Building Your Automotive Network With Time Sensitive Networking (TSN) and Ethernet

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NXP

SECURE CONNECTIONS
FOR A SMARTER WORLD

Agenda

- Overview
- Reliable Time Synchronization
- Seamless & instantaneous reliability
- Deterministic user defined switch policy
- Deterministic forwarding
- Summary

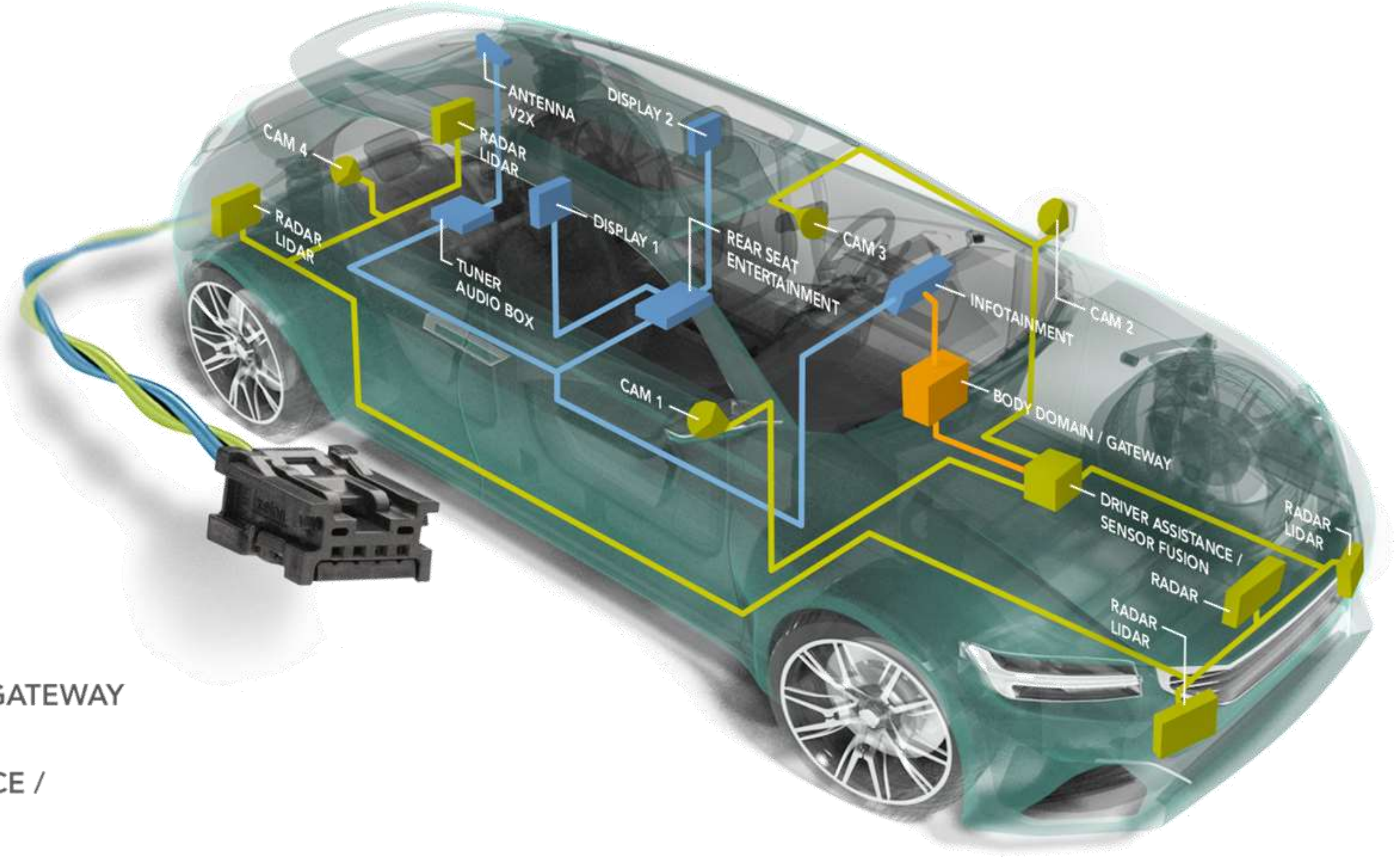
NXP Has a Long History with Automotive Ethernet

OPEN ALLIANCE — **CO-FOUNDER**

IEEE — **MEMBER RTPGE**
Reduced Twisted Pair
Gigabit Ethernet

AVNU — **PROMOTER**

JasPar — **MEMBER**



INFOTAINMENT

BODY DOMAIN / GATEWAY

DRIVER ASSISTANCE /
SENSOR FUSION

ETHERNET BACKBONE

A Leading Contributor to High Speed Networking Standards

- NXP is a contributing member of
  - **IEEE Ethernet workgroups**
    - 802.3 – 10 Mbps, 100BASE-T1, 1000BASE-T1 and 2.5/5/10 Gbps
    - 802.1 – TSN
  - **OPEN Alliance**
    - Member steering committee
    - Leading member of technical committees
      - TC-9 (1000BASE-T1 UTP channel specification)
      - TC-10 (Sleep/Wake-up Specification & IOPT for Automotive Ethernet 1000BASE-T1)
      - TC-12 (1000BASE-T1 PHY interoperability and EMC specs)
  - **MIPI automotive workgroup**
    - Automotive SerDes special interest group
    - Driving specification for MIPI BoF and MIPI Auto WG

Overview

Using Time Sensitive Networking (TSN) in automotive networks:

Selected TSN/switching concepts:	Example applications:
Reliable Time Synchronization	Sensors & sensor fusion Audio & noise cancelation
Seamless & instantaneous reliability	Delivery of safety critical data
Deterministic User Definable Switch Policy	Future proofing & security Network debugging & policing
Deterministic forwarding	Security & network management

Notes: “frame” and “packet” are used interchangeably in the standards
“bridge” is the IEEE 802.1 term for what many call a “switch”

Need: Reliable Time Synchronization

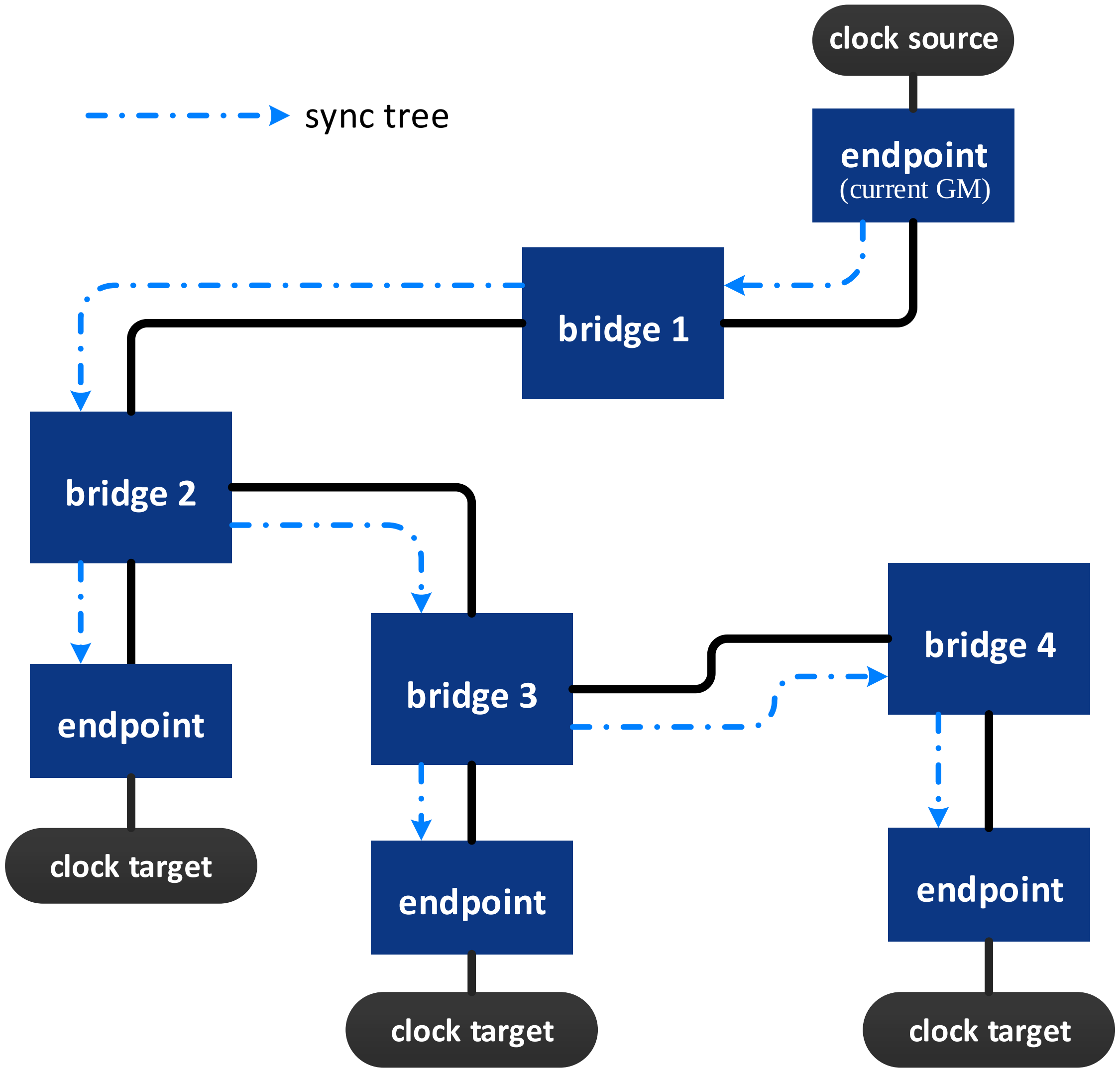
Applications Needing Reliable Time Synchronization

- Cars have an ever increasing number of sensors
  - Camera's, Radar, Lidar, microphones, etc.
- Fusion of lots of this data from all around the car is required
  - Determines what is important and what is not
- If the data contains event time stamps, it can be correlated more easily
  - This reduces the number of computations needed & minimizes fusion artifacts
- Cabin noise cancelation requires acquiring microphone samples
- And outputting audio to the speakers
  - If both are synchronized the required commutations go down and the quality goes up

Implementing Reliable Time Synchronization

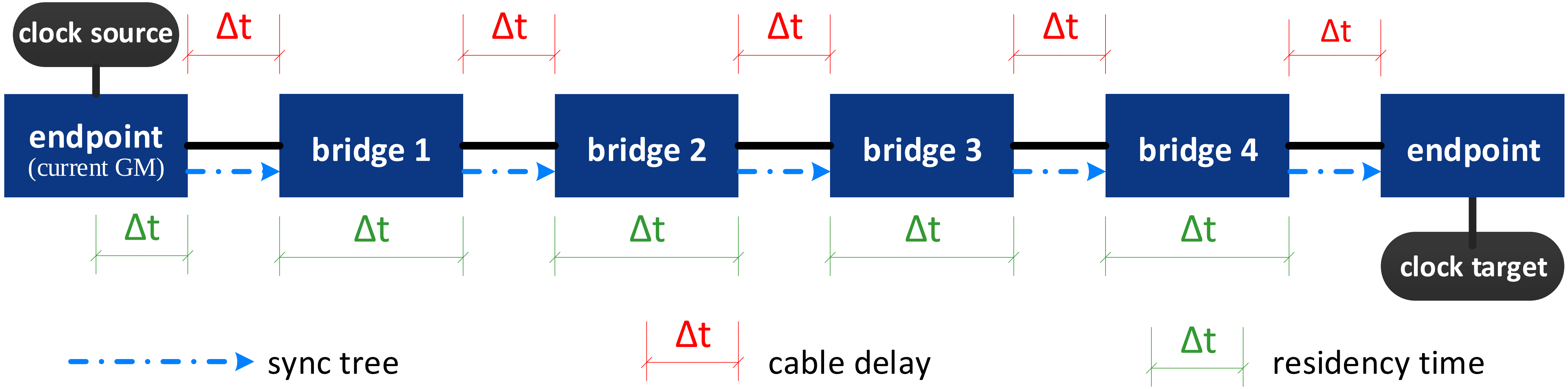
- A network supporting Time Synchronization is a fundamental requirement of many of the IEEE 802.1 Time Sensitive Networking (TSN) standards
  - It is difficult to be Time Sensitive if the network is not Time Aware
- The mechanism used is called the Precise Timing Protocol (PTP)
  - In IEEE 802.1 this is defined in the IEEE 802.1AS-2011 standard
- The IEEE 802.1AS-Rev (soon-to-be) standard adds support for redundant clock sources (Grand Masters) and redundant clock paths

How It Works – Basic Time Synchronization



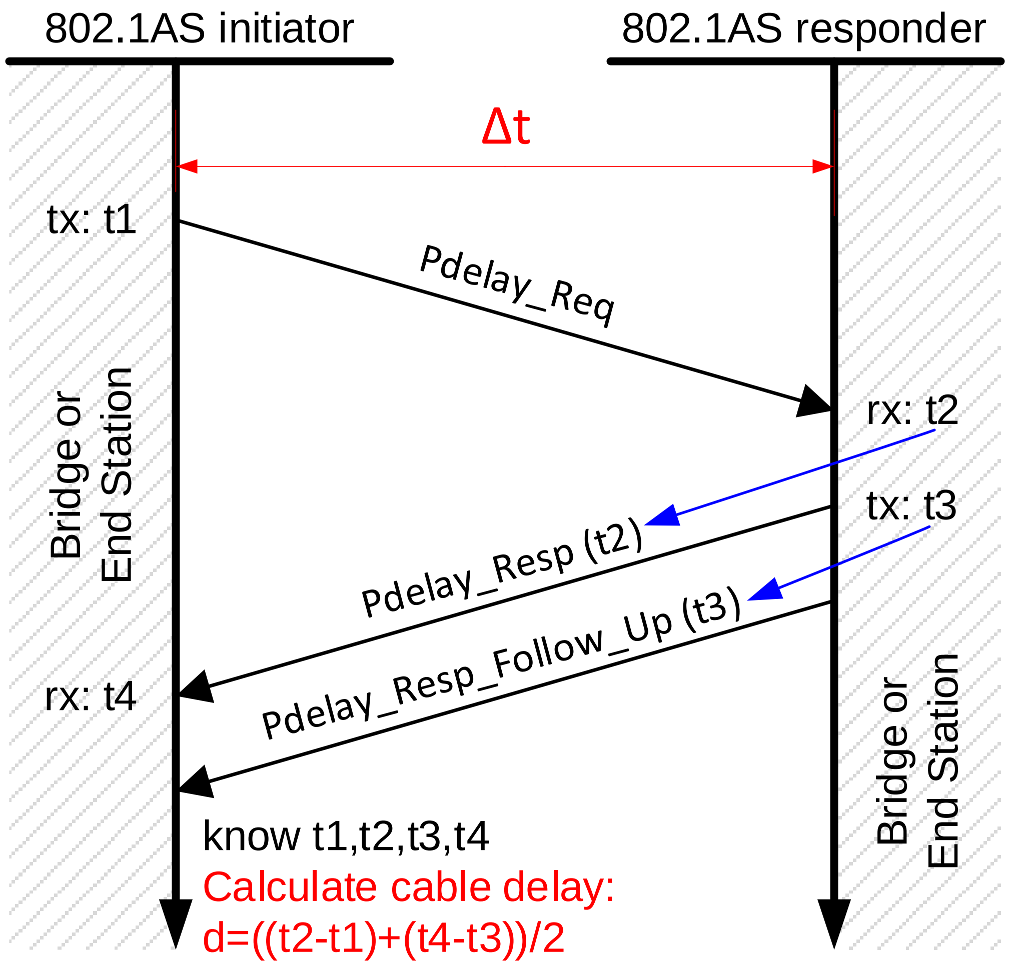
- Shown is a typical Star Network
- A Clock Source (Grand Master) is needed to supply "time"
  - Can be discovered or defined
- A sync tree path connects the clock source to its destinations
  - Path can be discovered or defined
- Both are discovered in 802.1AS
- Both are defined in the Avnu.org Automotive profile

How It Works – Time Synchronization



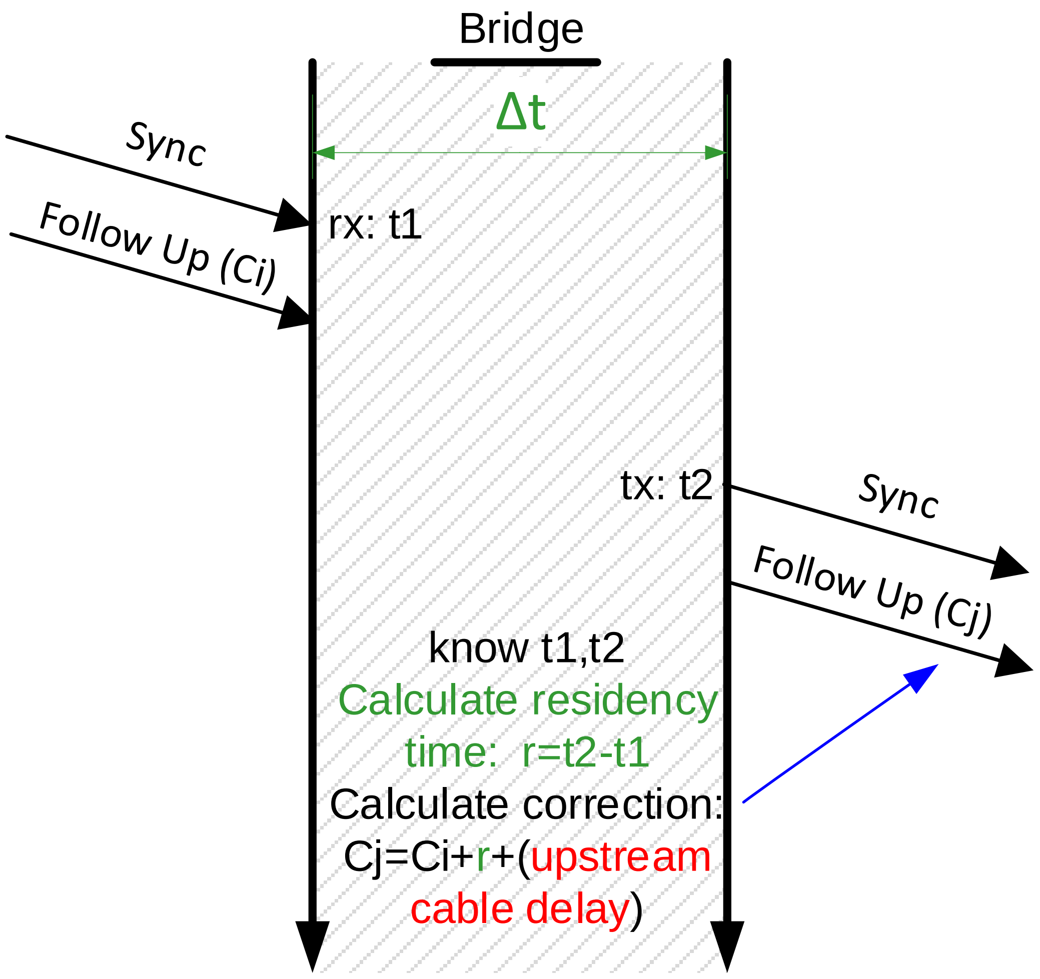
- The previous network is shown with only the farthest endpoint
- Each link (cable) delay is measured (~ once per second)
- Each bridge delay (residency time) is measured (~ 8 x per second)
- Each endpoint gets the original "time" and the sum of all these delays

How It Works – Cable Delay Measurements



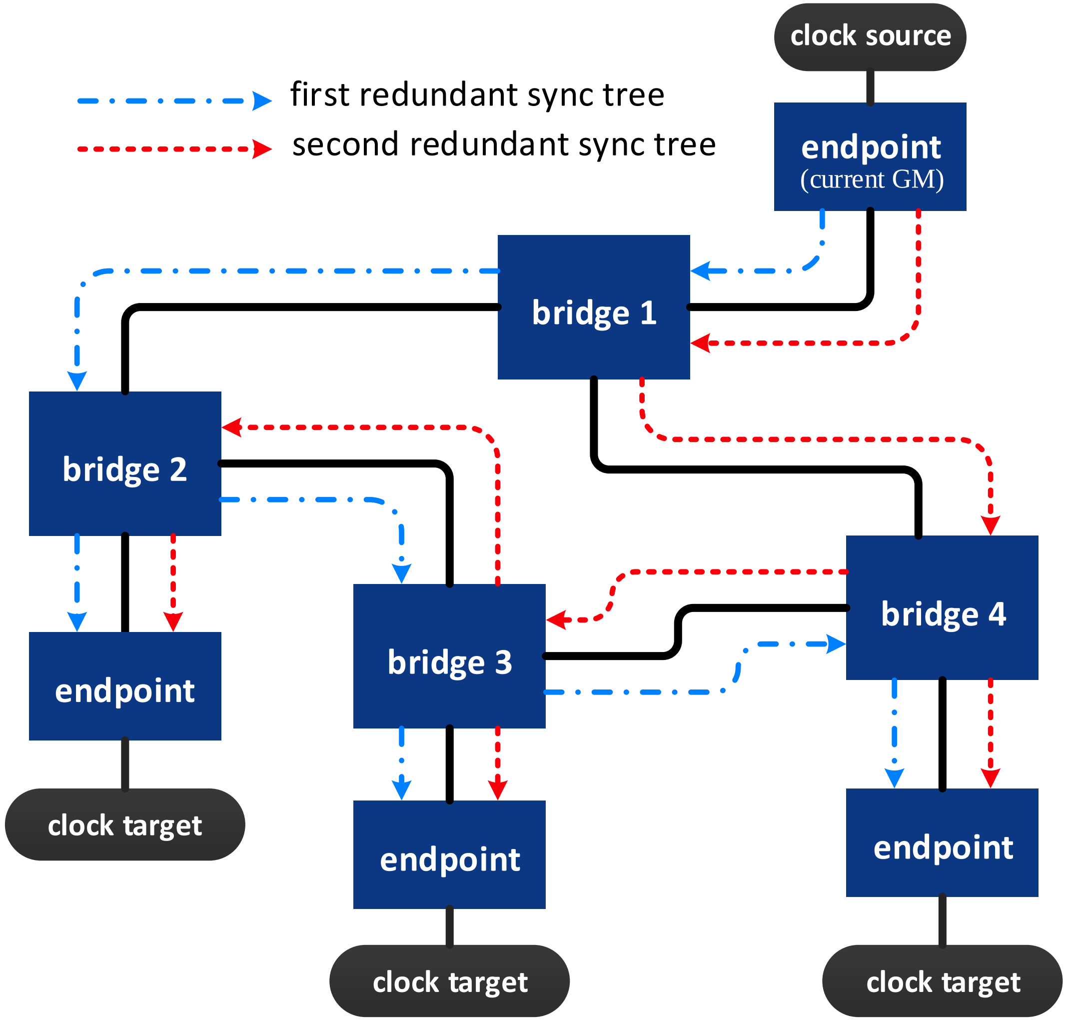
- Cable delays are measured by the Pdelay mechanism
- As a request frame is transmitted & received it is time stamped
  - This results in times t1 & t2
- It's response frame is also time stamped in the same way
  - This results in times t3 & t4
- A follow up frame is used to get the last time stamp to the initiator
- Now the delay can be measured

How It Works – Bridge Delay Measurements



- Bridge delays are measured by the sync mechanism
- As a sync frame is received it is time stamped (t1)
- When a sync frame is transmitted it is also time stamped (t2)
- A follow-up frame is used to send the correction time down the path
- The outgoing correction is the sum of the incoming correction + the residency time + upstream cable delay

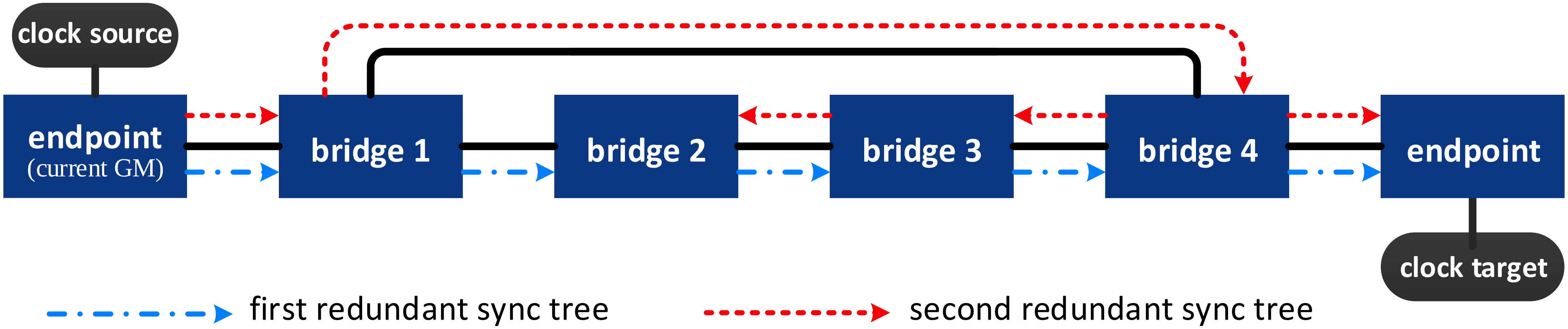
How It Works – AS-Rev Reliable Time Synchronization



From Figure 7-4, AS-Rev draft 7.0

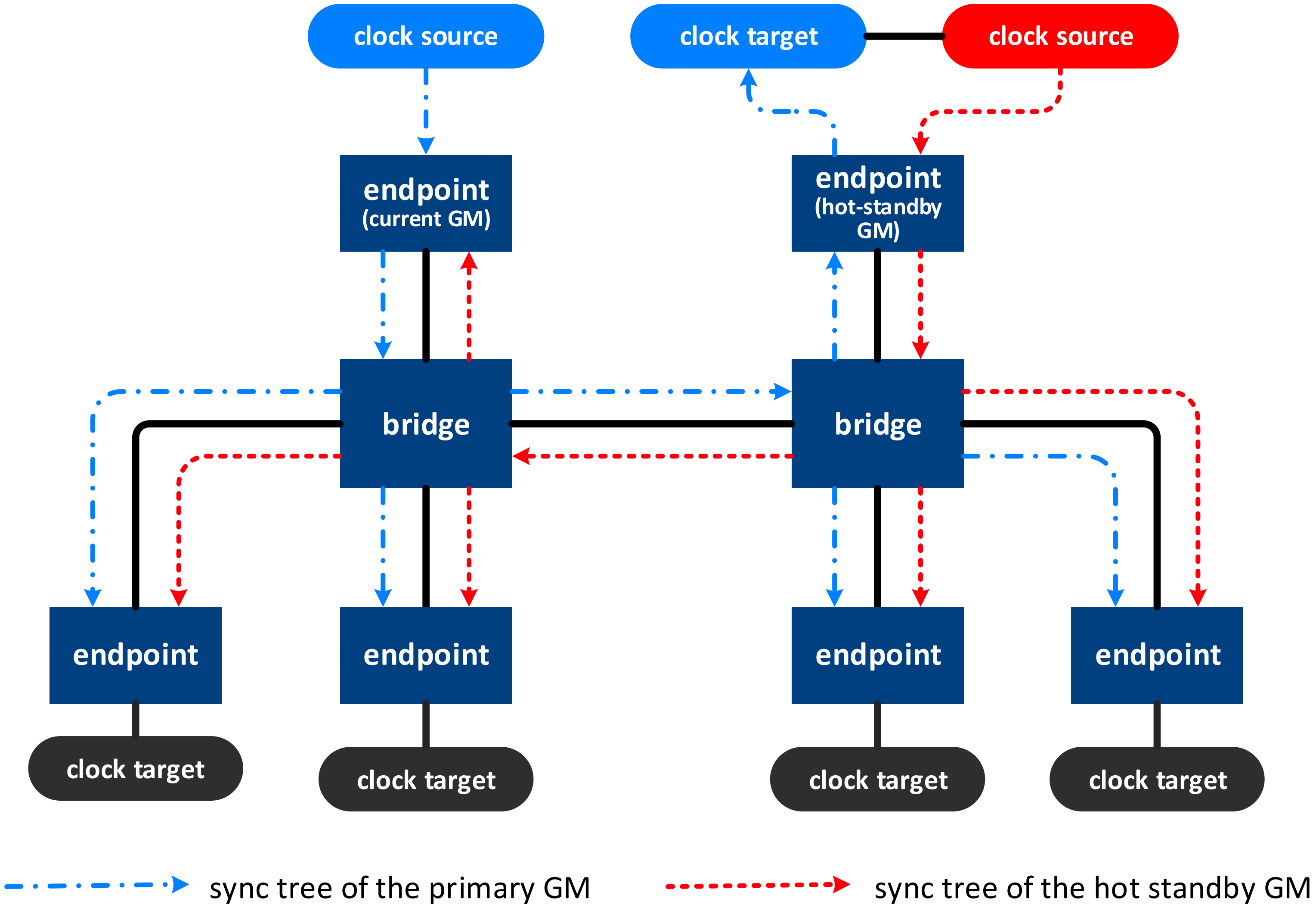
- Previous network is now a ring
- The bridges are connected into a ring with one new link between bridge 1 & bridge 4
- Multiple sync tree paths now connect the clock source to the destinations
  - Redundant paths need to be defined
  - Domain numbers separate sync trees
- Endpoints merge the multiple clocks (from each tree) into one

How It Works – AS-Rev Reliable Time Synchronization



- The previous ring network is shown with only the farthest endpoint
- Redundant rings are easy to build as all it takes is one extra wire!
- Only one Pdelay is done per link (not per domain)
- All other calculations are the same but done per domain per sync tree

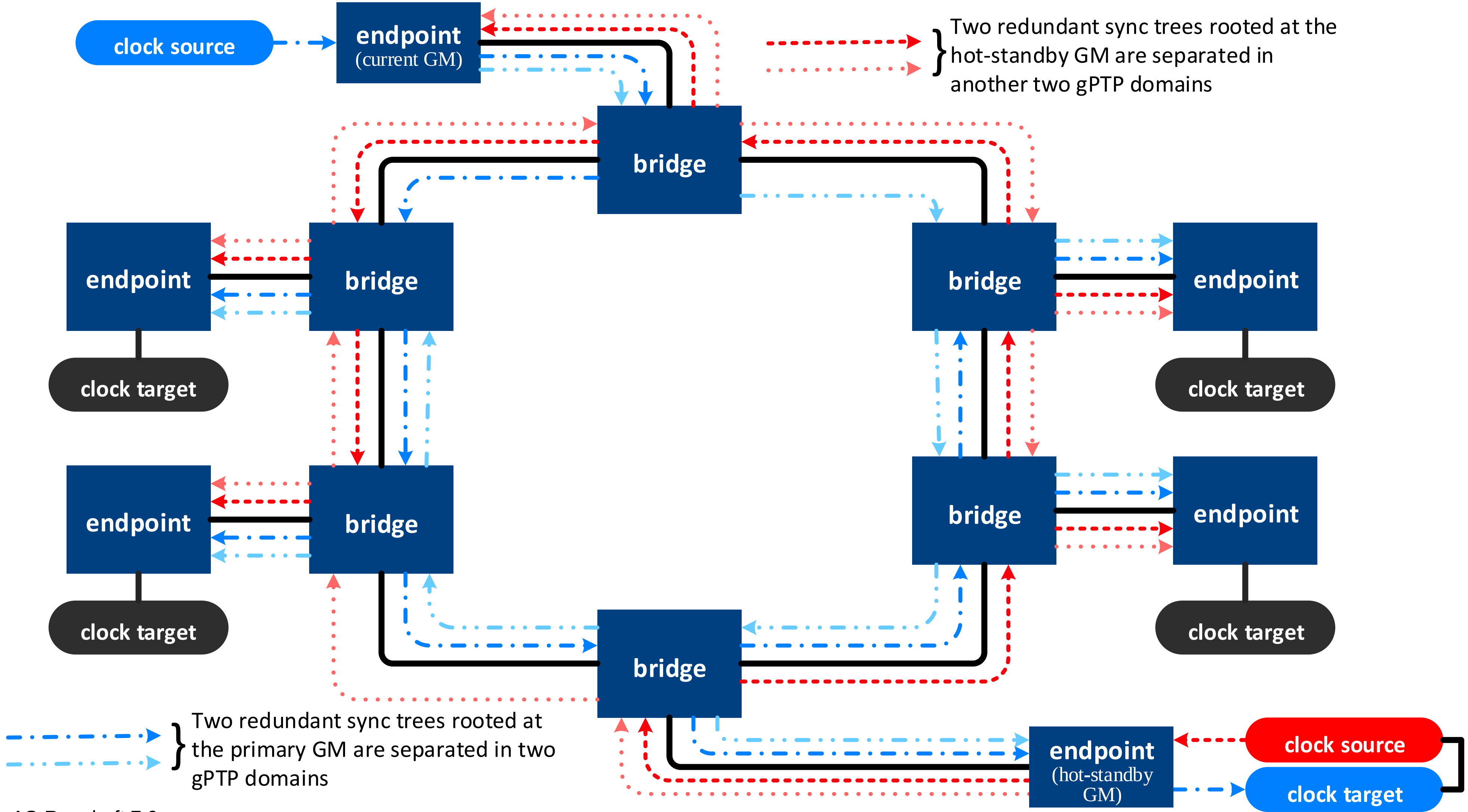
How It Works – AS-Rev Redundant Grand Masters



From Figure 7-5, AS-Rev draft 7.0

- AS-Rev also supports multiple, redundant, active Grand Masters
- Zero switch-over time in case of primary GM failure
- Multiple GM's can be combined with multiple clock paths
  - The number of clock domains = the sum of the number of sync trees each GM uses
  - 2 GM's with 2 sync trees each = 4 domains are needed

How It Works – AS-Rev Redundant Grand Masters & Trees



From Figure 7-6, AS-Rev draft 7.0

Need: Seamless & Instantaneous Reliability

Applications Needing Seamless & Instantaneous Reliability

- Where ultra-critical data must be received the first time
  - As re-transmissions cause too much added latency
  - For example: safety critical applications like applying the brakes
  - Where physically redundant sensors are needed, their data streams don't have to be

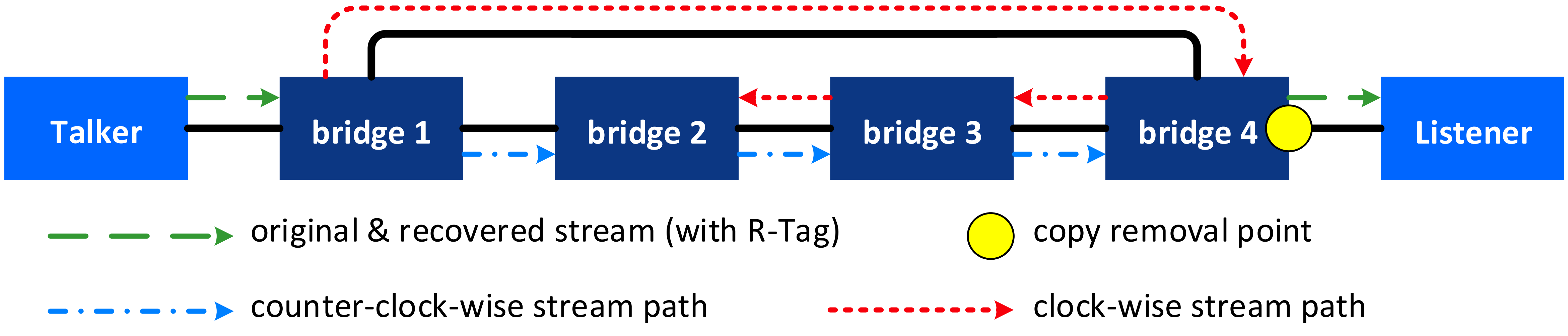
- With any single point of failure – the data still gets through
  - The failure could be a permanent situation like a broken wire or device (switch)
  - Or it could be an intermittent situation like a lose connector or a CRC error (noise)

- It is assumed that a small percentage of the streams in a car justify this added reliability – but its worth it for those streams that do need it
  - This reliability requires more network bandwidth due to the redundant streams

Implementing Seamless & Instantaneous Reliability

- Requires redundant paths for the ultra-critical data
- Rings or Ladder networks support very low-cost redundant paths
  - Only one extra wire (link) is needed per ring or ladder rung
  - The same wire used to build rings for the PTP clocks can be used for this data too!
- Sources of the stream (talkers) need to add to the frames a 6-byte R-Tag (Redundancy Tag) with an incrementing sequence number
- Talkers or the 1st bridge copies the stream on two independent paths
- The “last” bridge or the listener(s) remove the extra copy received
  - Bridges on rungs of a ladder are the “last” bridge for “compound streams”

How It Works – 802.1CB Frame Replication & Elimination



- The clock redundancy ring network is shown with a talker & a listener
- Talker adds the R-Tag & bridge 1 replicates the stream on two VLANs
- Bridge 4 removes extra copies so the listener doesn't have to
- Other replication & elimination points are supported

How It Works – 802.1CB Frame Replication & Elimination

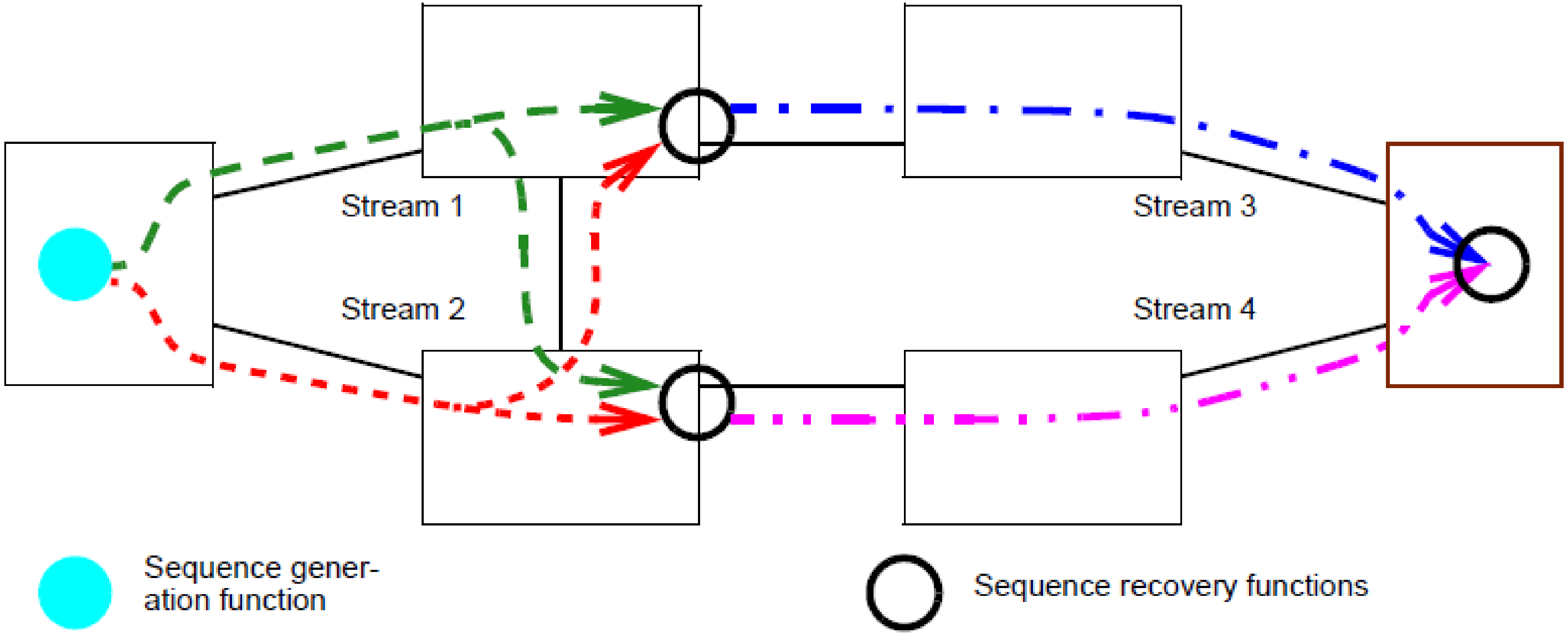


Figure 7-1—Compound Stream built from four Member Streams

From 802.1CB-2017

Ladder example from the 802.1CB standard with talker replication & listener removal points & bridge rung copy removal points

How It Works – Example 802.1CB Stream Frame Format

Field	Offset	Length
Destination MAC address	0	6
Source MAC address	6	6
C-TAG EtherType	12	2
Priority, DE, VLAN ID	14	2
R-TAG EtherType	16	2
Reserved	18	2
Sequence number	20	2
Payload Length/EtherType	22	2
Data	24	*n*
Frame Check Sequence	24+*n*	4

Figure 8-3—Example Ethernet frame format

From 802.1CB-2017

- The location of the 802.1CB's R-Tag in a frame is shown
- C-Tag VID can be used for clock-wise vs. counter-clock-wise flows
- C-Tag priority is used to indicate the TSN queue & thus its shaper
- The R-Tag contains 2 reserved bytes + a 16-bit sequence number
- The rest of the frame can be anything – including IEEE 1722

What to Look for in Frame Replication & Elimination H/W

- It needs to maintain full wire speed for deterministic behavior
  - Adding duplicate generation or removal must not impede the bridge's performance

- The duplicate removal function needs to detect the loss of copies
  - If this is not done the user is in a "fool's paradise" as everything is still "working"

- The standard supports intermittent -one packet in flight at a time in the ring/rung- & bulk streams -multiple packets in flight at a time – but packets can be received out of order in this case
  - Few automotive use cases need bulk stream support & its more expensive

Need: Deterministic User Defined Switch Policy

Applications for Deterministic User Defined Switch Policy

- Debugging Ethernet Automotive Networks
  - To support identification and mirroring of only the specific flows being debugged
    - Ethernet is a switched network – not a bus; a single “tap” cannot show all the flows
  - To support Unified Diagnostic Service (UDS Protocol) in Automotive – ISO 14229
- To support new, not-yet-defined, protocols
  - Firmware upgrades can add new features where special frame handling is required
- Security – White listing, Black listing, & trapping for extra handling
- Identification of any individual flow for 802.1Qci policing
  - You can’t support per flow policing if you can’t clearly identify each flow

Implementing Deterministic User Defined Switch Policy

- Requires Deep Packet Inspection (DPI) that keys off of all or parts of a frame’s Layer 2, Layer 3 and/or Layer 4 header
- To support new protocols, the DPI implementation needs to be able to match every bit of every byte of the 1st “N” bytes of a frame
  - “N” defines how deep the frame’s header processing can go
  - Need to use a TCAM (Ternary Content-Addressable Memory)
  - TCAMs can match each frame bit to a “1”, a “0”, or “don’t care” (i.e., don’t match this bit)
- When a frame matches a TCAM entry, a set of actions is applied
  - Actions include: changing the mapping of where a frame goes (including discarding it), assigning to it a: Qci Policer, queue (traffic class), priority (PCP) & VLAN identifier (VID)
- Consistent rules are needed when multiple TCAM entries match a frame

What to Look for in User Defined Switch Policy H/W

- It needs to maintain full wire speed for deterministic behavior
  - Adding deep packet inspection must not impede the bridge's performance
- Designs that can match every bit of every byte of a search
  - Can match all bits of a 64 byte frame for example – supports all old & new protocols
- Designs that support options for depth vs. # entries
  - Allows the implementation to be configured to best meet your needs/applications
- Designs that go deep enough to support all applications
  - Need 98 bytes deep for Unified Diagnostic Services (UDS) in Automotive on IPv6 single tagged frames, and double tagged needs 102 bytes – to get the L4 header

Need: Deterministic Forwarding

Applications for Deterministic Forwarding

- All TSN guarantees require proper forwarding of “known” frames
  - A “known” frame has it’s DA+VID contained & found in a bridge’s address database
  - This means all MAC addresses being used in a bridge must be successfully stored in that bridge regardless of the MAC addresses values

- Network management (including gPTP) depends upon the proper mapping of each protocols “known” address

- Security – L2 White listing, Black listing, & trapping for extra handling

- Identification of individual TSN flows for 802.1Qci policing
  - The L2 header (DA+VID) is sufficient to identify most TSN flows

Implementing Deterministic Forwarding

- Requires inspection of a frame's Layer 2 header (DA & VID)
  - Multiple VIDs could be in the frame so this needs to be selectable

- The OPEN Alliance TC-11 requirements for an Ethernet switch document defines a forwarding address table size of at least 1024 entries where at least 256 entries must be stored without conflict
  - i.e., ANY combination of 256 different address values must be successfully stored
  - Implementing a TCAM for the L2 Forwarding address table is an easy way to do this

What to Look for in Deterministic Forwarding H/W

- All addresses must be found all the time if they are in the database
  - Full wire speed address searches on all ports at the same time must be supported
- Even periodic flooding of frames breaks determinism
  - The flooding of frames to ports & queues they are not intended for breaks AVB/TSN
  - These frames jam up the ports/queues where they don’t have a reservation
  - If these frames are not properly identified, they can’t be policed properly either
- Look for L2 forwarding tables being implemented using a TCAM
  - Insures any combination of address values will always be stored – meets TC-11
- Look for L2 forwarding actions to be similar to the DPI TCAM
  - Like assigning a frame to a Qci Policer, etc. (DA+VID is sufficient for most TSN flows)
  - This saves DPI TCAM entries for other uses when the L2 header is all that is needed

Summary

Summary

- Devices are not implemented the same way
  - IEEE 802.1 defines an interoperable baseline such that desirable enhancements can be made on top of the standard features
- For reliability use 802.1AS-Rev for redundant clocks and 802.1CB for redundant data flows
- Deep Packet Inspection using a TCAM with appropriate width, depth & actions facilitates debugging and in-the-field network upgradeability
- The forwarding table needs to be able to store & retrieve in real time ANY combination of MAC addresses for the network to be deterministic

- More info: All 802 standards are free 6 months after being published
  - https://ieeexplore.ieee.org/browse/standards/get-program/page/

IEEE 802.3 Automotive Ethernet PHY Standards Handout

	10 Mbit/s	100 Mbit/s	1000 Mbit/s	2500 Mbit/s	10 Gbit/s	Next
MAC Interface Digital/ SERDES	SNI, xMII/ SGMII OC-SGMII	xMII/ SGMII OC-SGMII	xGMII/ SGMII OC-SGMII 1000BASE-X	OC-SGMII 2500BASE-X	USXGMII XFI	?
Media Interface Single Twisted Pair	802.3cg 10BASE-T1S 15 m Point to Point 25 m Multi-Drop 10BASE-T1L 1000 m Point to Point	802.3bw-2015 100BASE-T1 15 m Point to Point	802.3bp-2016 1000BASE-T1 15 m Point to Point	802.3ch 2500BASE-T1 15 m Point to Point	802.3ch 10GBASE-T1 15 m Point to Point	?

Media Interface (PHY) Standards without an appended year are not completed yet.

Updated 6-2018

IEEE 802.1 Automotive AVB and TSN Standards Handout

	Transport	Synchroni-zation	Stream Reservation	Quality of Service	Redundancy	Security
AVB	1722-2011 Media Transport Protocol	802.1AS-2011 gPTP	802.1Qat-2010 SRP (now Q clause 35)	802.1Qav-2009 Credit Based Shaper (now Q clause 34)	-	802.1X-2010 802.1Xbx-2014 802.1Xck Network Access
802.1BA-2009 The AVB Profile						
TSN	1722-2016 Adds CAN, FlexRay, LIN, + more Audio/Video Transports	802.1AS-Rev Redundant gPTP	802.1Qcc-2018 Enhanced SRP 802.1Qca-2015 Path Control & Reservation	802.1Qbv-2015 Time Aware Shaper 802.1Qbu-2016 & 802.3br-2016 Preemption 802.1Qch-2017 Cyclic Queue Forwarding 802.1Qcr Asynchronous Shaping	802.1CB-2017 Frame Replication & Elimination 802.1AS-Rev Redundant gPTP	802.1Qci-2017 Policing 802.1AEcg-2017 (end-to-end) MACSec

Standards without an appended year are not completed yet.

Updated 6-2018

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