How to achieve redundant time synchronization using 802.1AS-2020 features

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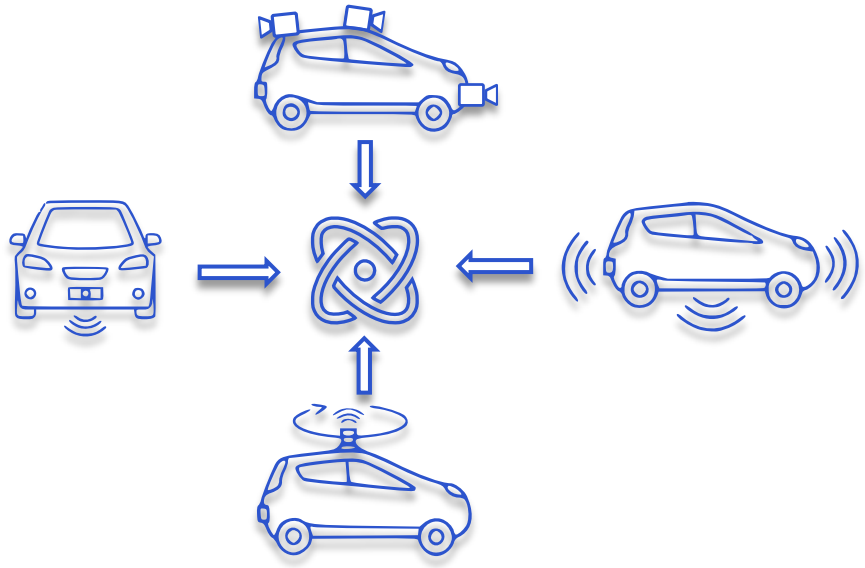
Table of contents

Sensor fusion

Why is critical for L4/L5 autonomous driving?

	Radar	Lidar	Camera	Sensor Fusion
Object detection	+	+	O	+
Object classification	-	O	+	+
Pedestrian detection	-	O	+	+
Works in all weather conditions	+	O	-	+
Works in all lighting conditions	+	+	O	+
Is affected by dirt	+	O	-	+
Velocity	+	O	O	+
Distance – accuracy	+	+	O	+
Distance – range	+	O	O	+
Data density	-	O	+	+
Form size & cost	+	-	O	+

+ Strength O Can Handle - Weakness



- Sensor fusion:
  - combines data from multiple sensors:
    - Cameras
    - Radars
    - Lidars
    - Ultrasonics
  - paints a more accurate image of the environment around the vehicle
  - balances the strengths of the different sensors

SAE – level of driving automation

When seamless redundancy is mandatory?

Driver support features			Automated driving features		
L0	**L1**	**L2**	**L3**	**L4**	**L5**
No Automation	Driver Assistance	Partial Automation	Conditional Automation	High Automation	Full Automation
Blind spot warning Lane departure warning	Adaptive Cruise Control OR Lane Centering	Adaptive Cruise Control AND Lane Centering	Traffic jam chauffeur	Local driverless taxi	Robo taxi everywhere
The driver is the fallback when automation fails				**The car handles all scenarios**	

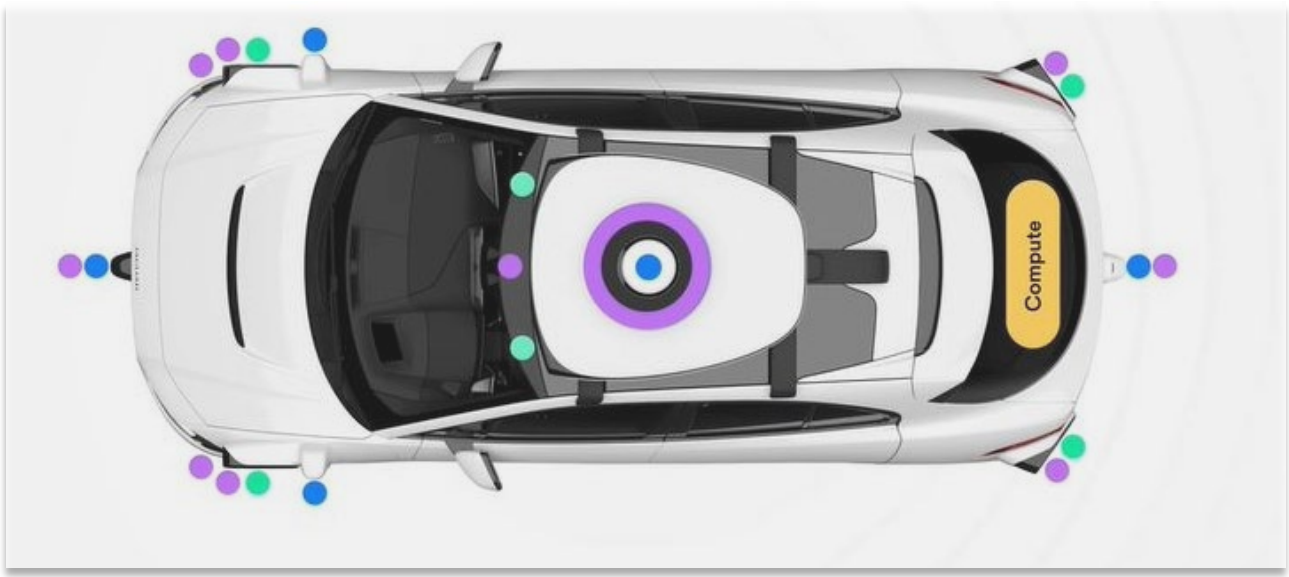
High availability & seamless redundancy is a must!

Sensor fusion in practice

- Tesla Autopilot (L2):
  - 8 cameras
  - 1 radar
  - 12 ultrasonics

https://www.tesla.com/autopilot

- Waymo Driver (L4):
  - 29 cameras
  - 6 radars
  - 5 lidars

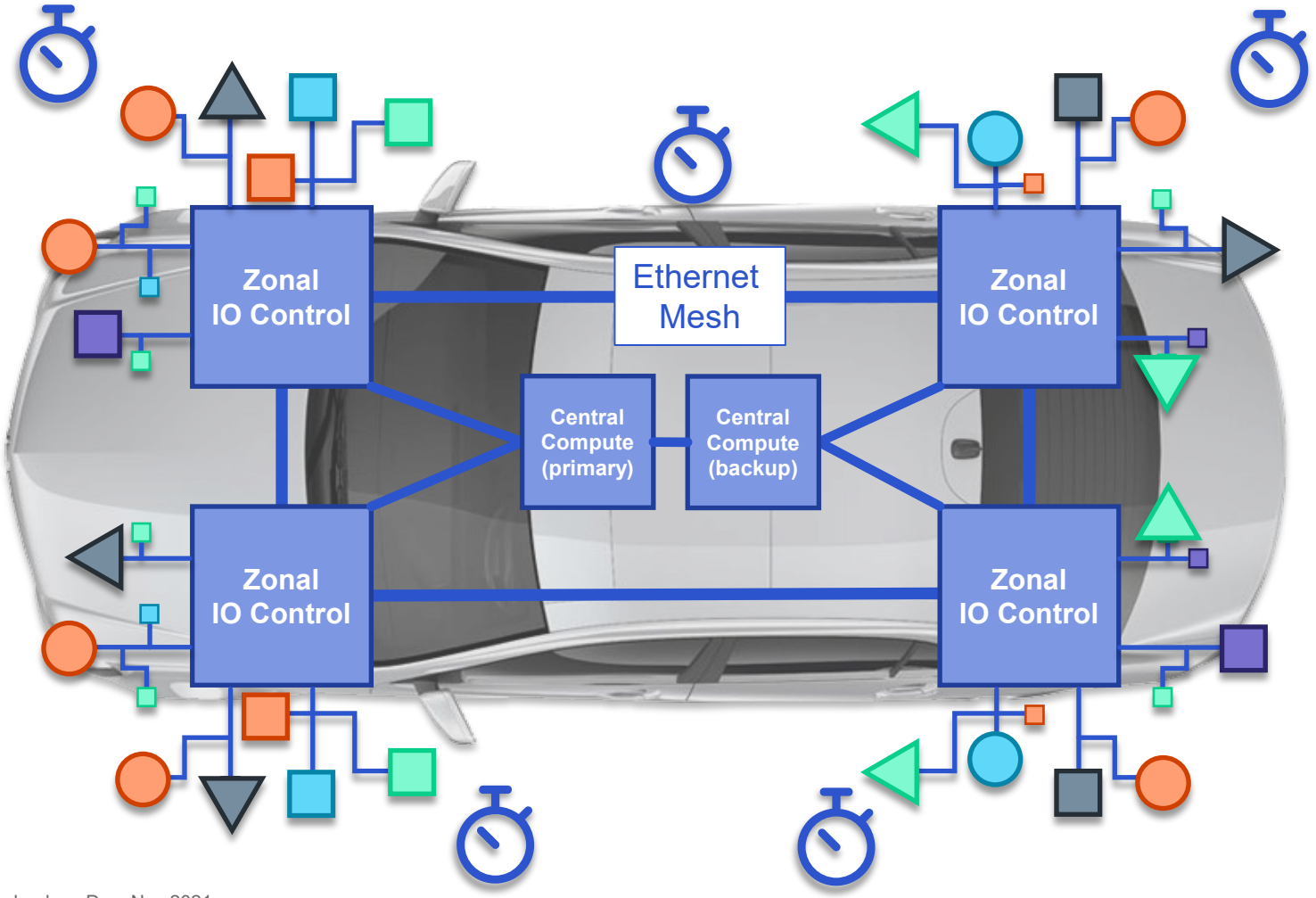


Camera Lidar Radar

https://blog.waymo.com/2020/03/introducing-5th-generation-waymo-driver.html

Sensors, Actuators & Compute ECUs in a zonal E/E architecture

Why time synchronization is a must



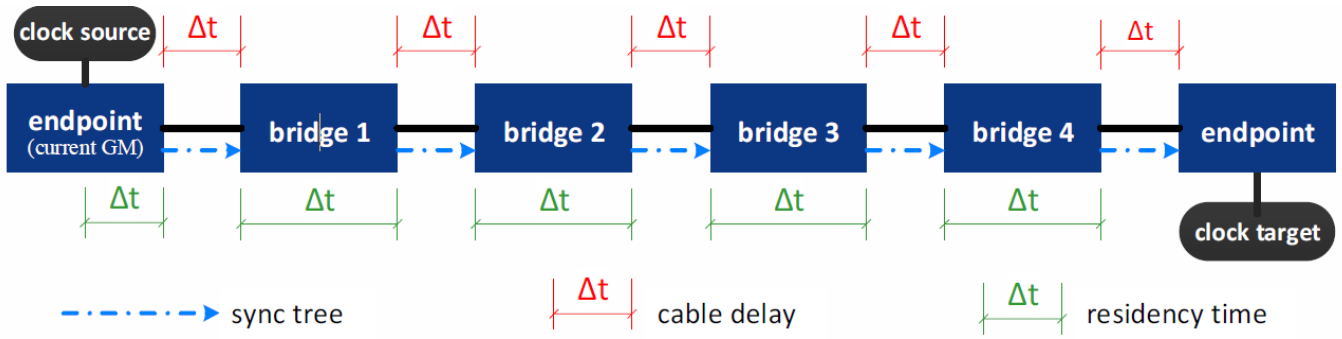
- Sensors
- Actuators
- ECU / Compute

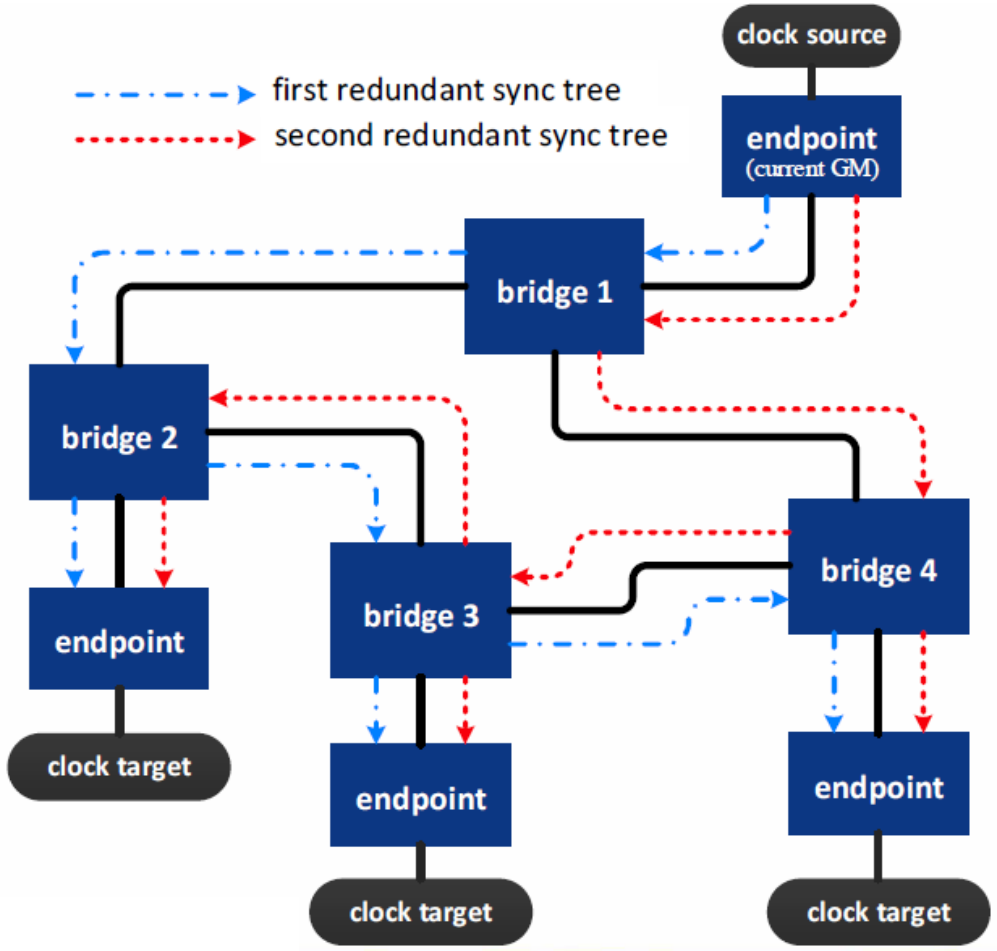
- Powertrain
- Body & Comfort
- Infotainment
- Connectivity
- ADAS & highly automated driving

Generalized Precision Time Protocol (gPTP)

802.1AS-2011 & 802.1AS-2020

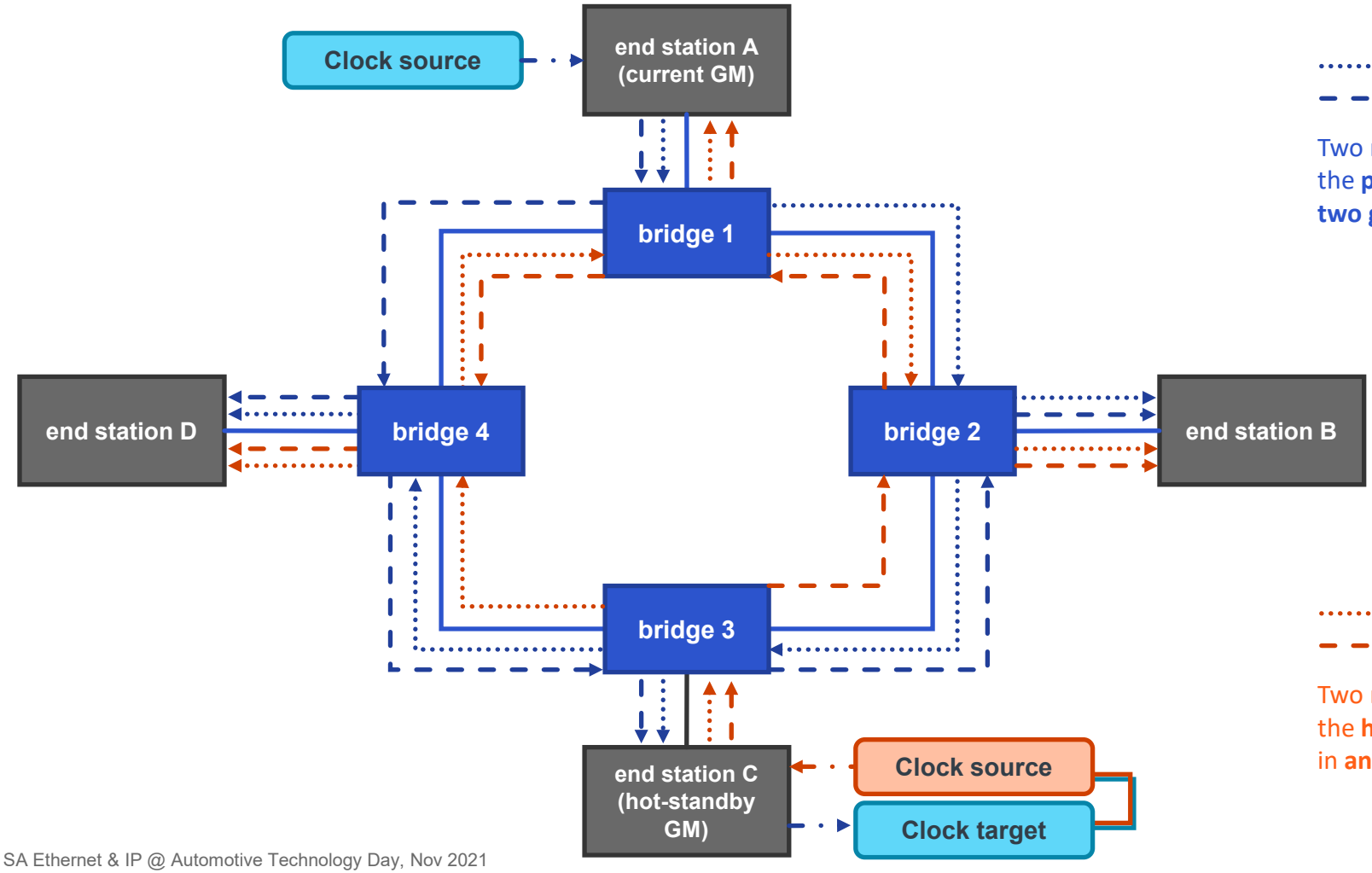
- 802.1AS time at any two LAN-attached stations accurate to within 1us
  - If one station thinks it's 10:25:55 AM PST, all others agree to within specified # of network hops
- A Clock Source (Grand Master) is needed to supply "time"
  - Can be discovered or defined (new in AS-2020)
- A sync tree path connects the clock source to its destinations
  - Path can be discovered or defined (new in AS-2020)
- New in AS-2020: Multiple time domains (e.g. working clock and global time), Common Mean Link Delay Service, multiple sync trees and more





Redundant gPTP – 802.1AS-2020

Two GMs with two sync trees each

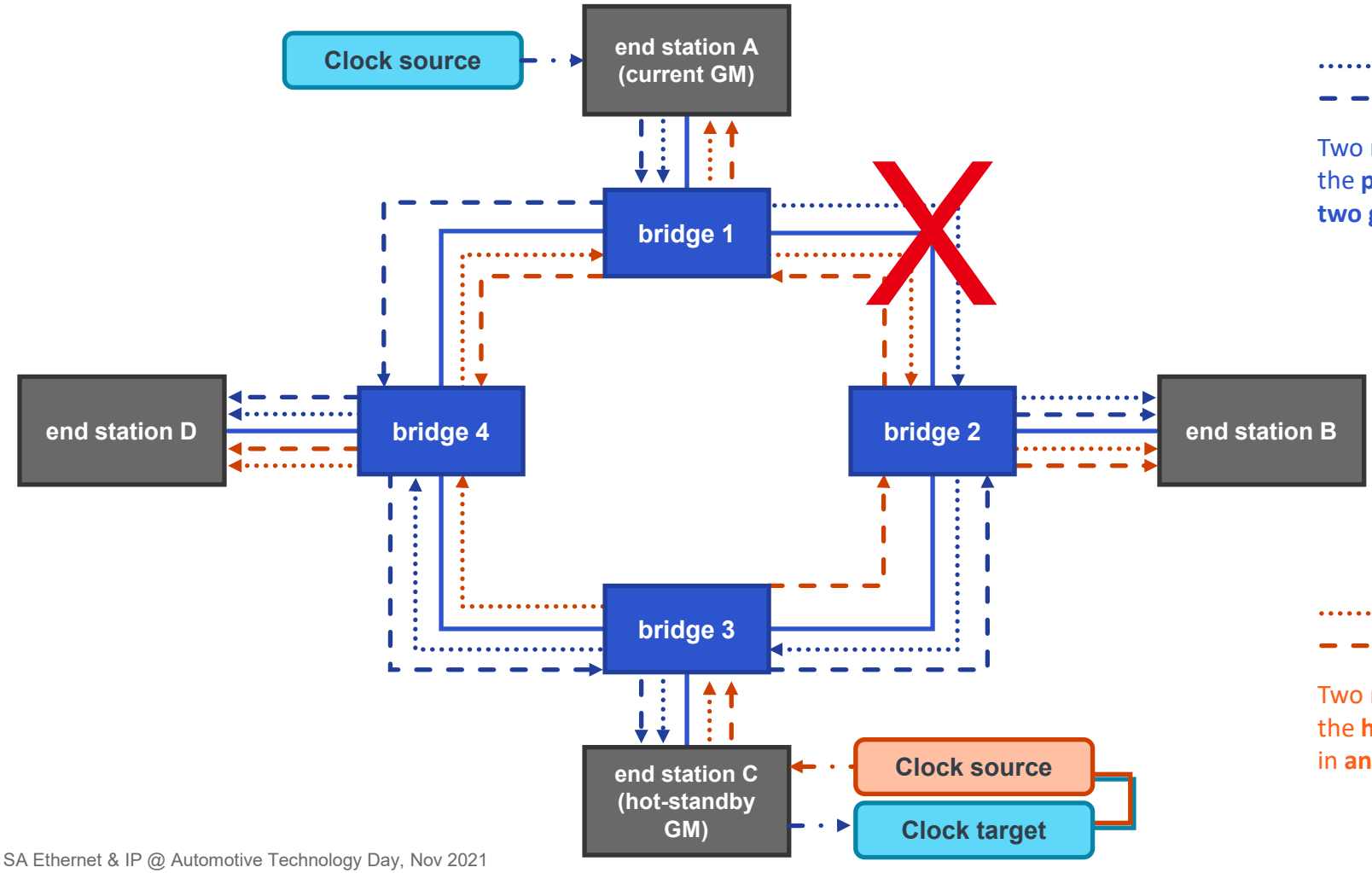


Two redundant sync trees rooted at the **primary GM** are separated in **two gPTP domains**

Two redundant sync trees rooted at the **hot-standby GM** are separated in **another two gPTP domains**

Redundant gPTP – 802.1AS-2020

Link failure



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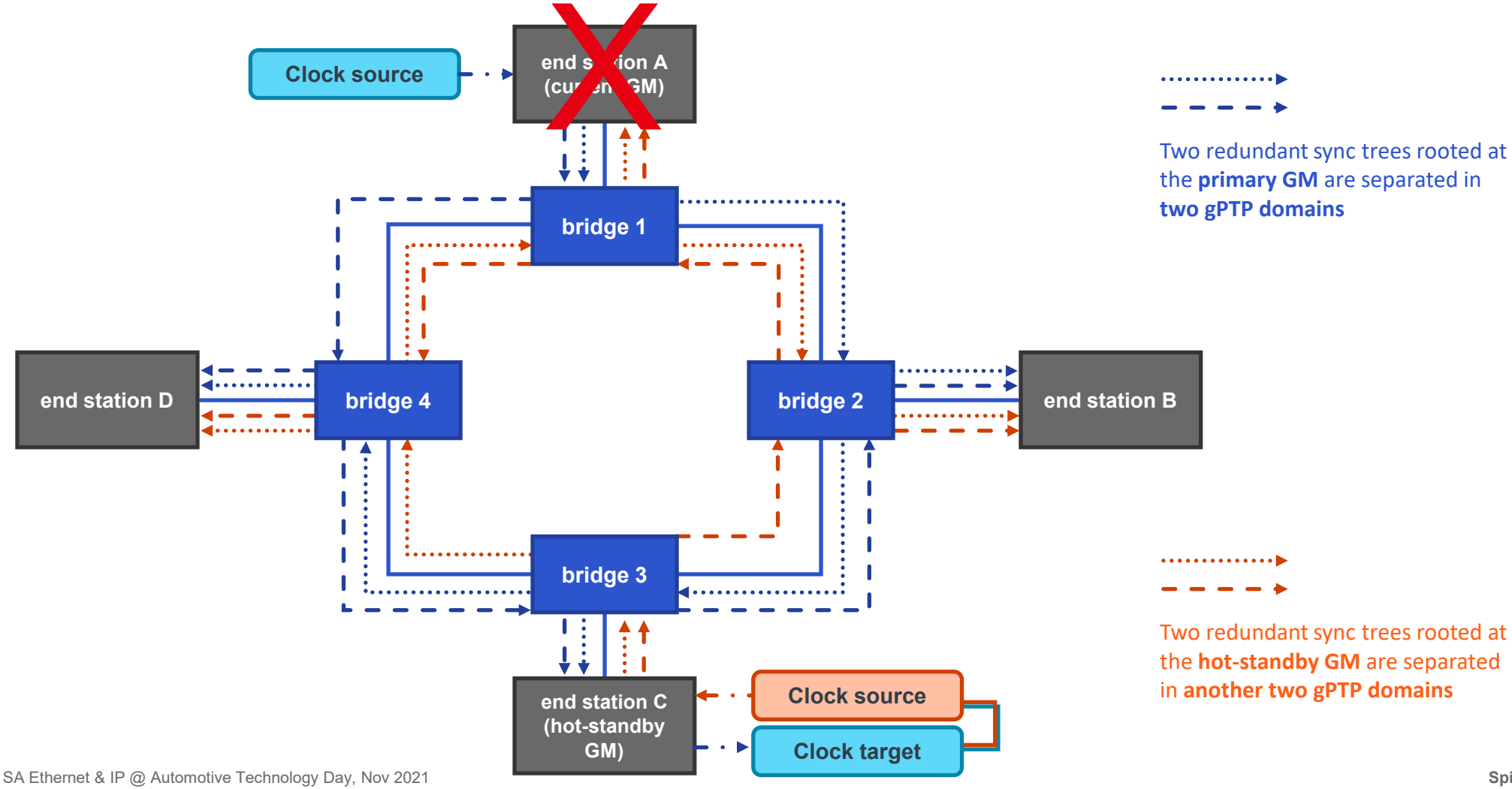
Redundant gPTP – 802.1AS-2020

GM failure



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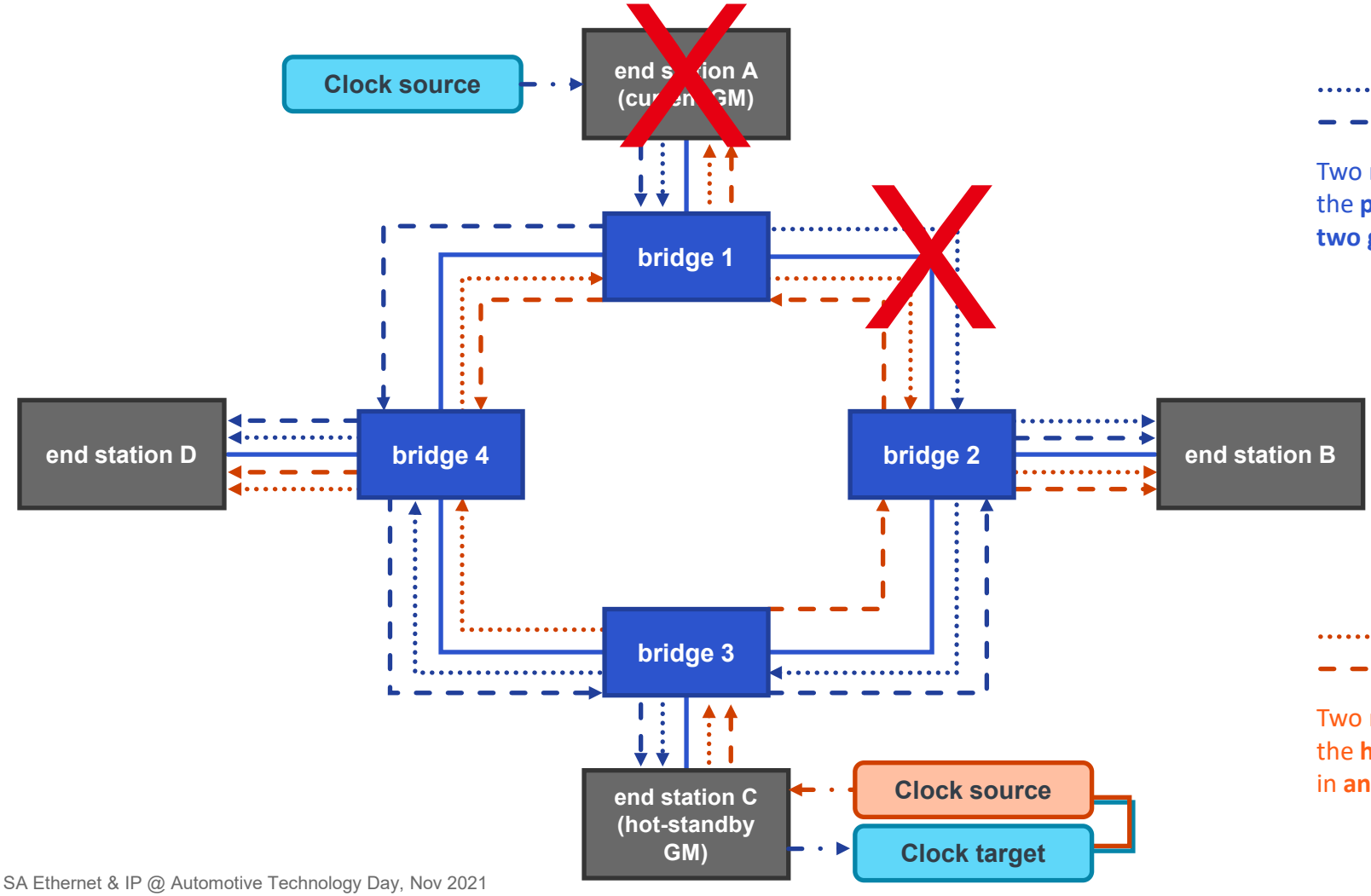
Redundant gPTP – 802.1AS-2020

Link & GM failure



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Advanced gPTP Redundancy

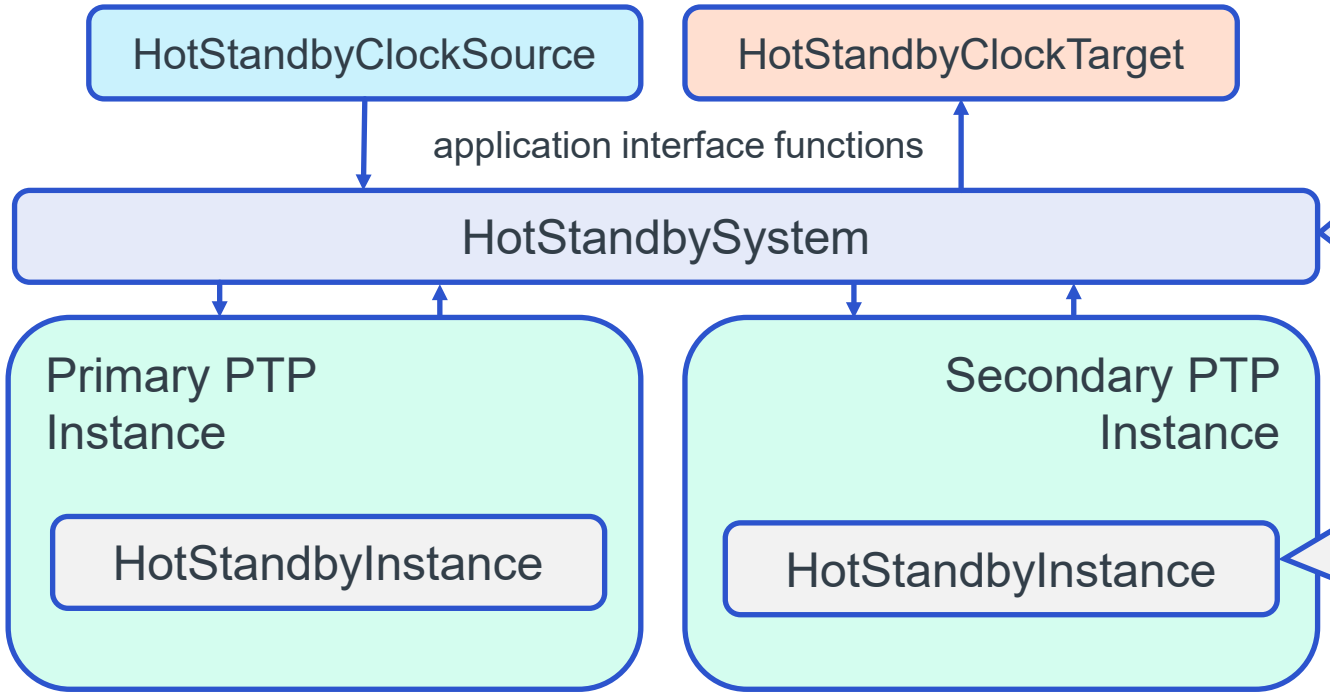
P802.1ASdm – Hot Standby

- AS-2020 provides a basic level of redundancy:
  - A detection component
  - A correction component
  - An action component
- AS-2020 provides the ability to support more sophisticated network configurations:
  - To take advantage of these failure correction configurations:
    - New types of fault detection are required
    - The appropriate correction mechanisms needs to be defined
- Advanced gPTP redundancy not fully specified in AS-2020

- 802.1ASdm aims to fill in the gaps and define advanced gPTP redundancy by introducing:
  - Mechanisms that determine whether a gPTP domain has sufficient quality to be used for hot standby
  - A function that transforms the synchronized times of two generalized Precision Time Protocol (gPTP) domains into one synchronized time for use by applications
  - A function that directs the synchronized time of one gPTP domain into a different gPTP domain

Model of hot standby redundancy for time synchronization

P802.1ASdm



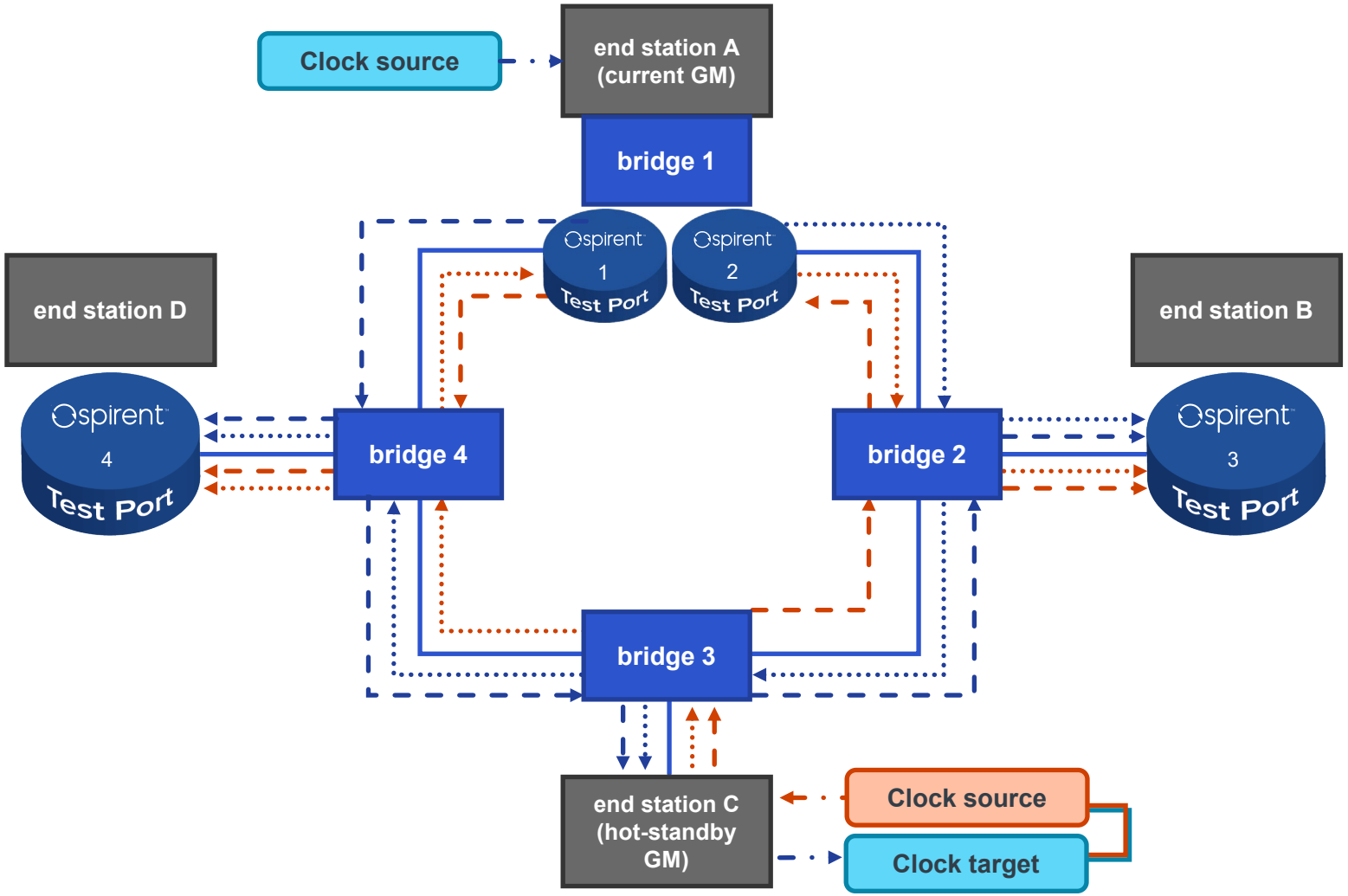
Hot Standby System

- Provides a single value of time to the application
- One HotStandbySystem for each timescale that uses hot standby
- Can be in 1 of the 4 states:
  - INIT
  - REDUNDANT
  - NOT_REDUNDANT
  - HOLDOVER
- No transition from NOT_REDUNDANT to REDUNDANT (non-revertive behavior) unless intervention by a higher-layer entity

Hot Standby Instance

- Monitors the PTP Instance to determine whether it is failed according to the requirements of the respective application or TSN profile
- One HotStandbyInstance within each PTP Instance used for hot standby
- Can be in 1 of the 4 states:
  - NOT_CAPABLE
  - SYNCED
  - SYNC_TIMEOUT
  - NOT_SYNCED

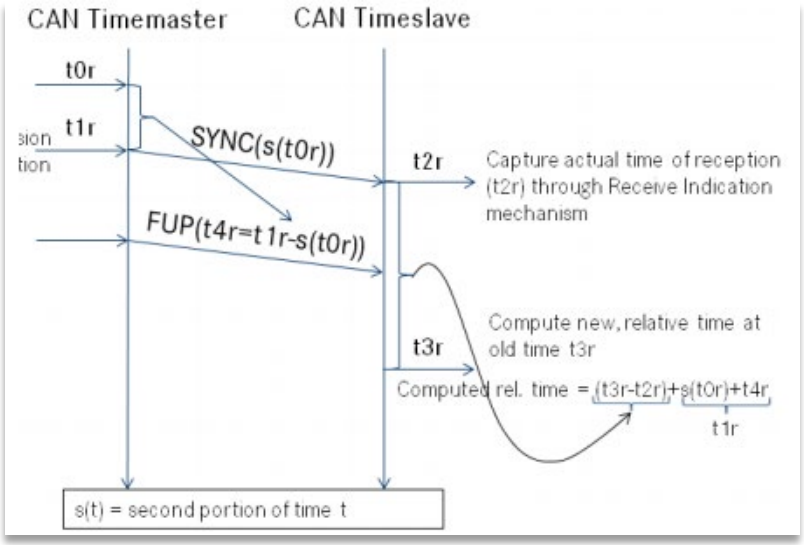
Testing Redundant gPTP



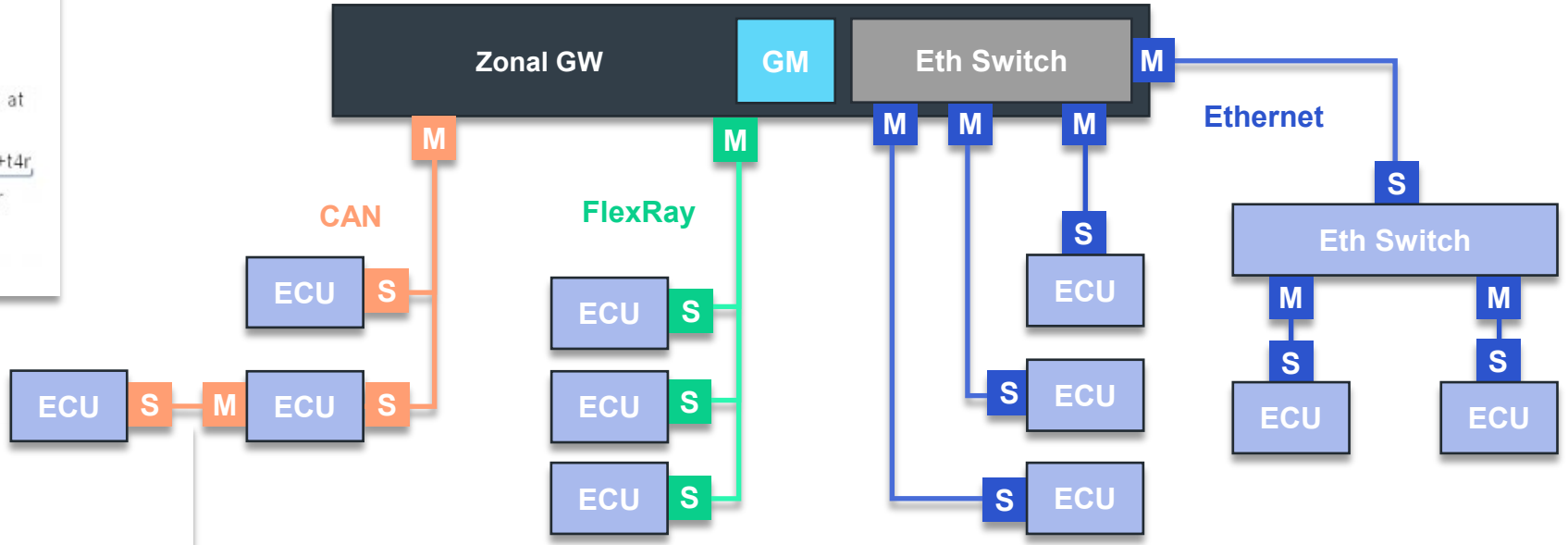
- Measure timing accuracy
  - Offset from GM
  - Device Delay Calculation
  - Path Delay Calculation
  - Neighbor Rate Ratio (NRR) Calculation
- Measure response to negative conditions
  - Link failure
  - GM failure
  - Link & GM failure

Time Sync over CAN or FlexRay

AUTOSAR Time Sync



- AUTOSAR Time Sync over CAN
  - Uses 2 types of broadcast messages
  - No hardware timestamp support, needs interrupts in the CAN driver
  - Targets a worst-case accuracy of 10µs, in practice achieves ~7µs

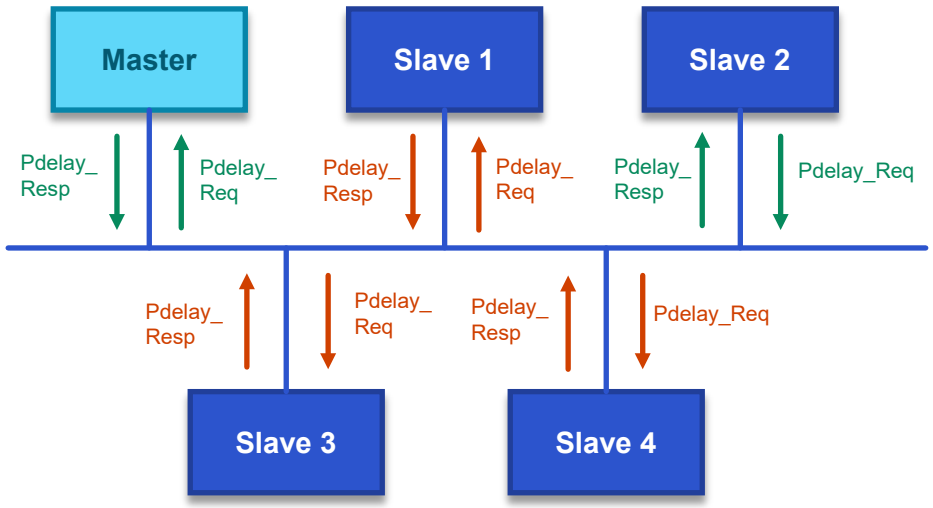


[SWS_CanTSyn_00017][
SYNC CRC secured message format:
Byte 0: *Type* = 0x20
Byte 1: *CRC*
Byte 2: *D* = Time Domain 0 to 15 (Bit 7 to Bit 4)
SC = Sequence Counter (Bit 3 to Bit 0)
Byte 3: User Byte 0, default: 0
Byte 4-7: *SyncTimeSec* = 32 bit LSB of the 48 bits seconds part of the time
If `CanTSynUseExtendedMsgFormat` = `TRUE`:
Byte 8-15: reserved, always 0

AUTOSAR Specification of Time Synchronization over CAN
https://www.autosar.org/fileadmin/user_upload/standards/classic/4-3/AUTOSAR_SWS_TimeSyncOverCAN.pdf

Time Sync over 10BASE-T1S

P802.1ASds



- Different possible solutions are currently explored in IEEE for standardization (P802.1ASds)

- 802.1AS-2020 (gPTP) defines media-dependent layer specifications for…
  - Full-duplex point-to-point links
  - IEEE 802.11 links (WLAN)
  - IEEE 802.3 Ethernet passive optical network links (EPON)
  - Other mediums
- Current problem: 802.1AS-2020 lacks the specification of a media-dependent layer for multidrop busses (i.e. 10BASE-T1S)
  - Pdelay peer-to-peer delay mechanism fails
  - 802.1AS Signaling messages may not work as intended

Summary

- Sensor fusion builds a more accurate model of the environment around the vehicle by balancing the strengths of the different sensors
- Time synchronization is needed to efficiently combine data from multiple sensors
- Redundant time synchronization is a must for advanced (L4/L5) autonomous driving
  - 802.1AS-2020 introduces the building blocks for redundant gPTP, but
  - Further specification is required (P802.1ASdm)
  - Testing redundant gPTP as early as possible saves time and money
- AUTOSAR Time Sync over CAN could be used until Ethernet takes over completely
- 10BASE-T1S could replace CAN, but gPTP needs to be adapted to work on 10BASE-T1 links
  - Work already started in IEEE to address these challenges (P802.1ASds)