ITU-T Synchronisation Standards Overview

July 2018

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ITU-T Packet Sync Recommendations

Calnex

Definitions / Terminology

G.8260: Definitions and Terminology for Synchronisation in Packet Networks *(includes PDV metrics)*

	Frequency	Time and Phase	Enhanced Time for 5G
Basic Aspects	**G.8261:** Timing and Synchronisation Aspects in Packet Networks *(Frequency)*	**G.8271:** Time and Phase Synchronisation Aspects in Packet Networks	
Network Requirements	**G.8261.1:** PDV Network Limits *(Frequency)*	**G.8271.1:** Network Limits for Time/Phase *(Full Timing Support)* **G.8271.2:** PDV Network Limits for Time/Phase *(Partial Timing Support)*	**G.8271.1:** Enhanced Network Limits for Time/Phase *(Full Timing Support)* **G.8261:** Enhanced Network Limits for Frequency
Clock Specifications	**G.8262:** Ethernet Equipment Clock (EEC) Specification **G.8263:** PTP Slave Clock Specification *(Frequency)* **G.8266:** Grandmaster Clock Specification *(Frequency)*	**G.8272:** Primary Reference Time Clock (PRTC) Specification **G.8273:** Time/Phase Clocks Framework **G.8273.1:** T-GM Specification. **G.8273.2:** T-BC & T-TSC Class A, B Specifications **G.8273.3:** T-TC Specification **G.8273.4:** APTS Clock Specification	**G.8272.1:** Enhanced Primary Reference Time Clock (ePRTC) **G.811.1:** Enhanced Primary Reference Clock (ePRC) Specification **G.8262.1:** Enhanced EEC (eEEC) Specification **G.8273.2:** T-BC & T-TSC Class C, D Specifications.
Methods and Architecture	**G.8264:** Distribution of Timing Information (ESMC) **G.8265:** Architecture for Packet-Based Frequency Delivery	**G.8275:** Architecture for Packet-Based Time/Phase Delivery	
Profiles	**G.8265.1:** PTP Telecom Profile for Frequency	**G.8275.1:** PTP Profile for Time *(Full Timing Support)* **G.8275.2:** PTP Profile for Time *(Partial Timing support)*	

Published

Under development

ITU-T Sync Standards Categories

- Transfer of frequency to meet 50ppb *(2G/3G/4G FDD)*
  - Using SyncE, or using PTP over existing networks

- Transfer of time to meet 1.5μs *(3G/4G TDD, LTE-A)*
  - Using PTP over new networks with T-BC and SyncE at every node

- Transfer of time to meet 1.5μs *(3G/4G TDD, LTE-A)*
  - Using PTP over existing networks

- Transfer of time to meet 100 – 200ns *(5G potential)*
  - “Enhanced” clock specifications

- Sync OAM *(general)*

What’s new?

Recently published, March 2018

- Amended or Revised Recommendations:
  - G.8264 Amd. 1 – modifications to the QL codes for the enhanced clocks
  - G.8266 Amd. 1 – additional information on measuring noise transfer
  - G.8271 Amd. 1 – addition to appendix on asymmetry compensation
  - G.8271.1 Amd. 1 – new appendix on measuring relative time error; various other minor changes
  - G.8271.2 Amd. 1 – added network limits at clock output (reference point D)
  - G.8273 Revision – includes previous amendments, plus various minor changes
  - G.8275.1 Amd. 2 – revised appendix on clock states, plus various minor changes
  - G.8275.2 Amd. 2 – revised appendix on clock states, new section on handling PTSF (loss of sync), plus various minor changes

Planned agreements for Oct. 2018

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- High-accuracy “enhanced” clock specifications for 5G:
  - G.8262.1 *(new)* – Enhanced SyncE clock specification
  - G.8272 Rev. 3 – Adds the new Class B PRTC specification (40ns accuracy)
  - G.8273.2 Amd. 2 – Adds new “Enhanced T-BC” specs, Class C and Class D – Also adds 25/40/100G interfaces for all clock classes
- “Regular” clock specifications updates:
  - G.8262 Rev. 4 – Adds the OEC (OTN Equipment Clock), with same wander spec as EEC
  - G.8273.3 Amd. 1 – Adds 25/40/100G interfaces for all clock classes
- APTS/PTS updates:
  - G.8260 Amd. 2 – Clarifies the step size for the pktSelected2WayTE metric, should be 20s or less
  - G.8271.2 Amd. 2 – Adds network limit for point D (between slave clock and end application)
- General Information:
  - G.8271 Amd. 2 – Clarifies the FCS calculation procedure for the serial ToD interface
  - G.8275 Amd. 1 – Adds architecture information about Fronthaul
  - G.Suppl.Sim – A supplement detailing the assumptions used behind all the simulations

Major Work Items In Progress

- G.8262.1 (enhanced SyncE clock)
  - Simulations on noise generation for different bandwidths and oscillator types, plus noise accumulation in a chain of clocks
  - Noise generation spec should be finalised by next meeting
  - Status: to be approved by end 2018
- G.8273.2 (Class C and Class D T-BC and T-TSC)
  - Based on enhanced SyncE clock
  - Noise accumulation simulations for long chains under way
  - Noise generation limit to be in the ±5ns to ±10ns range
  - Status: to be approved by end 2018
- G.8273.4 (APTS and PTS clock specifications)
  - Restructured document to separate APTS and PTS clocks
  - Provisional agreement on noise generation (50ns wander, and ±50ns cTE)
  - Noise tolerance agreed (G.8271.2 network limit)
  - Noise transfer and holdover still work in progress
  - Status: possible approval by end 2018, might be 2019

ITU-T Recommendations for Frequency Synchronisation

In the beginning…

- “Mr. Watson, come here, I want to see you.” (10 March 1876)
  - Phones connected directly by copper wire – and stayed that way for over 60 years
  - FDM systems “L-carrier” introduced in the 1940s
  - Digital TDM systems “T-carrier” introduced in the 1960s, multiplexing 64kbit/s channels (8-bit PCM, sampling at 8kHz)

After about 100 years…

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- Digital switches introduced in early 1970s
  - Voice calls were no longer converted back to analogue for switching, but could be switched directly from one TDM circuit to another
- Digital switches required the circuits (phone calls) being switched to have the same sample 8kHz sample rate
  - "Slips" (missing or extra samples) introduced if they were different
  - Required the whole infrastructure to be based on the same master clock
  - Switches were frequency synchronised by using dedicated T1 or E1 circuits, driven from a central Primary Reference Clock (PRC)
- Synchronisation in telecoms was born!

Synchronous Digital Hierarchy (SDH) (1990s)

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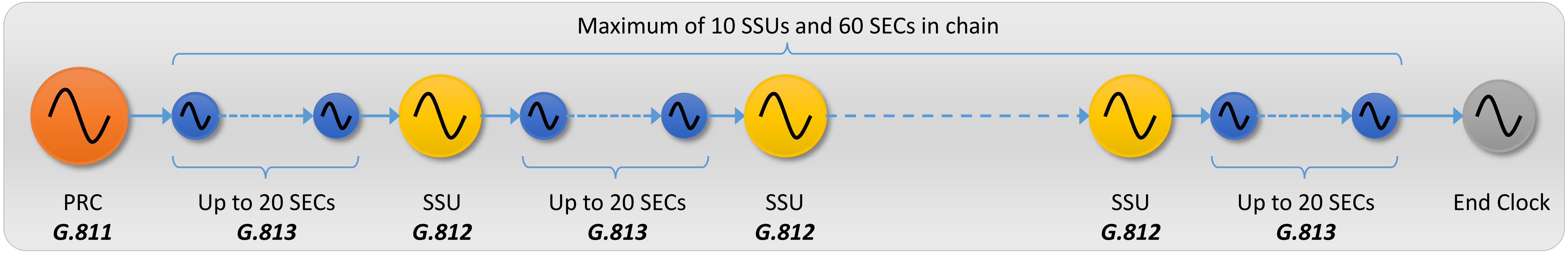
- Synchronisation reference chain defined in G.803:



- ITU-T Recommendations:
  - G.811: Primary Reference Clock (PRC) — Frequency accurate to 1 part in 10^{11}
  - G.812: Synchronisation Supply Unit (SSU)
  - G.813: SDH Equipment Clock (SEC)

  } define the maximum amount of phase noise each clock can introduce

  - G.823: Network Limits for E1 circuits
  - G.824: Network Limits for T1 circuits

  } define the maximum amount of phase noise permitted at any point in the synchronisation chain

- Only intended to provide frequency to the infrastructure

Mobile Technology

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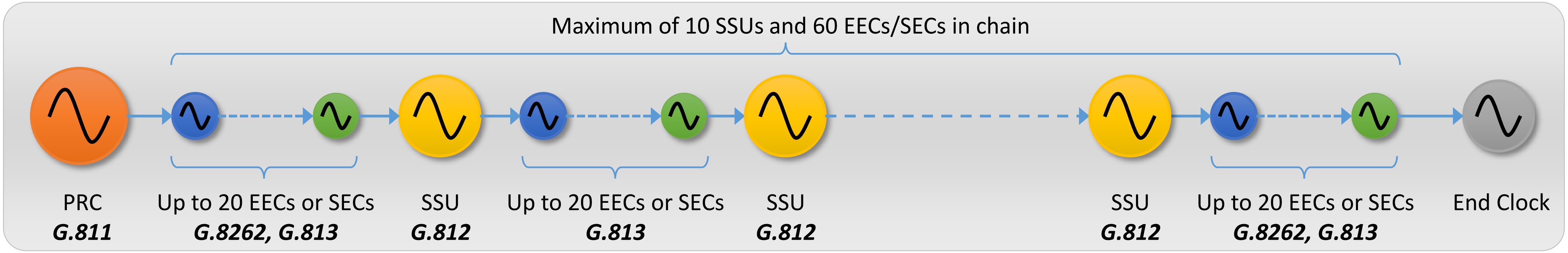
- ***1G and 2G:*** basestations connected using E1 or T1 circuits
  - Basestations required frequency accuracy of 50ppb (5 parts in 10^8)
  - "Freeloaded" off the known frequency accuracy of the E1 or T1 circuits from the SDH system
- ***3G:*** initially used E1 and T1 connectivity as before
  - Then data services came along…
  - HSDPA *(as used by iPhone 3G)* offered up to 14Mbit/s download speeds (although more typically 3.5Mbit/s)
  - Basestations needed to move to Ethernet connectivity to accommodate the higher data rates on the backhaul interface
- *Now where is that nice stable frequency again?*

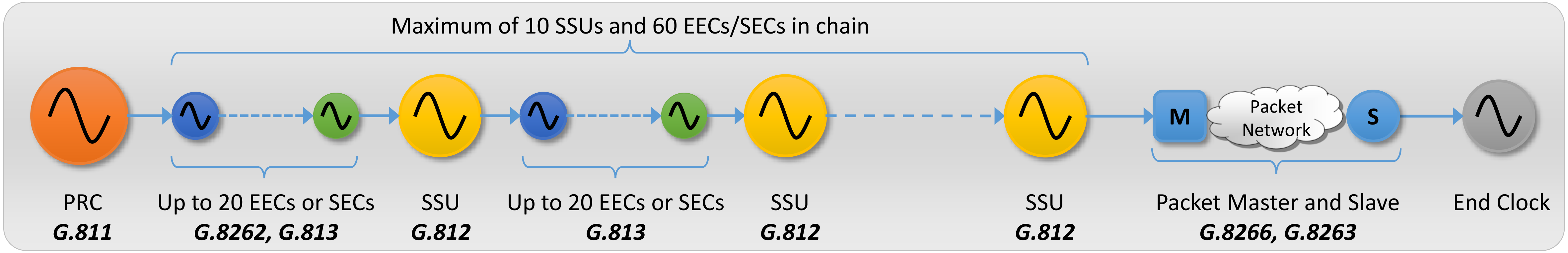
Transfer of frequency to meet 50ppb

G.8261: Frequency over Packet Interfaces

- Approach 1: Use the physical layer clock
  - SyncE clocks (EEC) made identical to SECs in performance terms



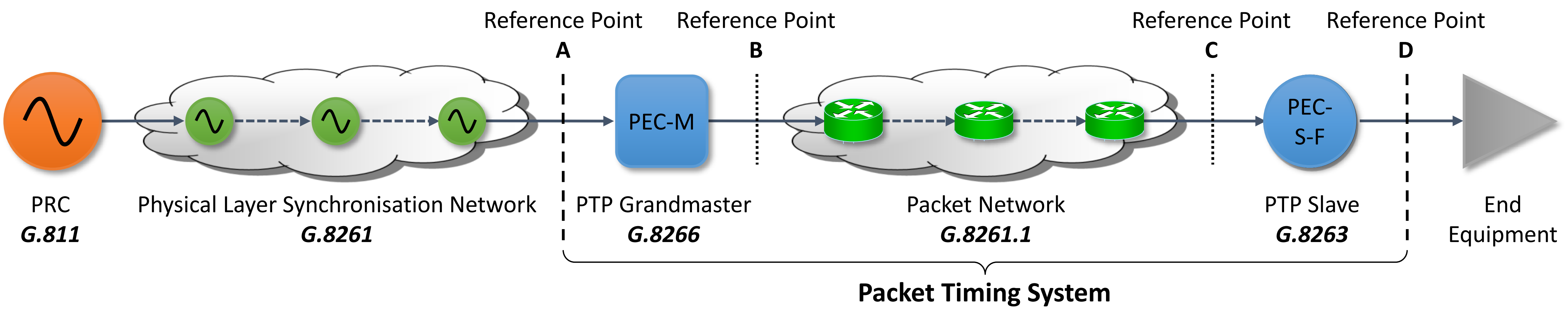
- Approach 2: Use a packet timing protocol
  - Packet timing protocols such as PTP or NTP used to deliver frequency



G.8262: Synchronous Ethernet Clock (EEC)

- Based on synchronising the physical layer of the Ethernet
- Identical in performance to SONET/SDH Equipment Clock (SEC)
  - Directly replaces SEC in the synchronisation chain
  - G.8262 mostly copy/paste from G.813
- Standard defines:
  - Free run frequency accuracy
  - Wander performance: generation, tolerance and transfer
  - Jitter performance: generation and tolerance
  - Transient behaviour: reference switching and entry into holdover
  - Interface types
- Latest revision (January 2015):
  - Includes jitter specification for 25, 40 and 100Gbit/s interfaces

G.8261.1: Network Reference Points



- **Reference Point A:** Network limits for physical layer sync chain (PRC, SSU, SEC or EEC)
- **Reference Point B:** Packet timing interface at GM output
- **Reference Point C:** Network limit on PDV
  - Defined in terms of "Floor Packet Percentage" (FPP)
- **Reference Point D:** Network limits based on:
  - traffic interface (for timing to end application),
  - physical layer sync chain (for timing to the network)

G.8263: PTP Slave Clock for Frequency

- Primarily aimed at frequency requirements for mobile basestations *(within 50ppb)*
- Input tolerance: FPP of 1% within 150μs in a 200s window *(G.8261.1 PDV network limit)*
- Output limit:

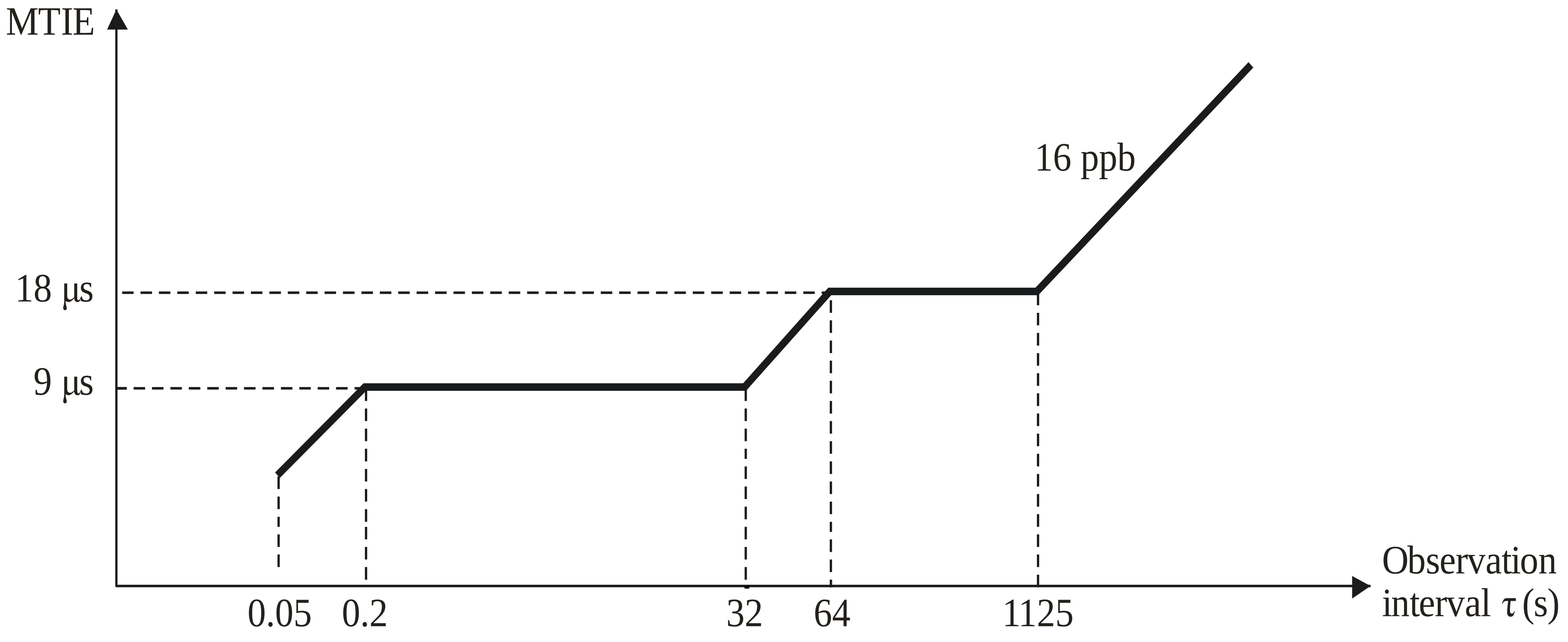


Figure 4/G.8261.1 – Slave clock output wander network limit

G.8265.1: PTP Telecom Profile Features

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- Unicast Messaging
  - Easier to support and manage in telecoms networks than multicast
- Message rates up to 128 packets per second
  - Typical operation around 16 or 32 packets per second
- Operates over IP protocol for universal applicability
  - Default mapping is “Annex D”: PTP/UDP/IPv4
  - Also allows use of “Annex E”: PTP/UDP/IPv6
- Operates over existing telecoms networks
  - No PTP “on-path” support required in switches and routers
- Planned protection schemes
  - Pre-defined protection routes allow maximum reliability and consistency
  - Based on G.781 Quality Levels for compatibility with current sync networks

Relevant Standards for Frequency

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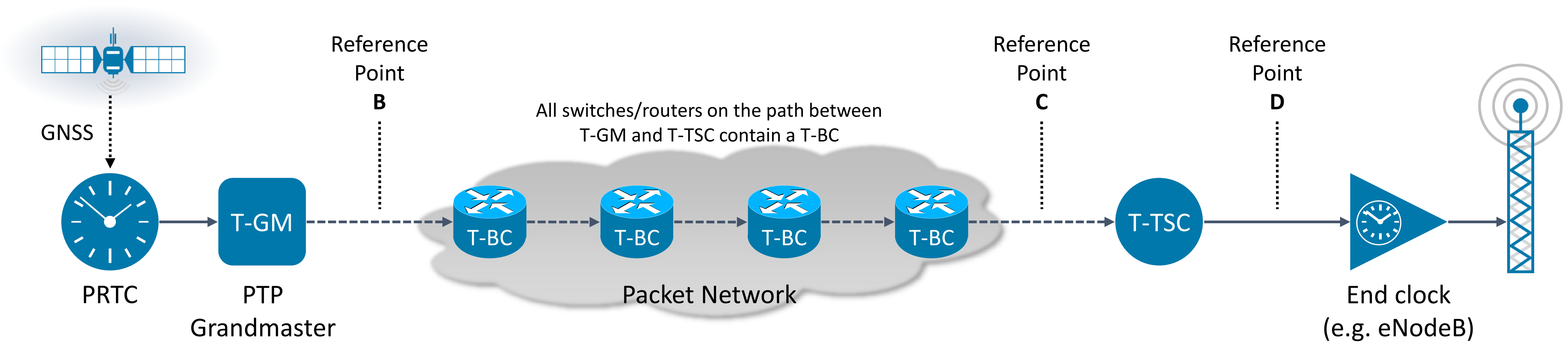
- Published recommendations related to frequency synchronisation:
  - G.8261 – General aspects, network limits for frequency synchronisation
  - G.8262 – Ethernet Equipment Clock Specification
  - G.8264 – Ethernet Synchronisation Messaging Channel (ESMC)

  - G.8265 – General network architecture for packet-based frequency sync
  - G.8265.1 – PTP Profile for frequency
  - G.8261.1 – Network limits for packet-based frequency synchronisation
  - G.8263 – PTP Slave Clock for frequency
  - G.8266 – Telecom Frequency Grandmaster Specification

- Standards complete and stable for several years

Transfer of time to meet 1.5μs over new networks

PTP with Full Timing Support



Features

- Every element in the path must be “PTP aware”
- Both T-BC (boundary clocks) and T-TC (transparent clocks) covered in standards
- Uses a combination of SyncE and PTP, where SyncE provides the frequency and PTP the phase/time

PTP with Full Timing Support

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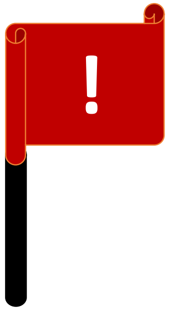
Benefits

- Controlled, deterministic environment suitable for both frequency and time/phase transfer
- “Building block” approach to network construction, with example time error budgets in G.8271.1
- Profile, architecture and clock performance well defined by ITU-T

Challenges

- All equipment in path needs to be PTP aware
- No control of asymmetry in the network



Synchronisation in Access

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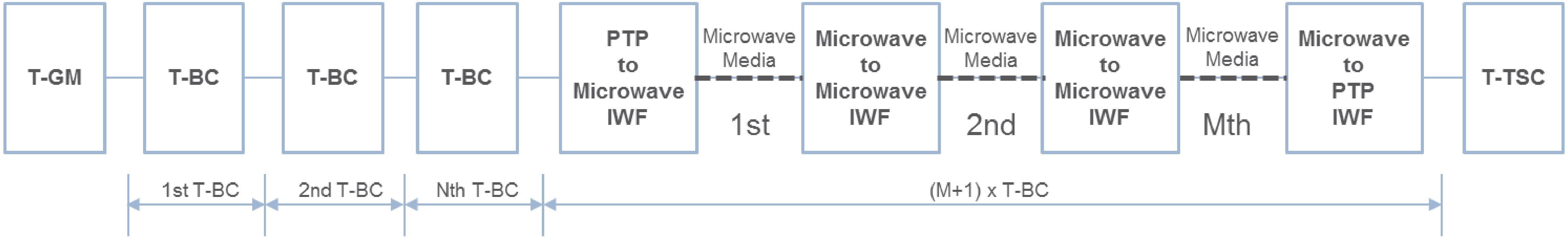
- From a performance perspective, each network element is allocated the equivalent budget to one T-BC:



- Internally, the communication between units does not have to be PTP (e.g. GPON may use the native time transfer mechanism)
  - This is a performance budget, not a protocol specification
- SyncE-assisted TCs to have same budget as SyncE-assisted BCs
  - i.e. G.8273.3 performance spec will be based on G.8273.2

Relevant Standards for FTS

- Published recommendations related to full timing support:
  - G.8271 – General considerations for time synchronisation
  - G.8275 – General network architecture for time synchronisation
  - G.8275.1 – PTP Profile for full timing support
  - G.8271.1 – Network limits for full timing support
  - G.8272 – Primary Reference Time Clock Specification
  - G.8273.2 – Telecom Boundary Clock Specification
  - G.8273.3 – Telecom Transparent Clock Specification

- Standards complete, but some recommendations are undergoing minor revisions and enhancements

Transfer of time to meet 1.5μs over existing networks

Partial Timing Support Use Cases - 1

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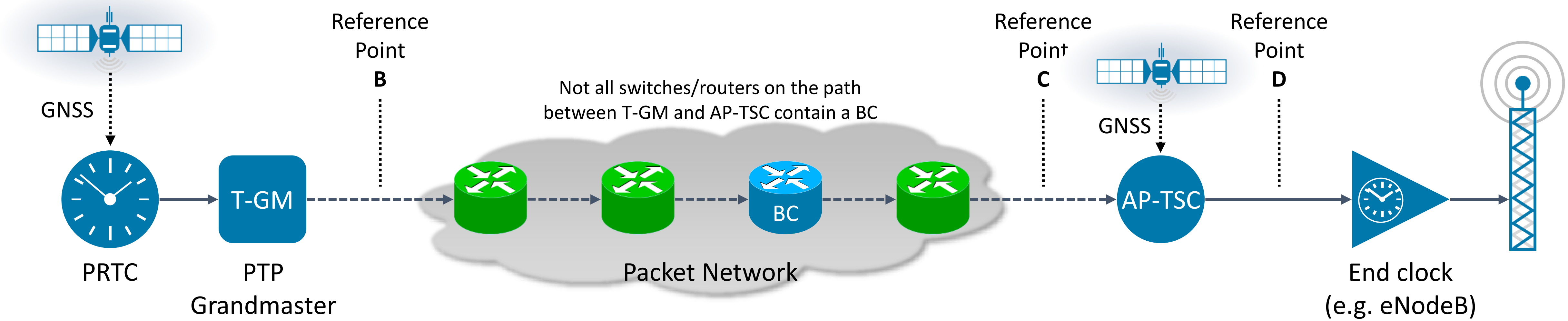
PTP backup to GNSS *("assisted partial timing support", or APTS)*



Features

- Objective is backup to GNSS, i.e. "assisted holdover"
- GNSS monitors PTP service quality and network asymmetry
- PTP can maintain timebase when GNSS is out of service (e.g. due to jamming or antenna failure)

Partial Timing Support Use Cases - 2

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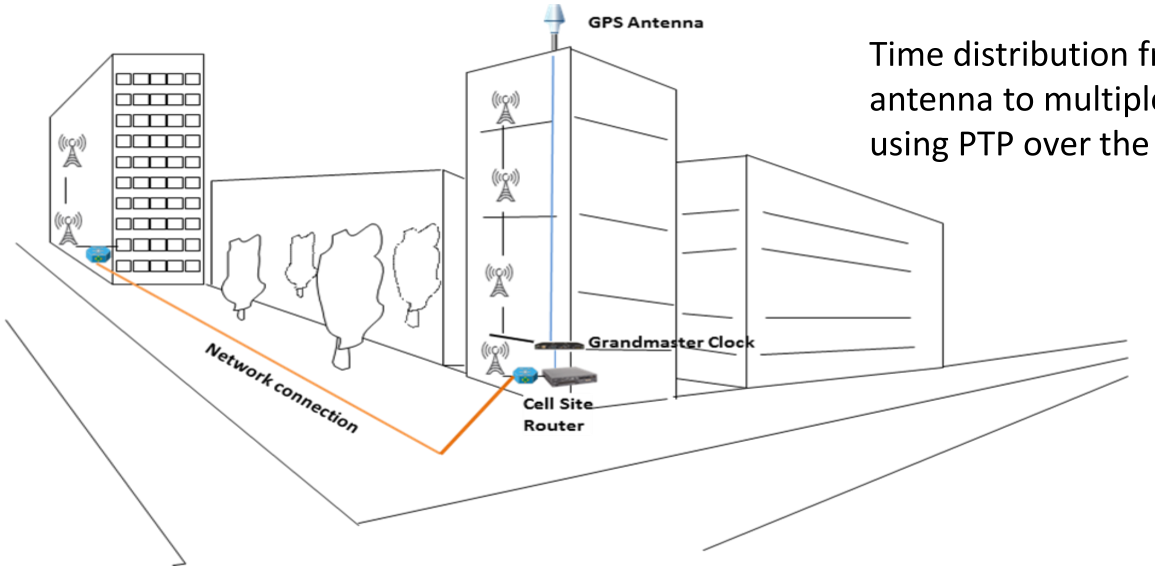
PTP distribution over a local LAN *("partial" or "no timing support")*



Time distribution from rooftop antenna to multiple small cells, using PTP over the building LAN

Features

- Objective is to distribute time over a small PTP-unaware (or partially unaware) network
- Small network, potentially only a single in-building network
- Places GNSS source as close to the end clock as possible

Partial Timing Support Use Cases - 3

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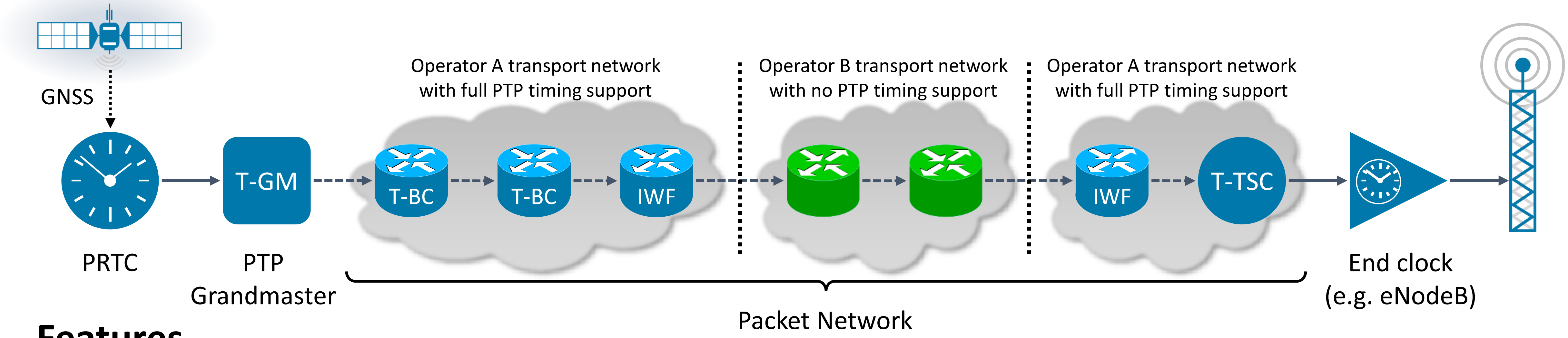
Network Bridging



Features

- Objective: bridge between two full timing support networks
- Example: a mobile operator may not own the access network, and need to bridge across a third party network
- Requires inter-working functions (IWF) to link between the networks

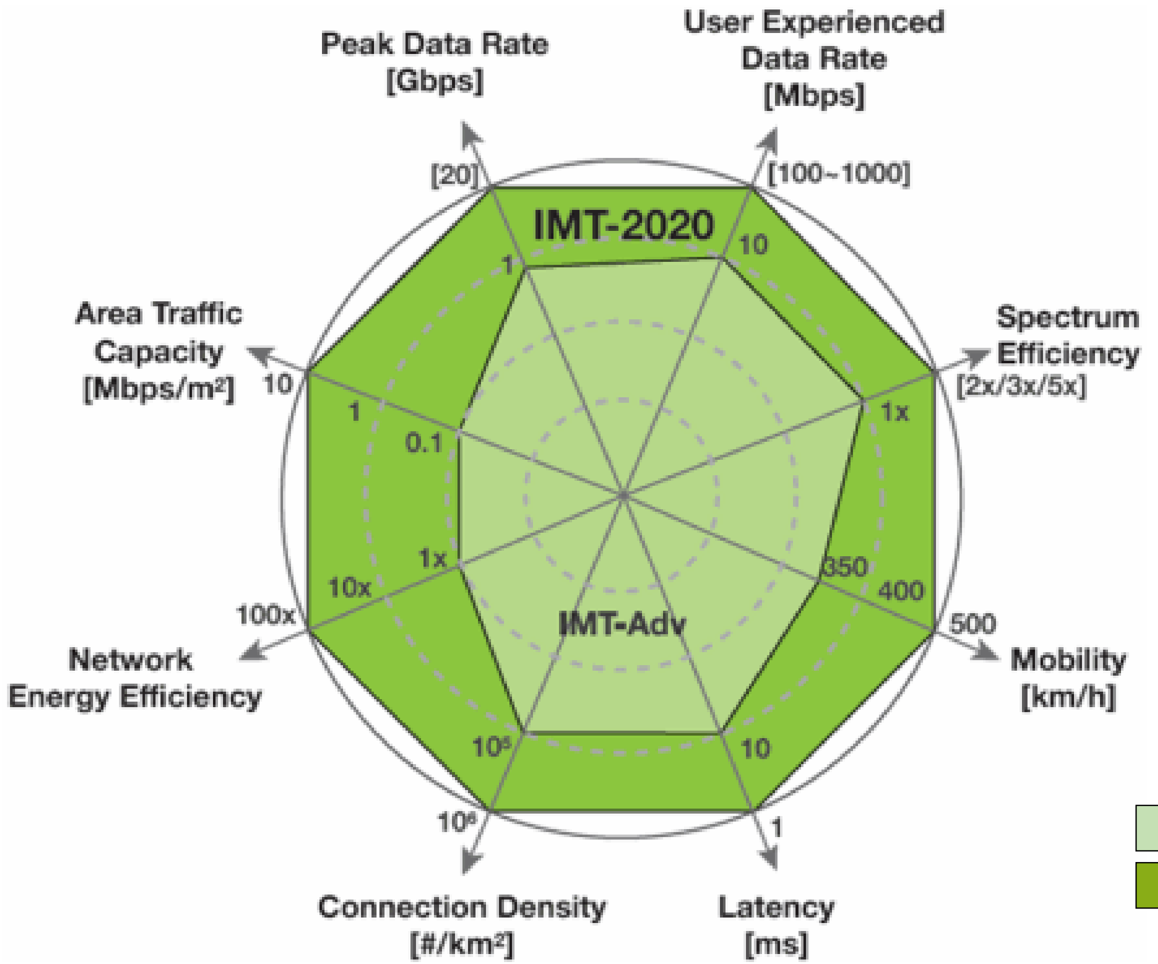
Relevant Standards for APTS and PTS

- G.8271.2: Partial Timing Support Network Limits
  - Uses pktSelected2WayTE as primary metric
    - This is the time error calculated on the 2-way flow, after packet selection
  - Two limits: APTS (PTP backup of GNSS), PTS (PTP-unaware networks)
  - Network limit for APTS
    - Peak-to-peak pktSelected2WayTE < 1100ns at input to slave
    - Selection criteria: 0.25% fastest packets in each 200s window
  - Network limit for PTS
    - Maximum absolute pktSelected2WayTE < 1100ns at input to slave
    - Selection criteria: 0.25% fastest packets in each 200s window
  - Status: Published August 2017
- G.8273.4: Assisted Partial Timing Support Clock
  - GNSS primary time source, PTP backup
  - Uses GNSS to measure PTP asymmetry during normal operation
  - Status: possible completion by mid 2019

Enhanced Specifications for 5G

What is 5G?

- **IMT-2020** – the ITU's vision of "5G", to roll out in 2020



IMT-Advanced (LTE, 4G)

IMT-2020 (5G), relative to IMT-Advanced

What are the implications?

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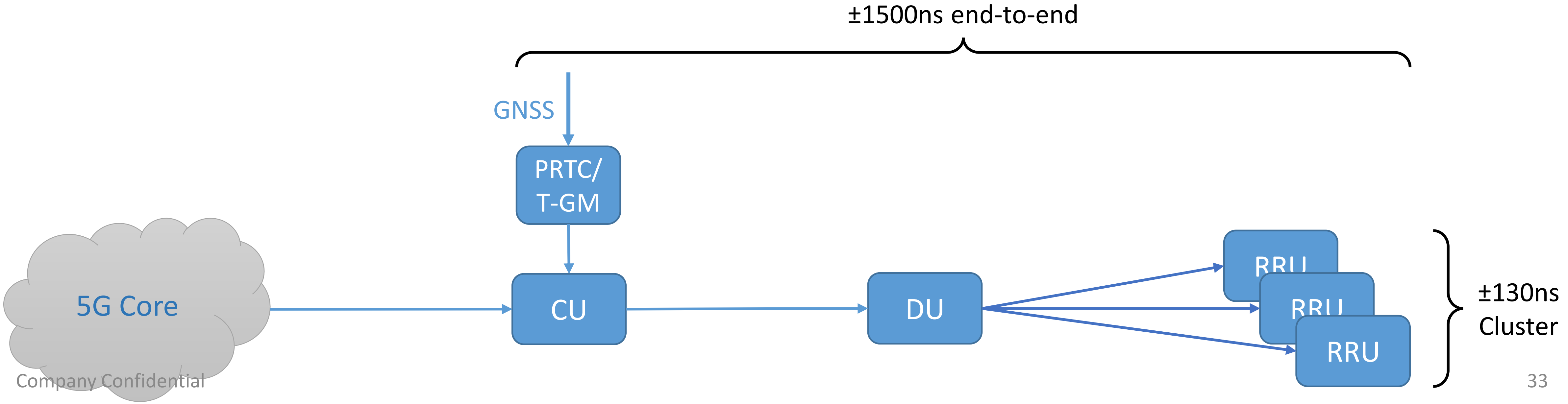
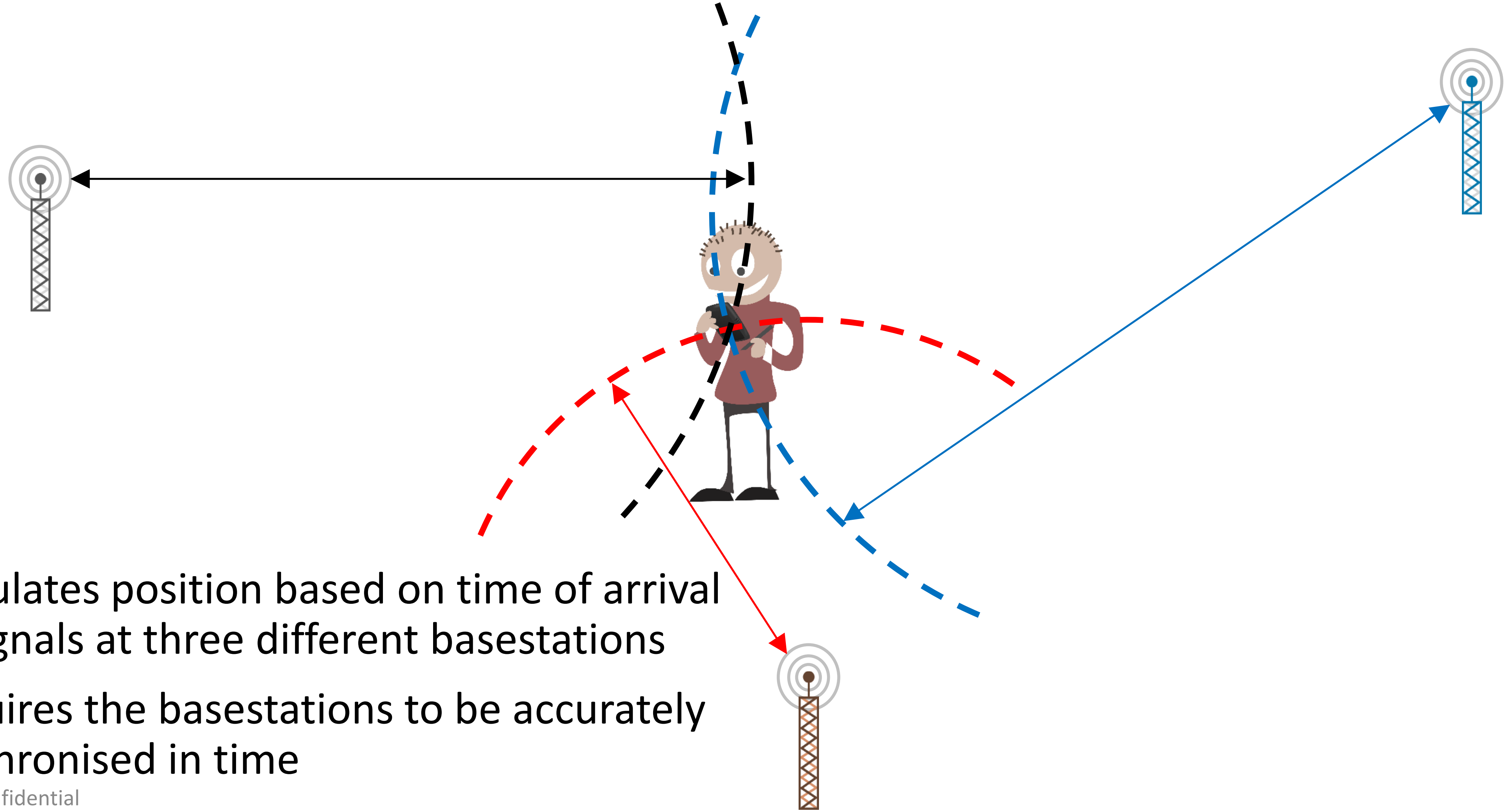
- Peak data rate of 20Gbit/s
  - eNodeB connections at least 25Gbit/s
  - Backhaul networks will require 100Gbit/s or more
- User experienced data rate of 100-1000Mbit/s
  - Co-operative processing and interference management
  - These techniques typically require very accurate synchronisation
- Connection density of 1M connections/km^2
  - Requires dense small cell or remote radio unit (RRU) deployment
  - Small, cheap RRU’s preferred due to the number of devices required
- Latency < 1ms
  - Distributed architecture, data processing and switching at the edge
  - Fronthaul architecture with distributed radio units and co-located baseband and switching in the core

5G Synchronisation Requirements

- Standard 5G TDD networks require ±1.5μs end-to-end *(same as 3G and 4G)*
- Co-operative radio techniques (e.g. inter-site CA, CoMP, MIMO) require much tighter synchronisation when deployed – consensus seems to be around ±130ns
  - BUT co-operative techniques take place in the DU
  - ±130ns is only required between RRUs connected to the same DU
  - This permits "sync clusters" of very tightly synchronised elements



Observed Time Difference of Arrival



- Calculates position based on time of arrival of signals at three different basestations
- Requires the basestations to be accurately synchronised in time

Positioning Requirements

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- E911: within 50m horizontal accuracy for 80% of emergency calls
  - Using OTDOA, requires time synchronisation to better than 150ns
- Targets for 5G “Higher Accuracy Positioning”: *
  - Accuracy level of <1m in 95% of the service area
  - Network-based positioning in 3D space to between 10m and <1m in 80% of situations
  - If implemented using OTDOA, requires time synchronisation to better than 3ns
- OTDOA not the only technique for positioning, but any positioning solution requires time to some degree

* 3GPP TR 22.862: Feasibility Study – Enablers for Critical Communications

Network Protection and Reconfiguration

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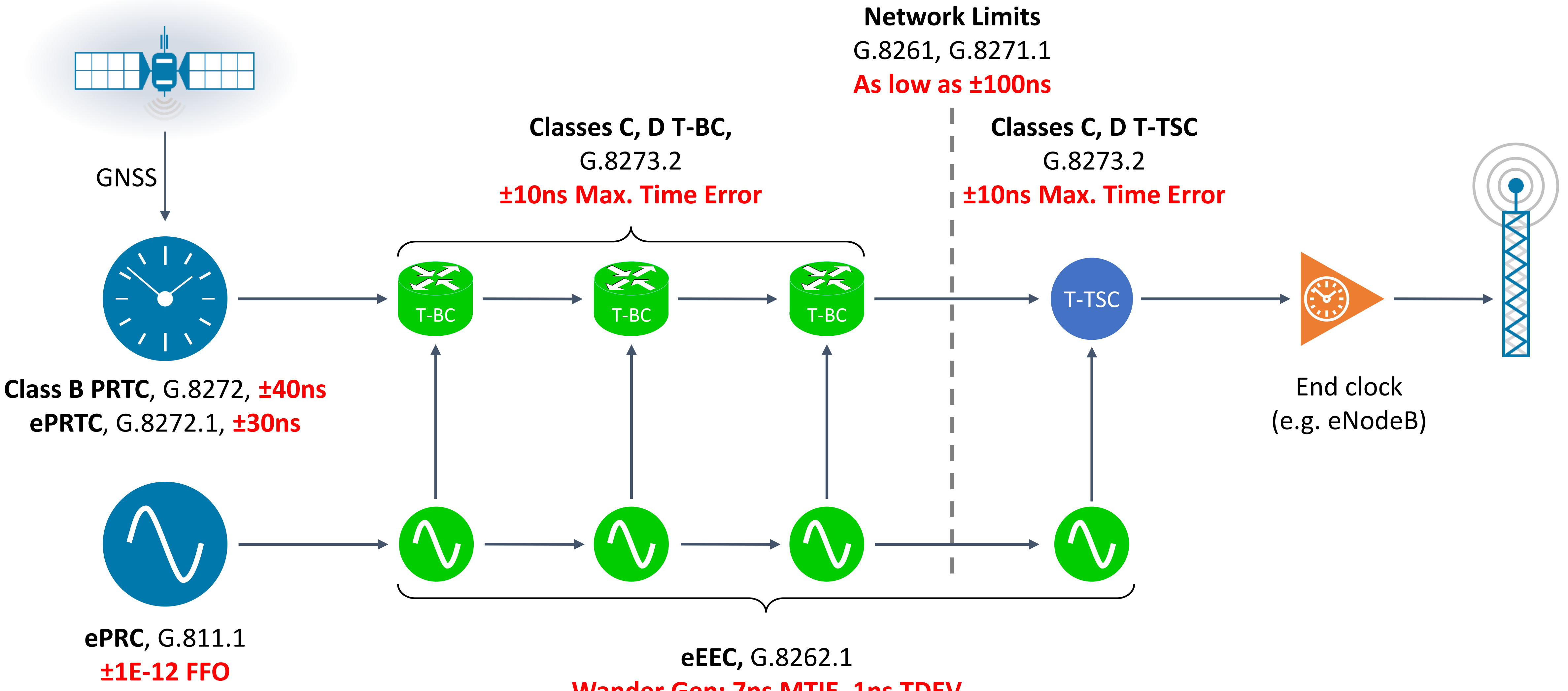
- Networks are dynamic and sometimes fail
- Planned fail-over paths and protection must consider synchronisation
  - DU's may be "multi-homed" – connected to more than one CU for protection purposes
  - Not always clear which RRUs are connected to which DUs
  - CloudRAN structure – RRUs may not share the same network section as the DU or CU, especially if dynamic reconfiguration occurs
- Therefore easier to plan for tight end-to-end synchronisation, rather than using "sync clusters"
- Example: China Mobile want a sync budget of ±200ns end-to-end

Enhanced Clock Specifications for 5G



Enhanced Specifications for 5G

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- G.8272: PRTC Class B
  - Time accuracy better than 40ns
  - Better solution than ePRTC (G.8272.1) for operators with distributed networks
  - Status: scheduled for publication by December 2018
- G.8262.1: “eEEC”
  - Enhanced version compatible with current EEC, but improves noise generation, transients and holdover
  - Facilitates long-term assisted holdover of accurate time clocks, plus lower-noise T-BCs
  - Status: scheduled for publication by December 2018
- G.8273.2: “Class C” and “Class D” T-BC and T-TSC to be developed
  - Exhibits lower noise generation and better SyncE-assisted holdover
  - Status: scheduled for publication by December 2018
- G.8261: Network Limit for chain of eEECs
  - Network limit much lower, to permit better SyncE-assisted holdover of T-BCs and T-TSCs
  - Status: expected completion by mid 2019
- G.8271.1: Network Limit for chain of T-BCs
  - To be based on Class C, D T-BC specification, targeting around ±130ns end-to-end
  - Status: expected completion by end 2019

Comparing G.8262 to G.8262.1

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Parameter	EEC (G.8262)	eEEC (G.8262.1) (proposed values)
Frequency Accuracy	4.6ppm	Same value
Pull-in/Hold-in	4.6ppm	Same value
Wander generation	MTIE: 40ns @ 0.1s, rising to 113ns @1000s TDEV: 3.2ns @ 0.1s, rising to 6.4ns @100s	MTIE: 7ns TDEV: 1ns
Wander tolerance	250ns @ 0.1s, rising to 5000ns @ 1000s	Same value *(allows mixed chains)*
Jitter generation	0.5UI *(1G, 10G)* 1.2UI *(25G lanes)*	Same value
Jitter tolerance	250ns @ 10Hz, reducing to 1.5UI (3.6UI for 25G lanes)	Same value
Clock Bandwidth	1 – 10Hz	1 – 3Hz
Transient response	120ns initial step, then 50ns/s *(const. temp)*	5 – 10ns initial step, then 1 – 10 ns/s *(const. temp)*
Holdover	120ns initial step, then 50ns/s frequency offset, plus 1.16 x 10^{-4} ns/s^2 drift *(const. temp)*	5 – 10ns initial step, then 1 – 10 ns/s frequency offset, plus 1.16 x 10^{-4} ns/s^2 drift *(const. temp)*

Key: Green – same as G.8262 EEC spec
Red – changes to G.8262 EEC spec

G.8273.2: Comparing T-BC Classes

Parameter	Conditions	Class A	Class B	Class C (proposed)	Class D (proposed)
Max|TE|	Unfiltered, 1000s	100ns	70ns	20ns	10ns
cTE	1000s	50ns	20ns	8ns	5ns
dTE_L MTIE	0.1Hz low-pass filter Const. temp, 1000s	40ns	40ns	10ns	5ns
	0.1Hz low-pass filter Var. temp, 10000s	40ns	40ns	FFS	5ns (TBC)
dTE_L TDEV	0.1Hz low-pass filter Const. temp, 1000s	4ns	4ns	2ns	1ns
dTE_H	0.1Hz high-pass filter Const. temp, 1000s	70ns	70ns	20ns	10ns

- Class C aimed at shorter chains (up to 10 nodes)
- Class D aimed at longer chains (up to 20 nodes)
- Some vendors discussing “Class D+” with even tighter cTE and dTE_L constraints

Synchronisation OAM

Sync OAM and Management

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- Model proposed using an alternative PTP flow as a reference
  - Not a perfect reference, but a sanity check and indication of network-related issues
  - Described in G.SuppSyncOAM, a working document collecting Sync OAM material
- Frequency sync defects and parameters to be documented in a revised version of G.781
  - Status: Published August 2017
- Time sync defects and parameters to be documented in new recommendation G.781.1
  - Status: possible completion by mid 2019

Insight and Innovation

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