The PTP Telecom Profiles for Frequency, Phase and Time Synchronization

Tim Frost

Symmetricom, Inc.,

May 2013

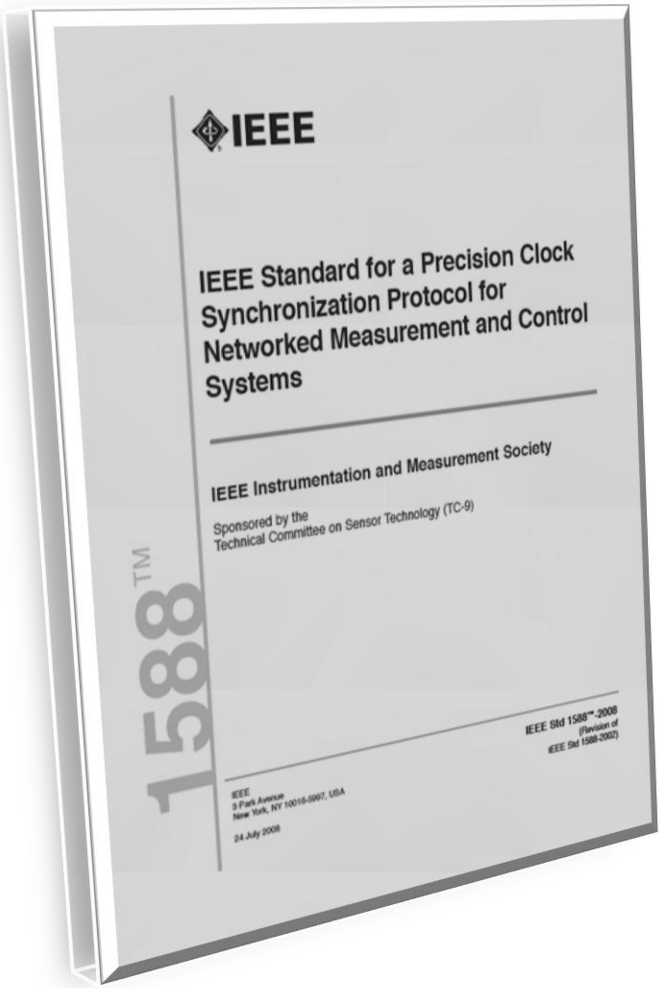
Agenda

- Introduction to Precision Time Protocol (PTP)
  - PTP Messages
  - Impairments to Packet Timing
  - Timing Support Elements (boundary and transparent clocks)
  - PTP Profiles
- PTP Telecom Profile for Frequency (G.8265.1)
  - Objectives and Design Features
  - Source Traceability
  - Multicast vs. Unicast messages
  - Rate of Timing Messages
  - Master Selection and Protection
- PTP Telecom Profiles for Time and Phase
  - “Full Timing Support” (G.8275.1)
  - “Partial Timing Support” (G.8275.2)

Introduction to Precision Time Protocol (PTP)

What is the Precision Time Protocol (PTP)?

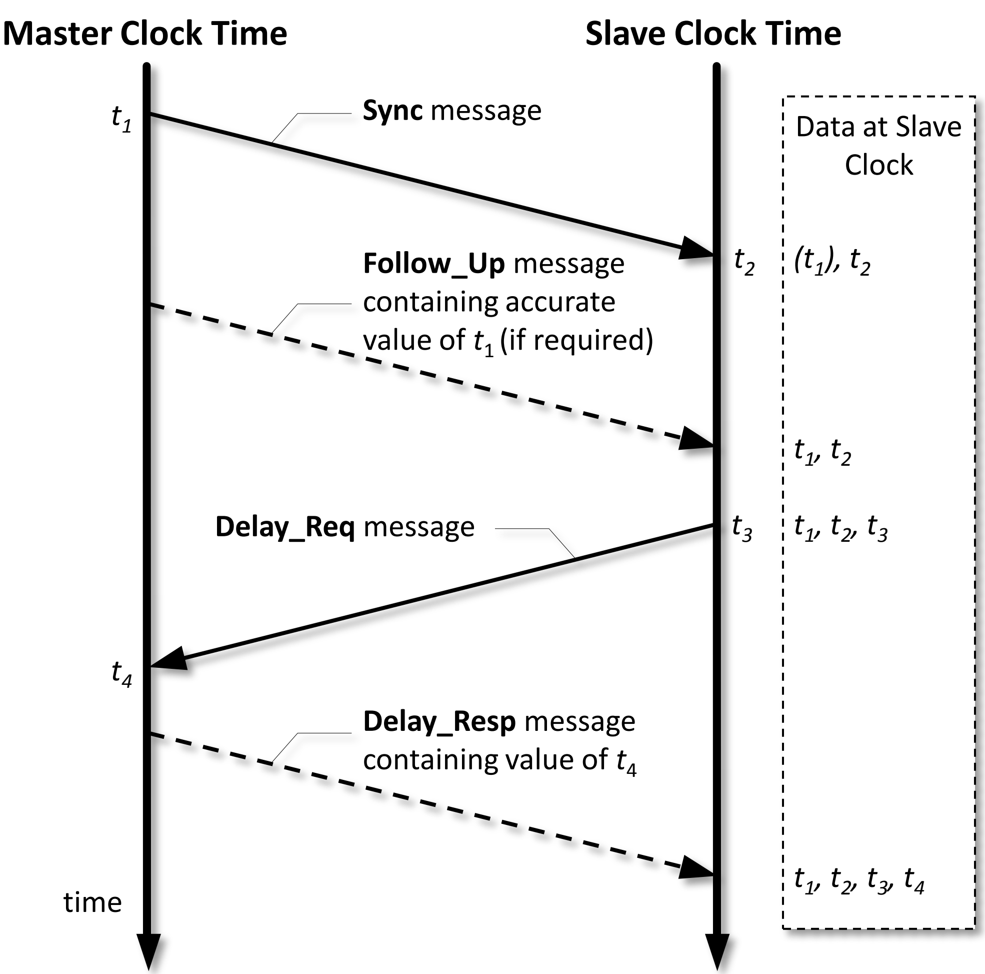
Symmetricom



- Protocol for distributing precise time and frequency over packet networks
- Defined in IEEE Standard 1588
  - First version (2002) targeted LAN applications
  - Second version (2008) expanded applicability to cover telecommunications networks
  - Third version now under discussion
- Time is carried in “event messages” transmitted from a Grandmaster Clock to a Slave Clock and vice versa
- Runs over Ethernet and/or IP networks
- Commonly referred to as:
  - PTP (Precision Time Protocol) or PTP v.2
  - IEEE1588-2008 or IEEE1588 v.2

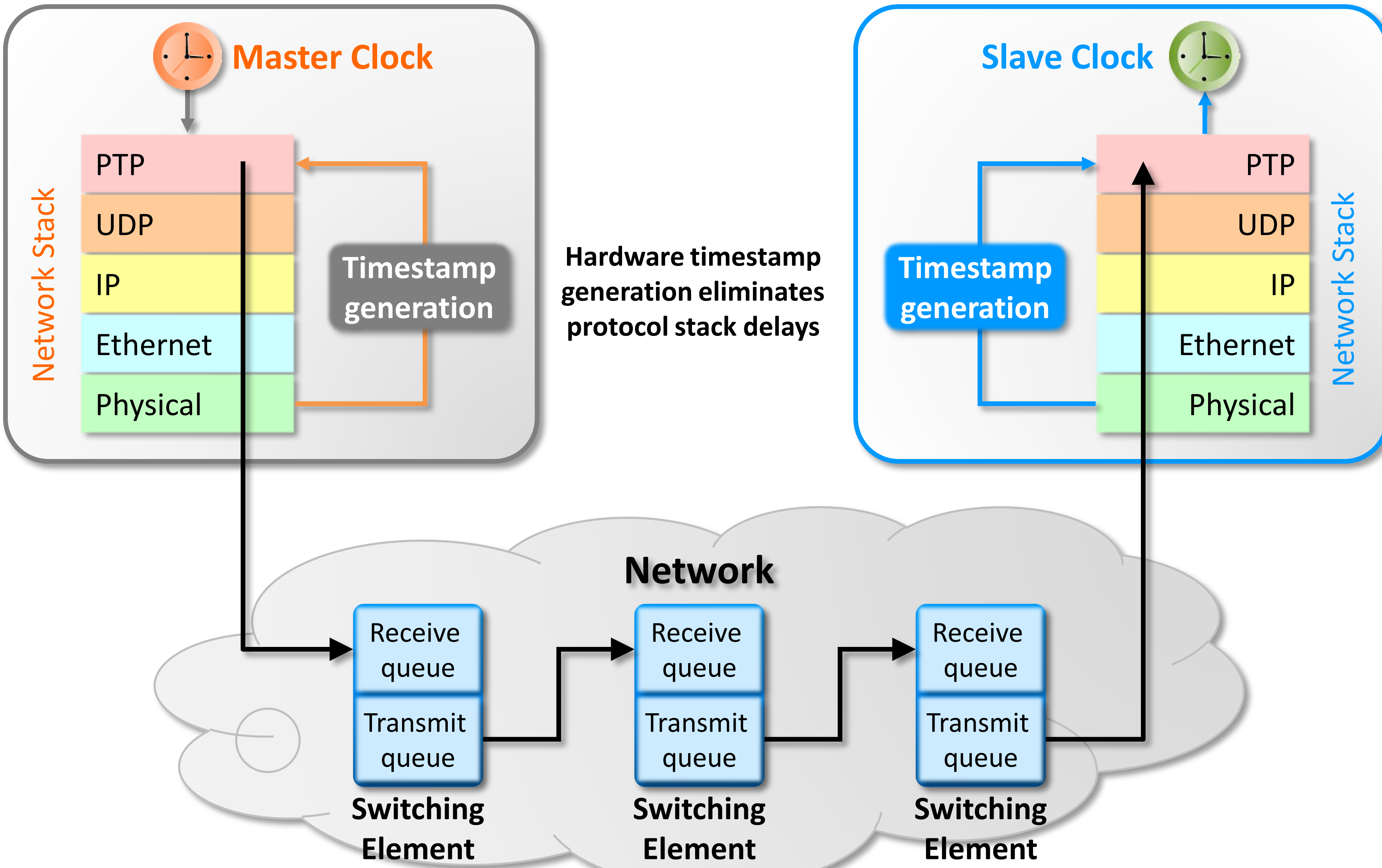
Precision Time Protocol (PTP)

- PTP defines an exchange of timed messages over a packet network

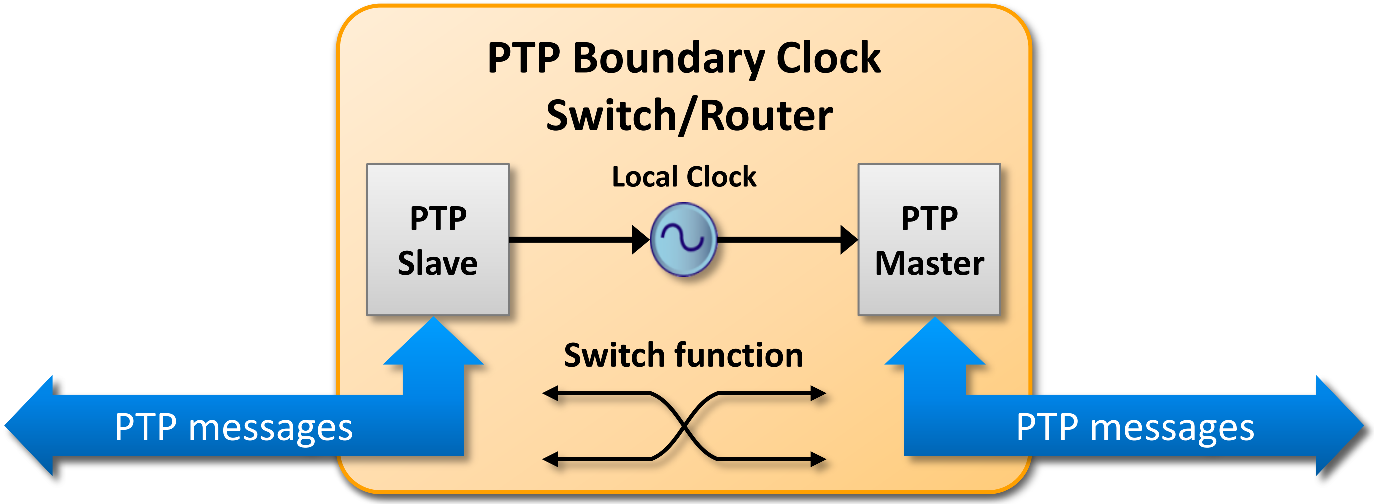


- Each **"event message"** flow (***sync***, ***delay_req***) is a packet timing signal
- Master **frequency** determined by comparison of timestamps in the event message flows
  - e.g. comparison of t_1 to t_2 over multiple ***sync*** messages, or t_3 to t_4 in ***delay_req*** messages
- **Time offset** calculation requires all four timestamps:
  - Slave time offset = $\frac{(t_1 - t_2) + (t_4 - t_3)}{2}$
  - assumes symmetrical delays *(i.e. the forward path delay is equal to the reverse path delay)*
- **Time offset error** = $\frac{\text{fwd. delay} - \text{rev. delay}}{2}$

Packet Timing Impairments

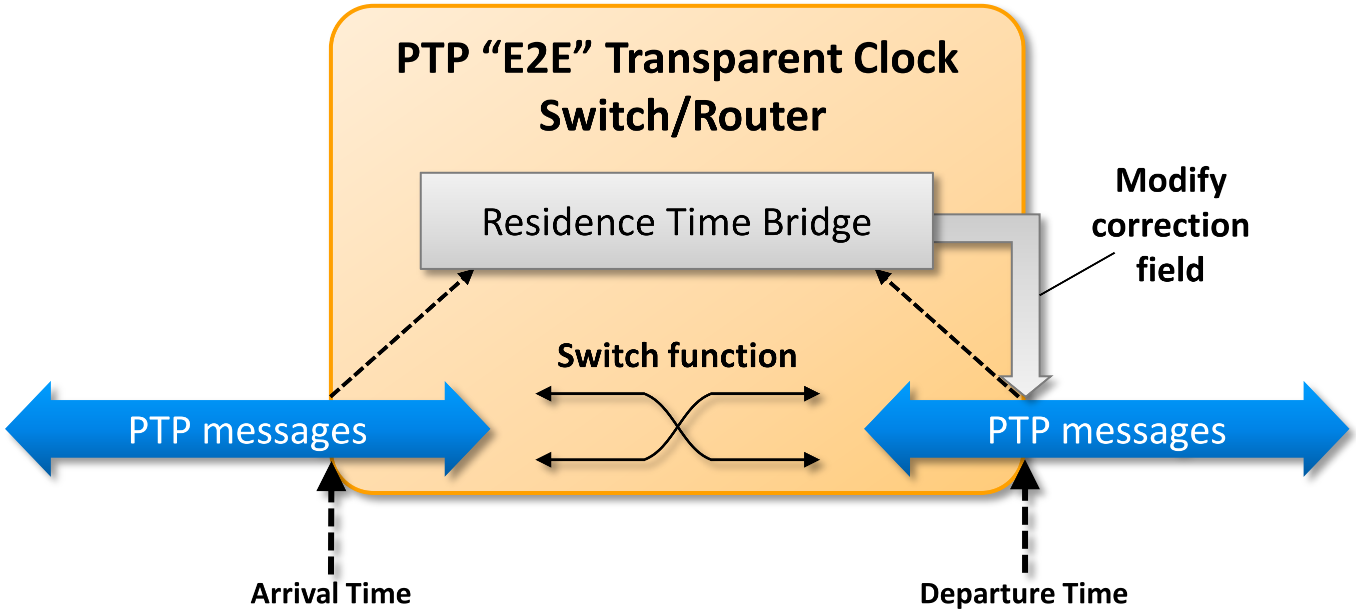


Boundary Clock



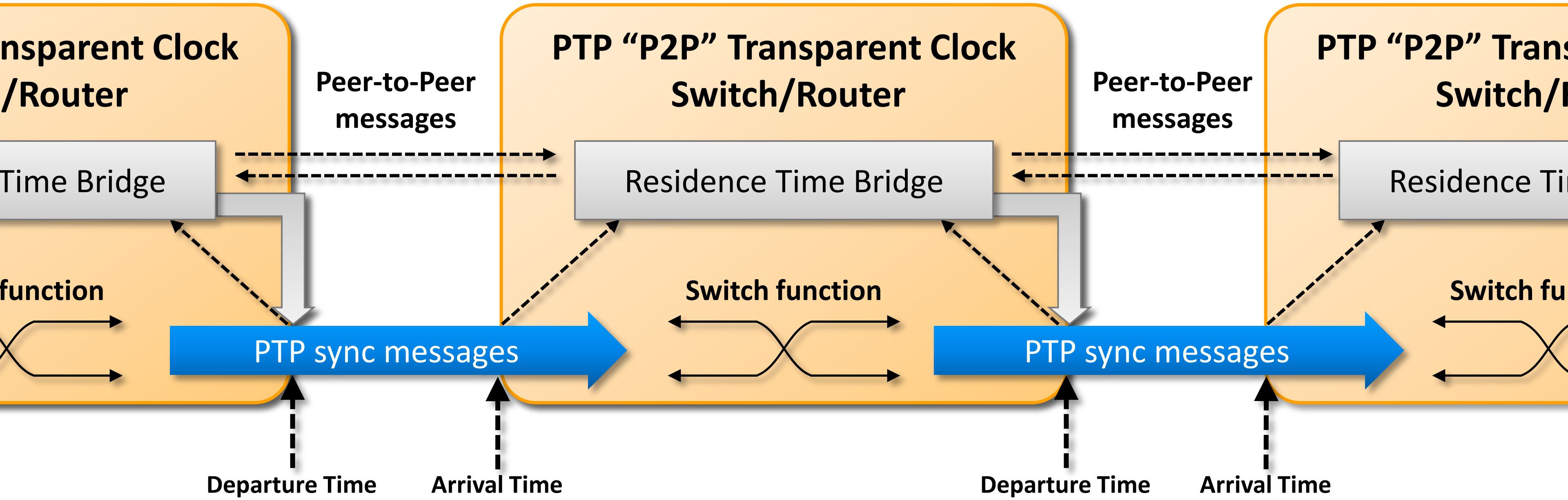
- A router or switch that contains an embedded PTP slave and PTP master, linked to the same local clock
- The PTP slave terminates the PTP traffic from the PTP Grandmaster, and synchronizes its local clock to the GM
- This local clock is used in turn to drive a new PTP master function

“End to End” Transparent Clocks



- Measures time of packet arrival and packet departure
- Adds the difference (known as ***“residence time”***) to a correction field in the packet header
- At the slave, the value of the correction field represents the total delay in each of the switches along the route

"Peer to Peer" Transparent Clocks



- ***Peer to peer messages*** measure the round trip link delay
- Link delay and residence time added to the correction field
- At the slave, the value of the correction field represents the total delay from master to slave
- Doesn't require ***delay_request/response*** messages

What is a PTP Profile?

- What is a profile?
  - Profiles were introduced in IEEE1588-2008, to allow other standards bodies to tailor PTP to particular applications
  - Profiles contain a defined combination of options and attribute values, aimed at supporting a given application
  - Allows inter-operability between equipment designed for that purpose
- PTP Telecom Profile for Frequency (G.8265.1) published Oct. 2010
  - Supports frequency synchronization over telecoms networks
  - Main use-case is the synchronization of cellular basestations

The G.8265.1 PTP Telecom Profile enables the deployment of PTP-based frequency synchronization by telecoms operators

PTP Telecom Profiles for Time/Phase

Symmetricom

- ITU working on two new PTP Telecom Profiles:
  - G.8275.1 – "Full Timing Support"
  - G.8275.2 – "Partial Timing Support"
- Both profiles target accurate time/phase distribution
  - G.8275.1 is aimed at new build networks
    - Requires boundary clocks at every node in the network
  - G.8275.2 is aimed at operation over existing networks
    - Permits boundary or transparent clocks, but not required
    - Boundary clocks placed at strategic locations to reduce noise
- Main target use case is the time/phase requirements of mobile cellular TDD and LTE-A systems
  - Target accuracy is time synchronization to within 1.5µs

The PTP Telecom Profile for Frequency (G.8265.1)

Prime Objectives

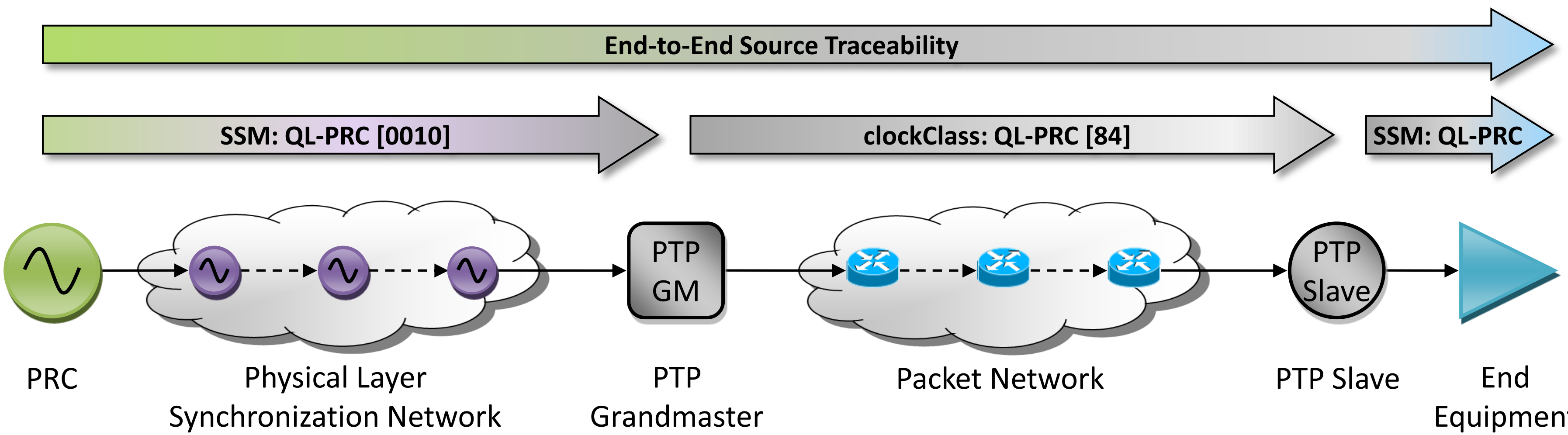
- To permit the distribution of frequency using PTP over existing managed, wide-area, packet-based telecoms networks
- To allow interoperability with existing synchronization networks (such as SyncE and SDH)
- To define message rates and parameter values consistent with frequency distribution to the required performance for telecom applications
- To allow the synchronization network to be designed and configured in a fixed arrangement
- To enable protection schemes to be constructed in accordance with standard telecom network practices

Key design decisions

- No on-path support, (e.g. boundary and transparent clocks), because these are not generally available in existing networks
- IPv4 was adopted as the network layer due to its ubiquity, rather than operation over Ethernet or other lower-layer protocols
- The PTP ***Announce*** message was adapted to carry the Quality Level (QL) indications defined in G.781, for continuity with SONET/SDH and SyncE synchronization status messaging.
- Unicast transmission was adopted over multicast, since it could be guaranteed to work over wide-area telecoms networks
- BMCA (Best Master Clock Algorithm) was replaced by static provisioning, allowing the synchronization flow to be planned, rather than dynamically adjusting itself

Source Traceability

- Encodes QL values in the clockClass field of the ***Announce*** message
  - Provides end-to-end traceability of the reference source along the synchronization chain
  - Informs the slave clock (and subsequent devices) of the quality of the timing source
  - Allows the timing chain to be managed in a similar way to existing synchronization networks

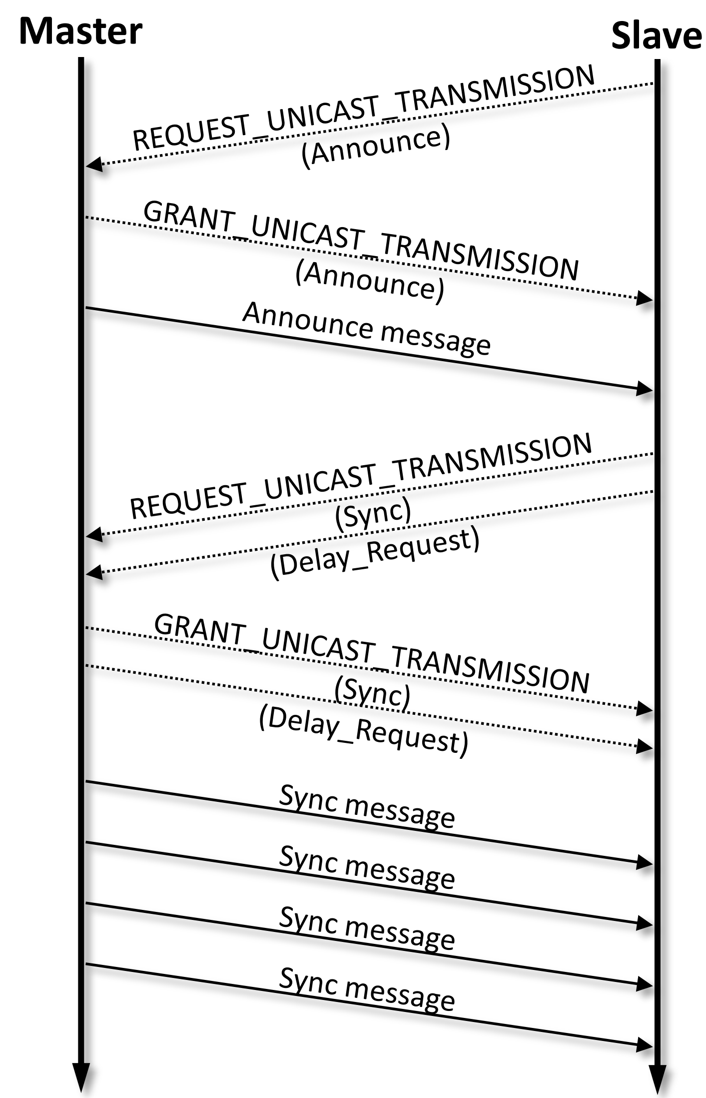


Multicast vs. Unicast

- Unicast facilitates the use of distributed masters
  - Each master-slave communication path becomes a separate PTP domain
  - Allows easier planning of the synchronization network
  - Redundancy strategy can be carefully managed
- Unicast packets propagate uniformly through the network
  - Multicast requires packet replication at each switch or router
  - Replication process adds variable delay
- Multicast harder to provision for network operators
  - Upstream multicast often not supported in telecom networks

Unicast Registration

- Master only provides Unicast service
  - No multicast announce messages sent
- Slave is manually configured with the IP address of one or more masters
- Slave requests Master to provide unicast service at a specified rate
  - Requests ***Announce*** service first, to verify quality of the master
  - If within capacity limits, Master responds with service grant acknowledgements
  - Slave requests ***Sync*** and ***Delay_Request*** service only if master quality is sufficient
- Grants are limited duration
  - Requests must be periodically repeated
  - Frees up master resources if slave fails



Rate of Timing Messages

Symmetricom

- The rate of timing messages required is dependent on several factors
  - Amount of noise in the network
  - Local oscillator stability
  - Efficiency of clock servo algorithm
- The Telecom Profile defines the range of message rates Masters and Slaves should support

Message rates	Minimum	Maximum	Default
Announce	1 msg. every 16s	8 messages/s	1 msg. every 2s
Sync	1 msg. every 16s	128 messages/s	Not defined
Delay_Request	1 msg. every 16s	128 messages/s	Not defined

- It is not expected that a slave will achieve the required performance at all message rates
  - Slave must request the message rates needed to maintain performance

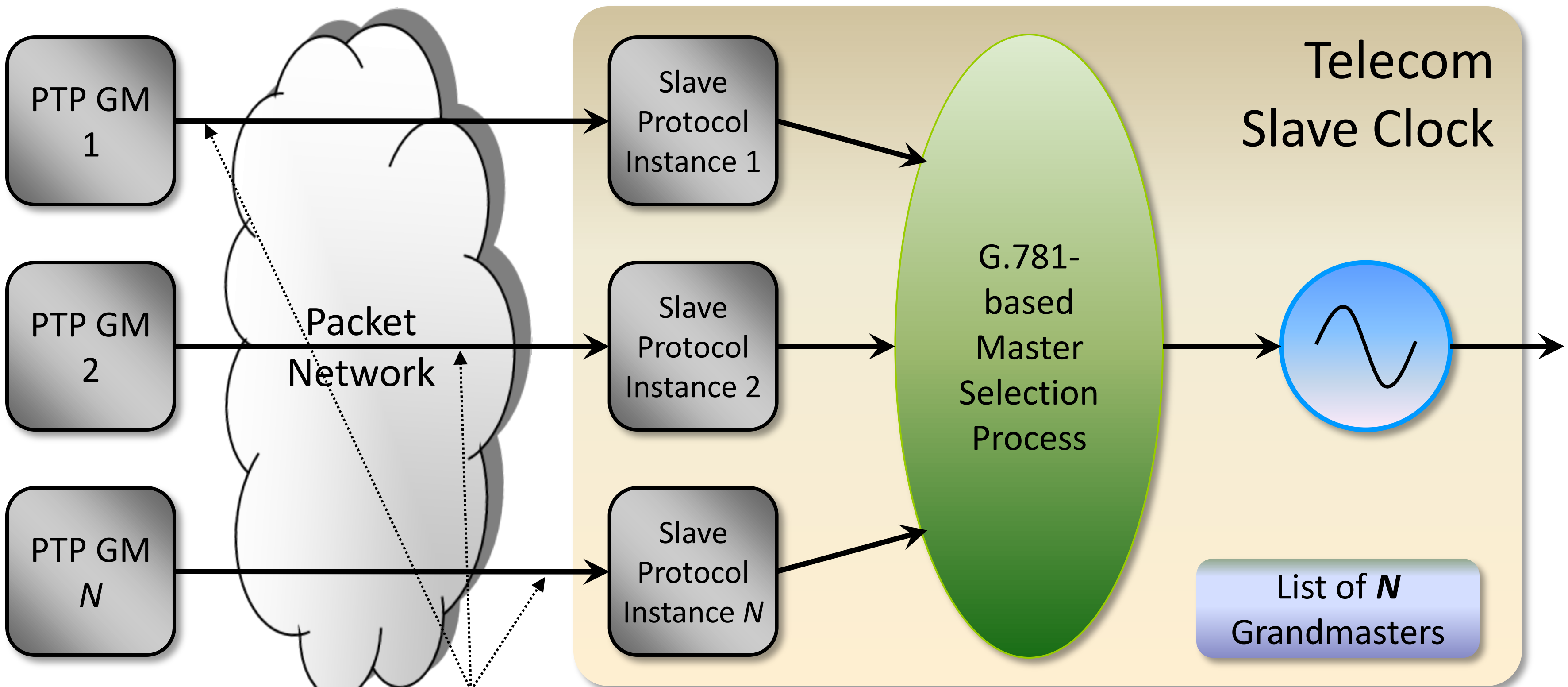
Packet Timing Signal Fail

Symmetricom

- Profile defines three types of signal failure:
  - ***PTSF-lossAnnounce,*** where the PTP Slave is no longer receiving ***Announce*** messages from the GM
    - This means there is no traceability information for that master
    - Slave should switch to an alternative GM after a suitable timeout period
  - ***PTSF-lossSync,*** where the PTP Slave is no longer receiving timing messages from the GM (i.e. ***Sync*** or ***Delay_Response*** messages)
    - This means there is no timing information for that master
    - Slave should switch to an alternative GM after a suitable timeout period
  - ***PTSF-unusable,*** where the PTP Slave is receiving timing messages from the GM, but is unable to recover the clock frequency
    - This means there is no recoverable timing information for that master
    - Action is undefined

Master Selection and Protection

- Telecom slave clock consists of several logical protocol instances, each communicating with a different grandmaster
- Selection process follows G.781 selection rules:
  - Availability, Traceability, Priority



Additional Protection Functions

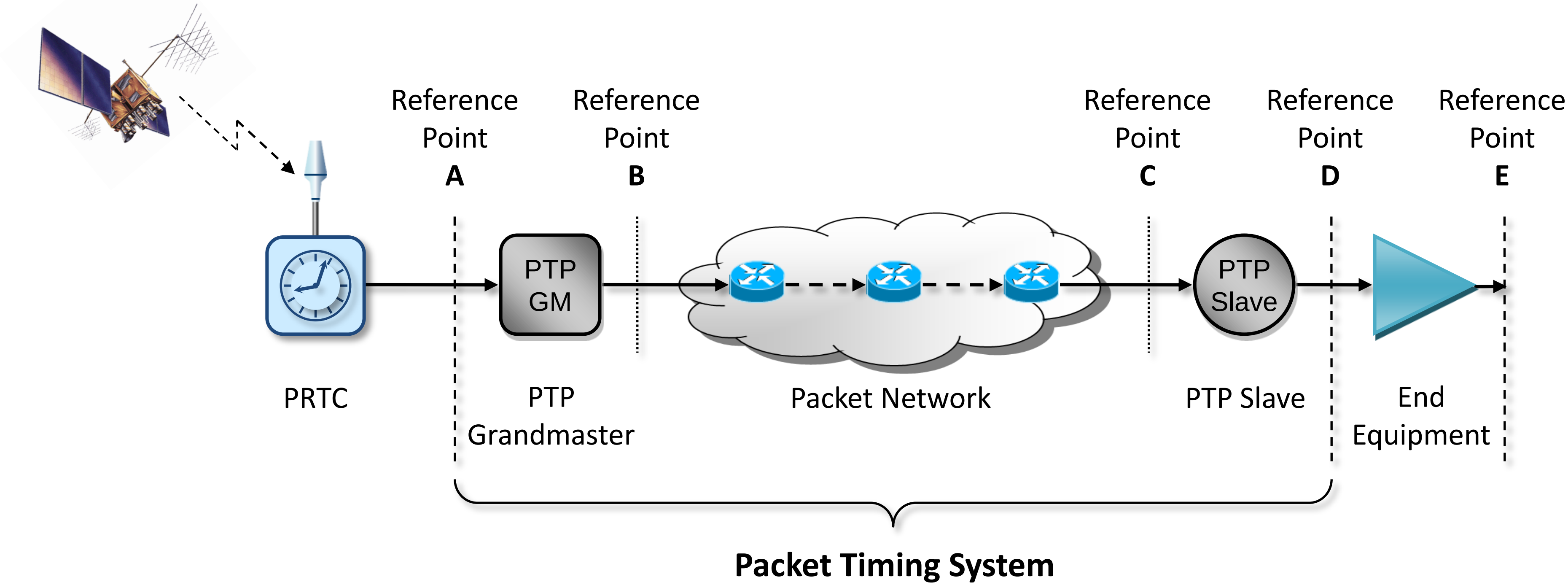
Symmetricom

- Non-reversion function
  - Disables automatic reversion to original master after fault has been rectified
- Wait-to-Restore Time
  - Defines the waiting period before switching back to the original highest priority master, once the failure condition has been rectified
- Forced traceability
  - If the PTP GM is connected to a reference by a signal with no SSM QL value, the input can be manually "forced" to a suitable value
- Output QL Hold-Off
  - Defines a waiting period following a change of QL in the incoming PTP clockClass before forwarding to downstream equipment
  - Allows time for synchronization to a new reference
- Output Squelch
  - Output clock signal of a PTP slave should be "squelched" in case of holdover
  - Only applies to signals that do not carry a QL value (e.g. a 2.048MHz unframed timing signal)

Symmetricom

The PTP Telecom Profiles for Time and Phase

Reference Points for Packet Timing (G.8271)



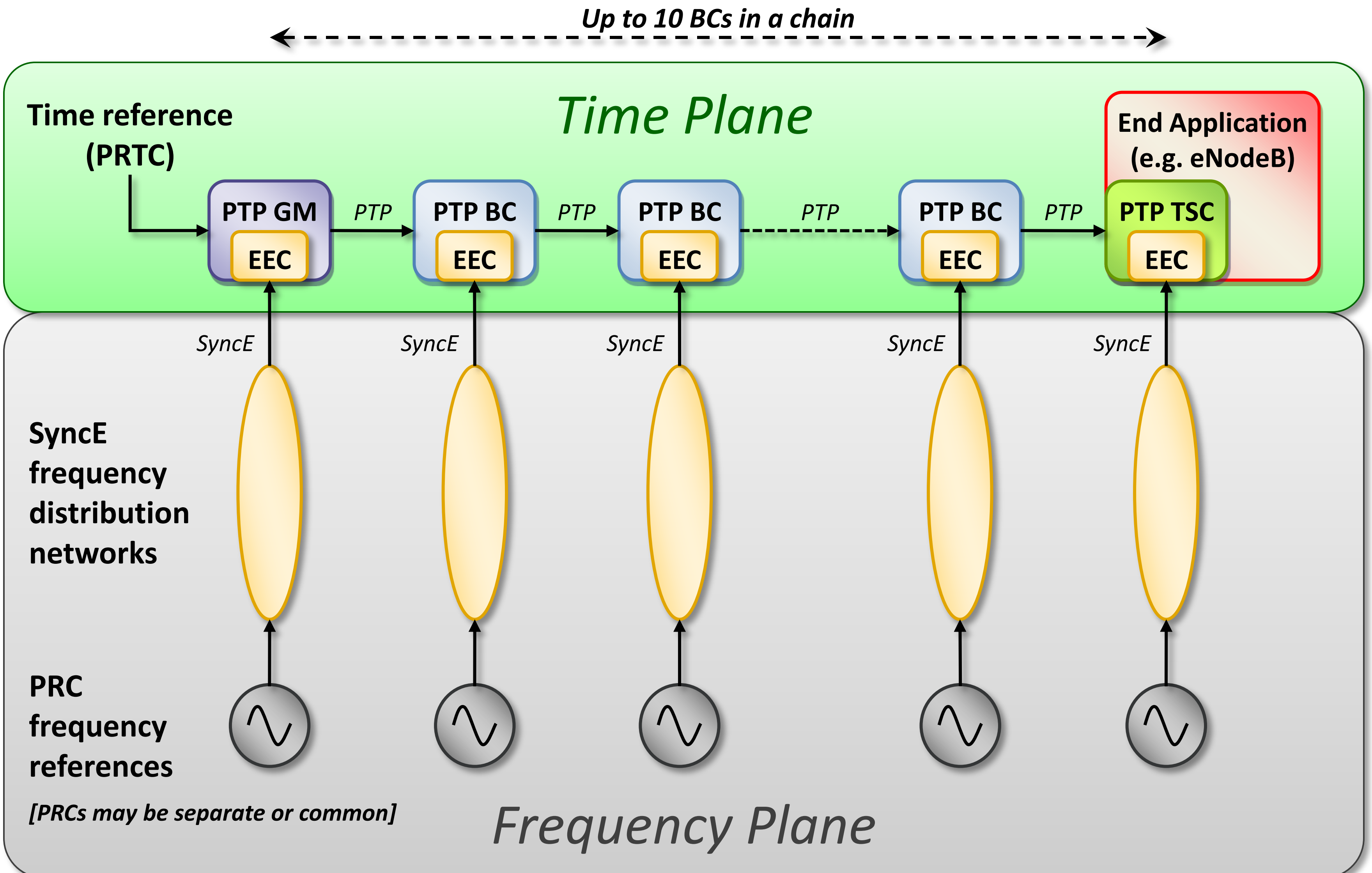
- **A:** Time accuracy and stability at output of PRTC *(defined in G.8272)*
- **B:** Packet timing interface at output of PTP GM
- **C:** Packet timing interface at input to PTP Slave *(defined in G.8271.1)*
- **D:** Time accuracy and stability to end application *(defined in G.8271.1)*
- **E:** End application requirements (e.g. air interface time/frequency spec.)

G.8275.1 “Full Timing Support” Profile

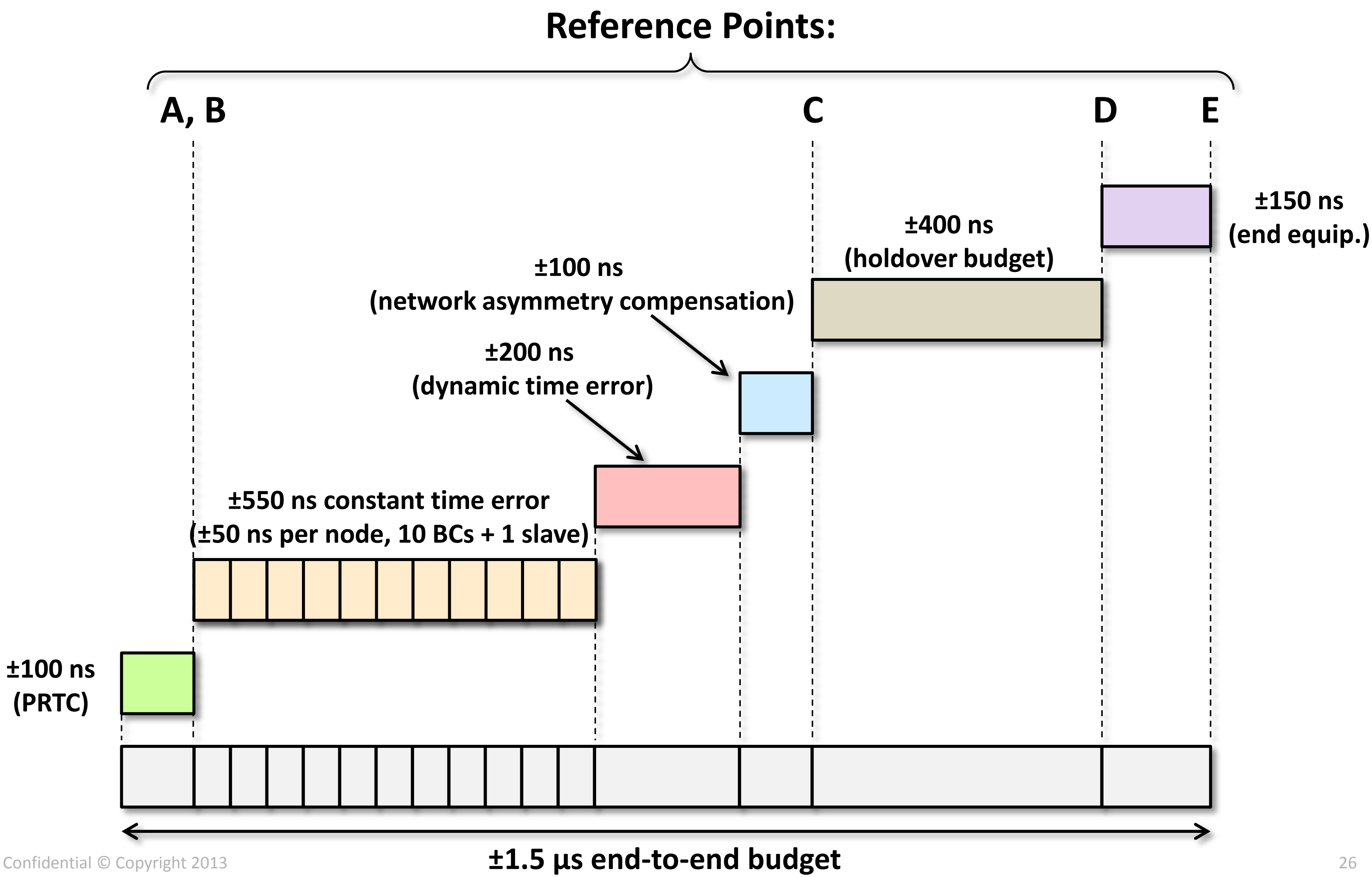
Symmetricom

- Uses a boundary clock at every node in the chain between PTP Grandmaster and PTP Slave
  - Reduces time error accumulation through the network
  - Boundary clocks defined with a filter bandwidth of 0.1Hz
- Recommends the use of Synchronous Ethernet to syntonize each boundary clock to a stable frequency
- Defines ***Sync*** and ***Delay_Request*** message rate of 16 messages/s
- Operates over a Layer 2 Ethernet network
  - Uses the Ethernet addresses identified in IEEE1588-2008 Annex F
  - Support of unicast IP has been proposed but not agreed (yet?)
- Supports multiple active grandmasters for redundancy

Hypothetical Reference Model



Time Error Budget (G.8271.1)



Component Recommendations

- **G.8271:** ***Time and Phase Synchronization Aspects of Packet Networks***

  - General aspects and concepts
  - Requirement categories (based on external standards, e.g. 3GPP)
- **G.8271.1:** ***Network Limits for Time Synchronization in Packet Networks***

  - Network performance limits at packet interfaces
- **G.8272:** ***Primary Reference Time Clock (PRTC) Specification***

  - Basic requirement: 100ns accuracy to UTC
  - Jitter/wander based on PRC specification (G.811)
- **G.8273.2:** ***Telecom Boundary Clock (T-BC) Specification***

  - Transfer function and model
  - Noise generation and tolerance
- **G.8275:** ***Architecture for Time/Phase Distribution***

  - Placement of boundary clocks and protection strategies
- **G.8275.1:** ***Precision Time Protocol (PTP) Telecom Profile for Time/Phase Synchronization***

  - PTP Profile based on use of boundary clocks at every node

G.8275.2 “Partial Timing Support” Profile

Symmetricom

- Why a second time/phase profile?
  - Some service providers need to operate time/phase synchronisation over existing networks
  - Reduces barriers to entry into LTE-A systems; don’t need to build an entirely new network
  - Allows operation over 3rd party network providers (given appropriate quality guarantees)
- Result: “Partial Timing Support Profile”
  - New ITU work item requested by four large service providers
  - Expected to be published in 2014

- Key features:
  - Operates over existing switches and routers, using unicast IP
  - Uses boundary or transparent clocks where necessary to “clean up” time signal as it passes through the network
  - Supports multiple active grandmasters for redundancy

For Further Reading

- White Paper:
  - *"Synchronization for Next Generation Networks – The PTP Telecom Profile",* Symmetricom White Paper, April 2012
- Primary References:
  - *"IEEE Standard for a Precision Clock Synchronization Protocol for Networked Measurement and Control Systems",* IEEE Std. 1588™-2008, 24 July 2008
  - *"Precision Time Protocol Telecom Profile for Frequency Synchronization",* ITU-T Recommendation G.8265.1, October 2010
- Background Reading:
  - *"Synchronization Layer Functions",* ITU-T Recommendation G.781, August 2008
  - *"Definitions and terminology for synchronization in packet networks",* ITU-T Recommendation G.8260, August 2010
  - *"Timing and synchronization Aspects in Packet Networks",* ITU-T Recommendation G.8261, April 2008
  - *"Architecture and Requirements for Packet-Based Frequency Delivery",* ITU-T Recommendation G.8265, October 2010
  - *"Time and Phase Synchronization Aspects of Packet Networks",* ITU-T Recommendation G.8271, February 2012
  - "*Timing characteristics of Primary Reference Time Clocks (PRTC)",* ITU-T Recommendation G.8272, November 2012
- Under Development:
  - *"Network Limits for Time Synchronization in Packet Networks",* ITU-T Draft Recommendation G.8271.1 *(exp. Sep. 2013)*
  - *"Timing characteristics of Telecom Boundary Clocks (T-BC)",* ITU-T Draft Recommendation G.8273.2 *(exp. Sep. 2013)*
  - *"Architecture for Time/Phase Distribution",* ITU-T Draft Recommendation G.8275 *(exp. Sep. 2013)*
  - *"Precision Time Protocol (PTP) Telecom Profile for Time/Phase Synchronization using Full Timing Support",* ITU-T Draft Recommendation G.8275.1 *(exp. Sep. 2013)*
  - *"Precision Time Protocol (PTP) Telecom Profile for Time/Phase Synchronization using Partial Timing Support",* ITU-T Draft Recommendation G.8275.2 *(exp. 2014)*

Thank You

Tim Frost
Principal Technologist,

Symmetricom, Inc.

Email: tfrost@symmetricom.com

Symmetricom, Inc.
2300 Orchard Parkway
San Jose, CA 95131-1017
Tel: +1 408-428-7907
Fax: +1 408-428-6960

www.symmetricom.com