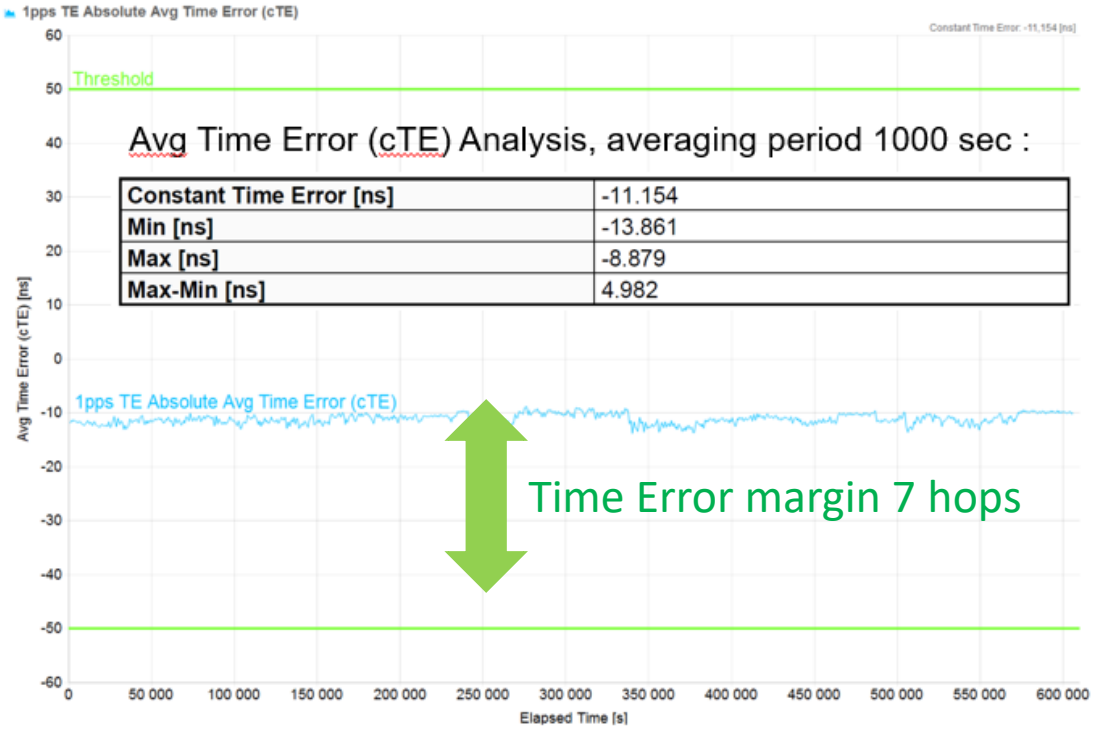
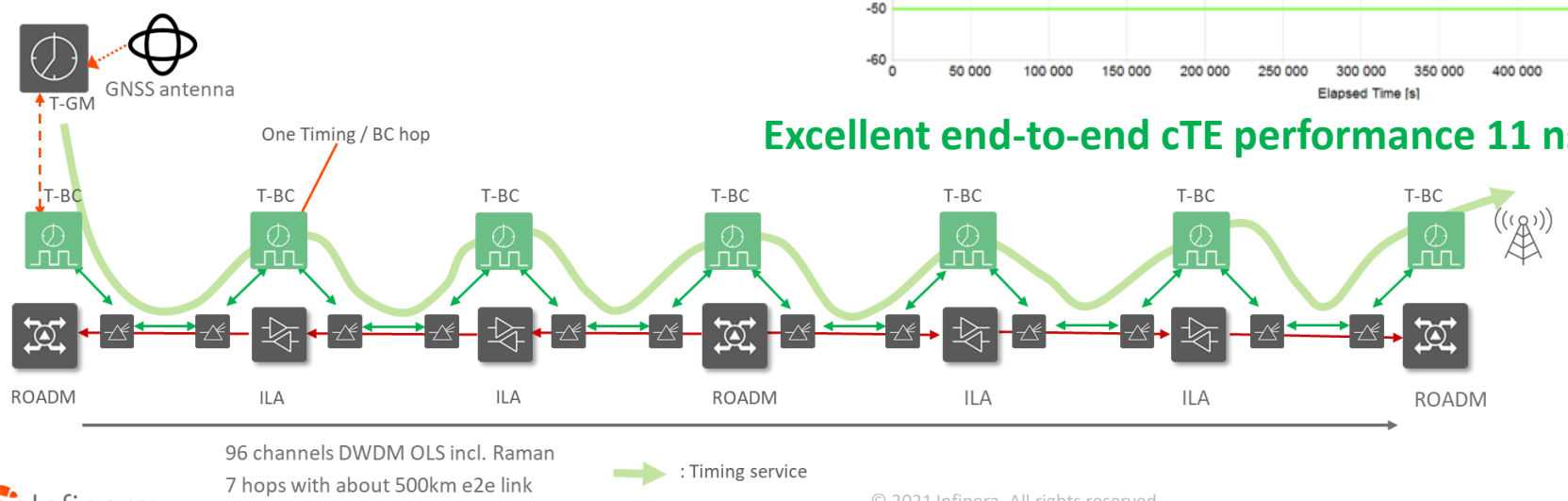
Field-proven Excellent Timing Performance and Robustness

Feedback from Tier 1 network provider after two month´s field trial :

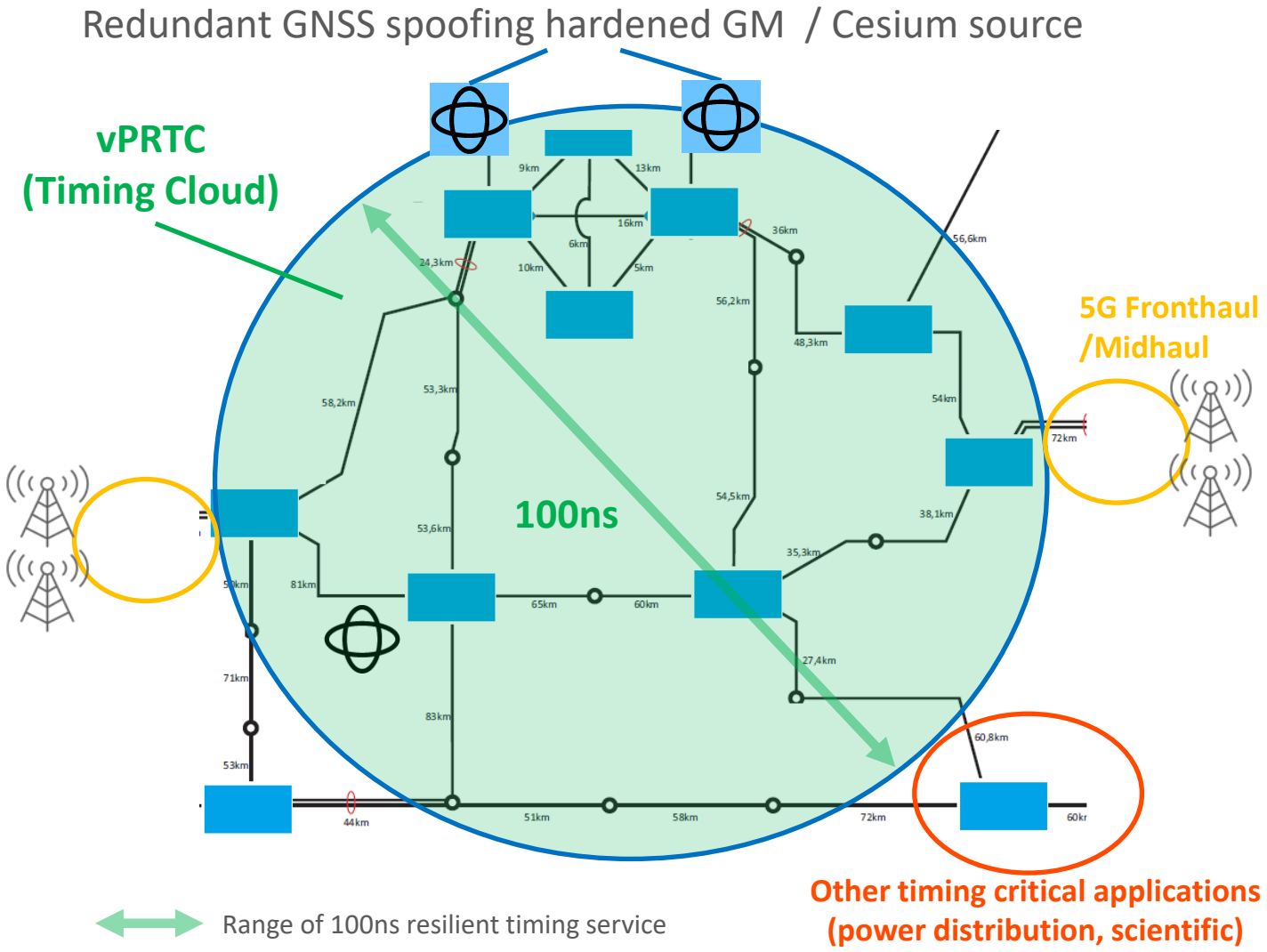
"Infinera OTC with TP4100 is well prepared for 5G radio application. It shows excellent timing performance better class D, enabling demanding radio use cases and provides stable operation and robustness in disaster situation. Some improvement potential shown in recovery scenario."



Excellent end-to-end cTE performance 11 ns, 1 week test case



Creating an Optical Timing Channel-enabled vPRTC

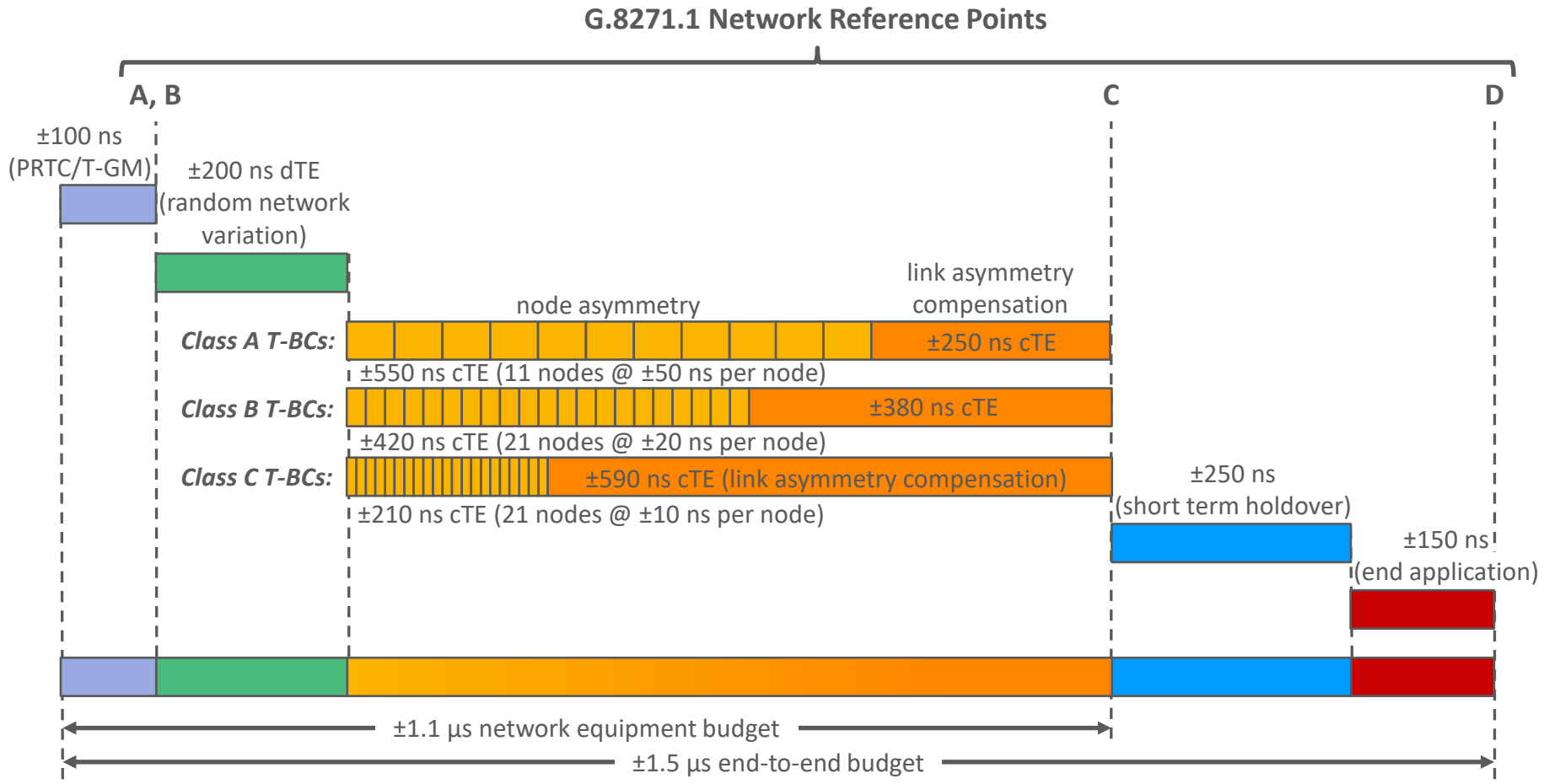


OTC-ENABLED vPRTC:

- Provides GNSS-like omnipresent timing, overcoming GNSS security/reliability/accessibility issues
- Uses secure and reliable optical network to deliver highly-accurate timing/synchronization:
  - Predictable, traceability to UTC and PRC
  - Reliable and secure
  - Highly-accurate
- Flexible and independent
- Every DWDM node capable of delivering timing/synchronization
- Preserves timing budget for access/aggregation networks
- Simplifies timing/synchronization planning and ongoing operations

Thank You

G.8271.1 Time Error Budget Impact on Transport Networks



Budget Allocations:

- 1.1 µs for network equipment
- 1 µs for transport
- 200ns for dTE
- 800ns for asymmetry
  - ~210-550ns for IP devices
  - ~250-590ns for DWDM transport