Time Sensitive Networking (TSN) Enable a Predictable and Robust Network

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SECURE CONNECTIONS FOR A SMARTER WORLD

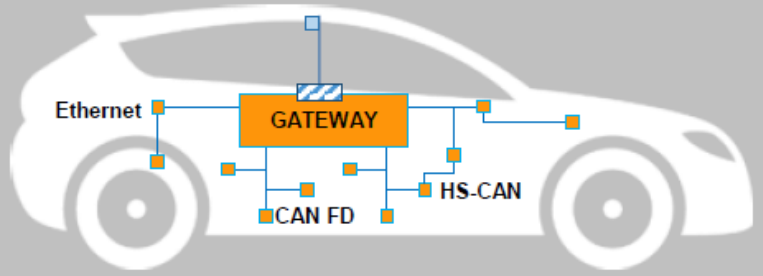
Agenda

- Overview Architecture Trends
- What is TSN?
- Getting Started
- Summary

Overview Architecture Trends

New Network Architectures Enable Autonomous Driving

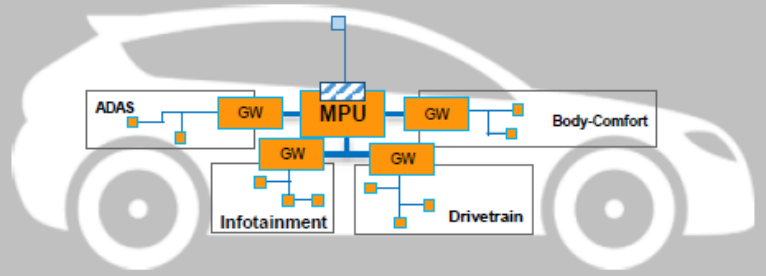
Today
Multi-Branch Network



Gateway as Hub

- Introducing layered security
- Ethernet for IVI and ADAS
- CAN FD for drivetrain
- CAN-LIN for body-comfort

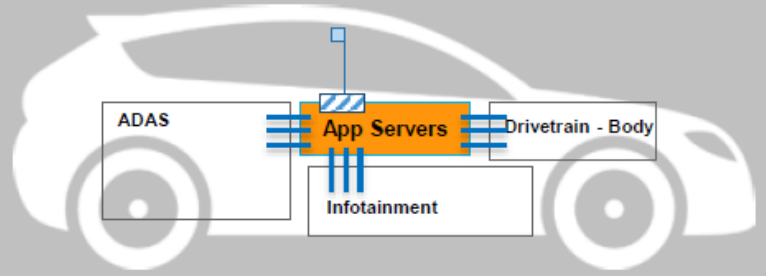
Tomorrow
Domain-Based Network



Hierarchy on Processing Duties

- Smart sensors / actuators
- Specialized domain controllers
- Central MPUs for Deep Learning
- AI-based autonomous vehicle

Tomorrow
Centralized Network

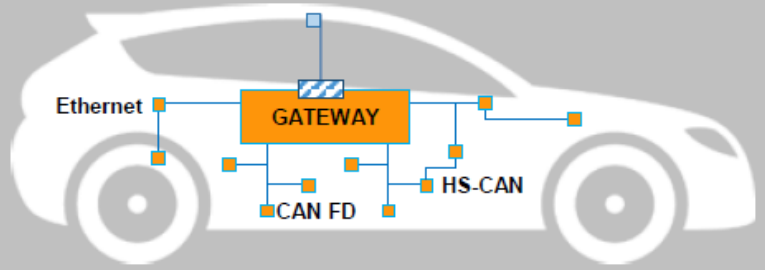


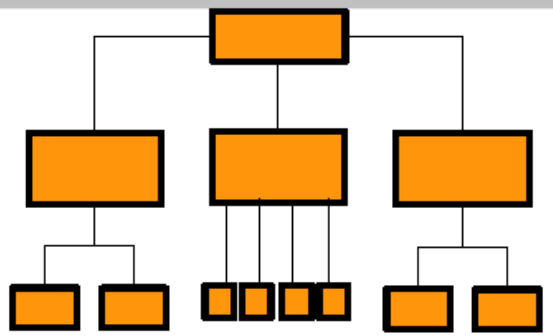
Highly Virtualized System

- Redundant central servers
- Unprocessed data highways
- Real-time cloud interaction
- AI-based autonomous vehicle

New Network Architectures Enable Autonomous Driving

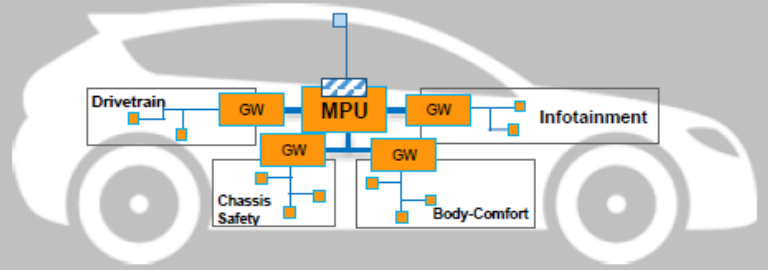
Today
Multi-Branch Network

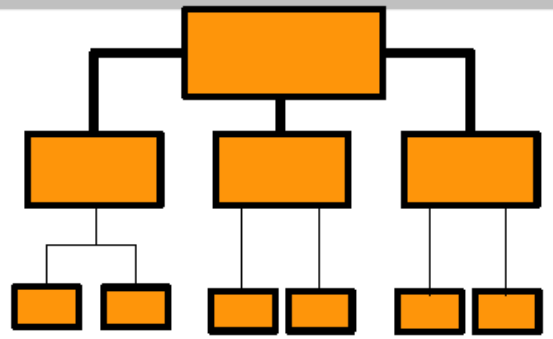




One Function per One Box
Post-processed Data on Bus

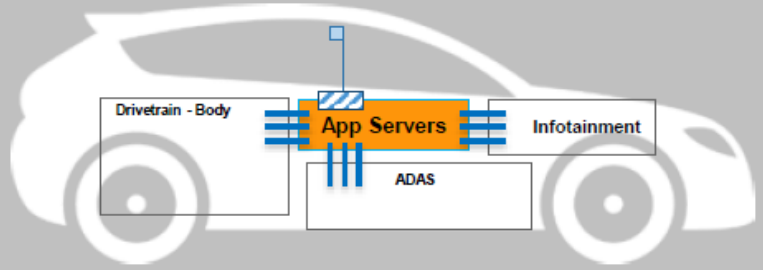
Tomorrow
Domain-Based Network

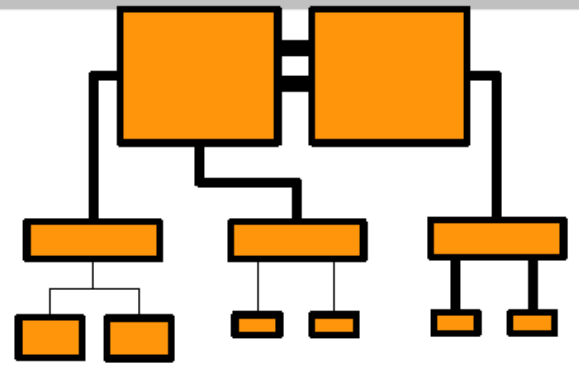




Few Functions in One Box
Un- or Pre-Processed Data

Tomorrow
Centralized Network





"Central Brains" replace ECUs
Un-Processed Data on Bus

A Leading Contributor to High Speed Networking Standards

- NXP is a contributing member of
  - IEEE Ethernet Workgroups
    - 802.3 – 10Mbps, 100BASE-T1, 1000BASE-T1 and 2.5/5/10Gbps
    - 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

What is TSN?

IEEE AVB and TSN Standards

TSN standards discussed today

	Transport	Synchronization	Stream Reservation	Quality of Service	Redundancy	Security
AVB	1722 (2011)	802.1AS	802.1Qat	802.1Qav	-	-
TSN	1722 (2016)	802.1AS-Rev	8021Qcc 8021Qca	802.1Qbv 802.1Qbu+ 802.3br 802.1Qcr	802.1CB 802.1AS-Rev	802.1Qci

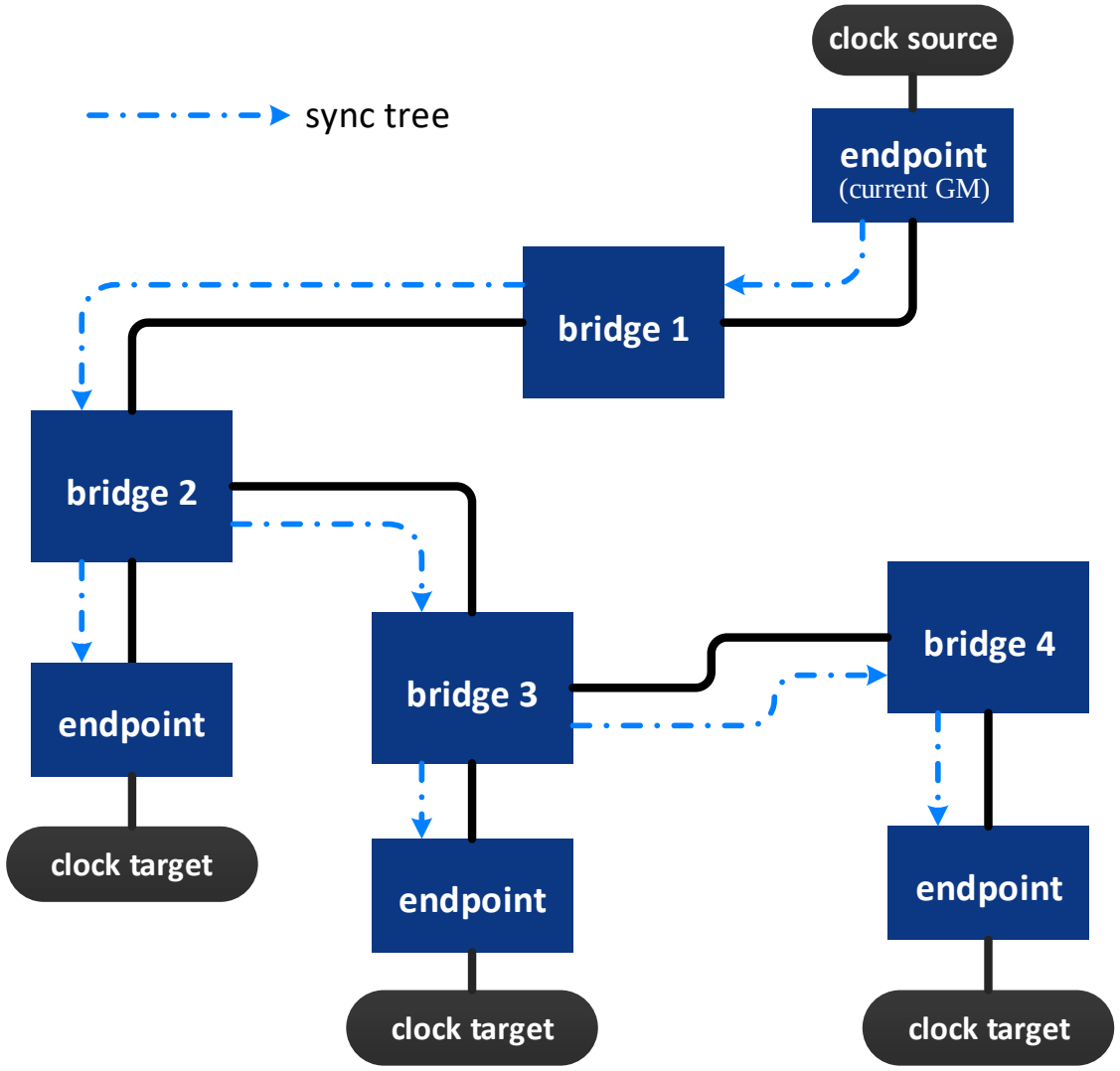
Applications Needing Reliable Time Synchronization

- 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 corelated 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 computations go down and the quality goes up

Implementing Reliable Time Synchronization

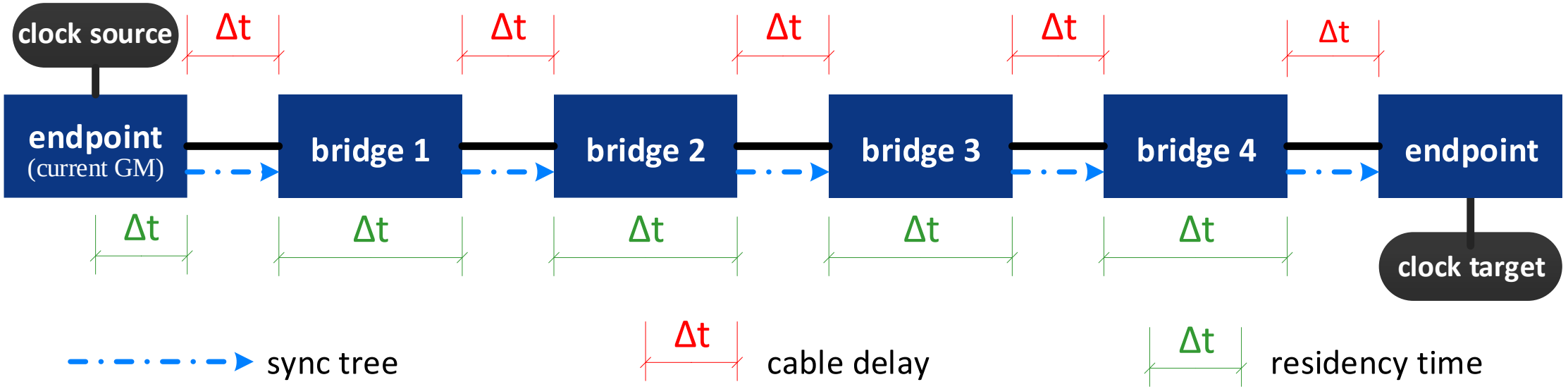
- A network supporting Time Synchronization is a fundamental requirement of many of the IEEE 802.1 Time Sensitive Networking (TSN) standards
  - It is difficult to be Time Sensitive if the network is not Time Aware
- The mechanism used is called the Precision Time Protocol (PTP)
  - In IEEE 802.1 this 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 – 802.1AS Basic Time Synchronization



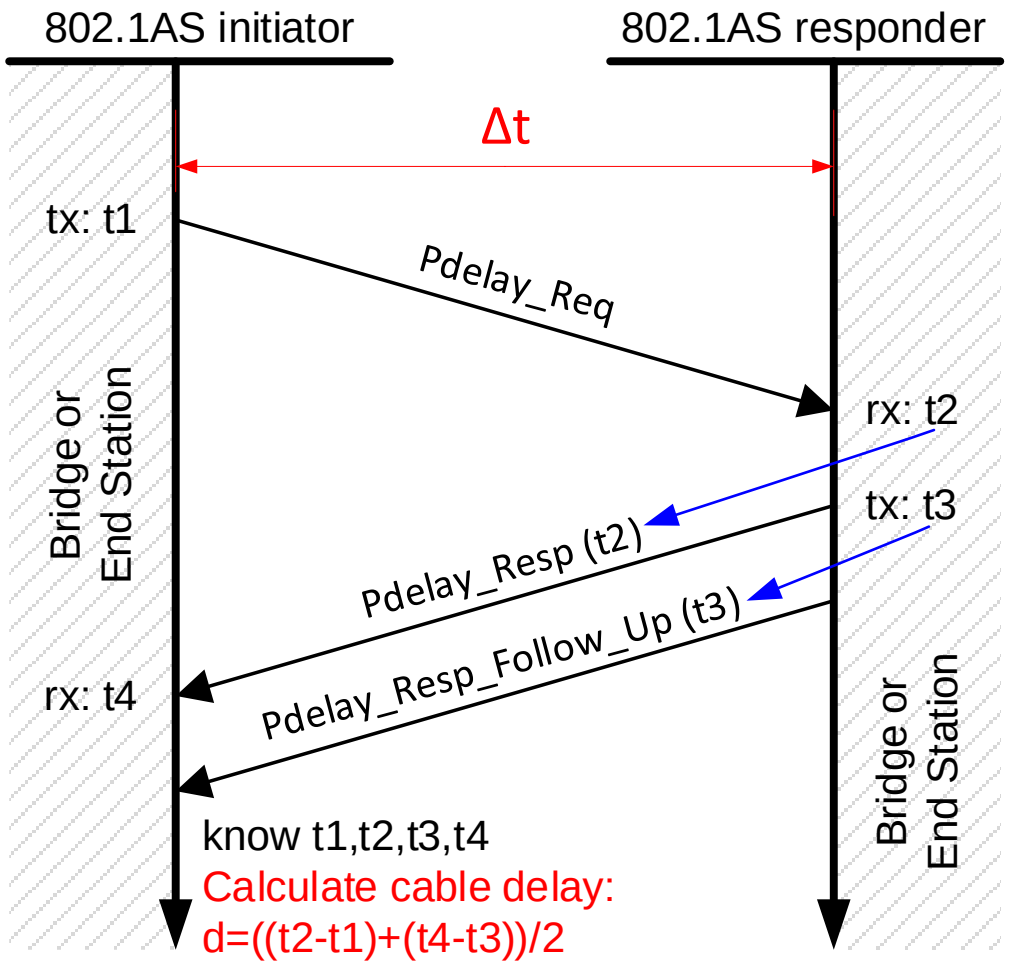
- Shown is a typical Star Network
- A Clock Source (Grand Master) is needed to supply “time”
  - Can be discovered or defined
  - Periodically broadcasts the current network time
- A sync tree path connects the clock source to its destinations
  - Path can be discovered or defined
- Both are discovered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

How It Works – Time Synchronization



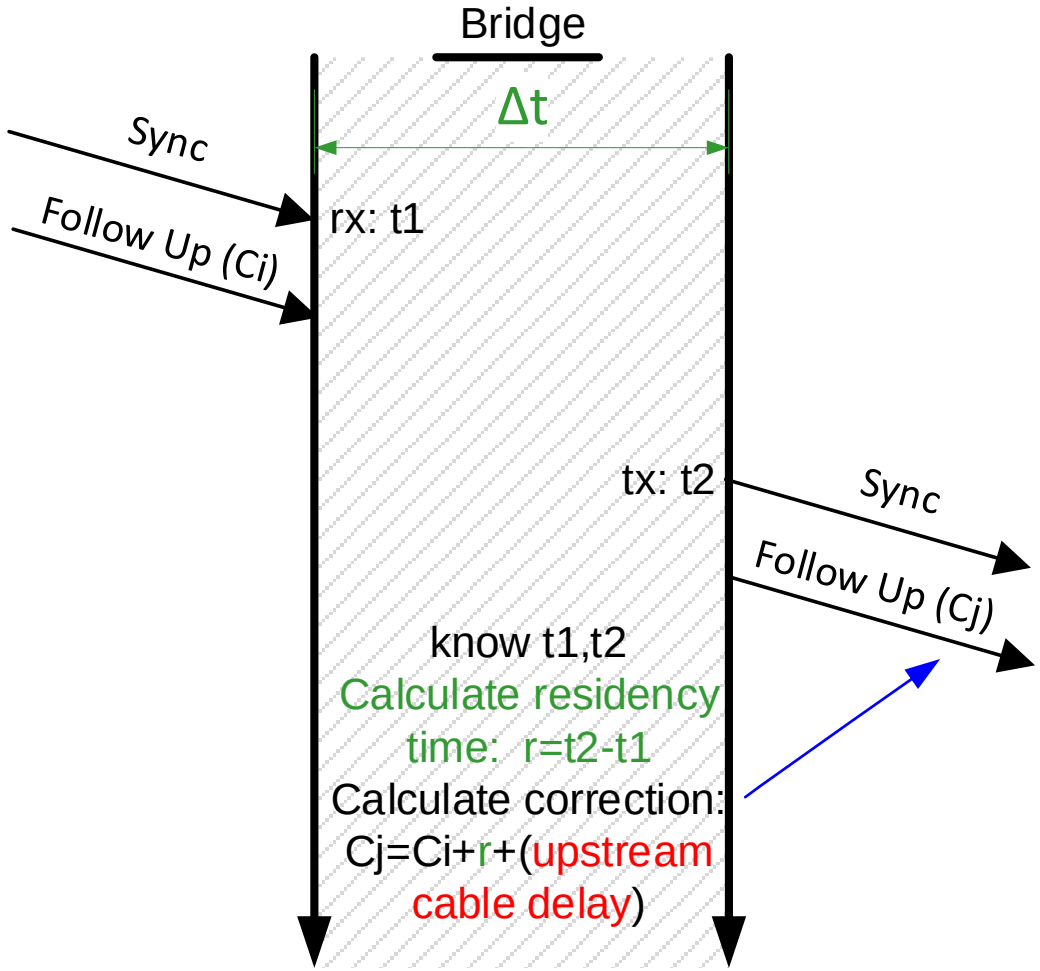
- The previous network is shown with only the farthest endpoint
- Each link (cable) delay is measured (~ once per second)
- Each bridge delay (residency time) is measured (~ 8 x per second)
- Each endpoint gets the original “time” and the sum of all these delays

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

802.1AS Automotive Profile

Default IEEE 802.1AS

Support for P&P end-nodes

Dynamically selected time grand masters etc…

AVNu automotive profile

Tuned for use in the car

Reduced SW complexity

- GM is selected at design time
- Link delay value can be set to static/constant
- Rate-Ratio can be set to constant etc…

Increased robustness in case of failure

- Switch can act as GM in case the GM stops working
- Etc…

Summarizing 802.1AS

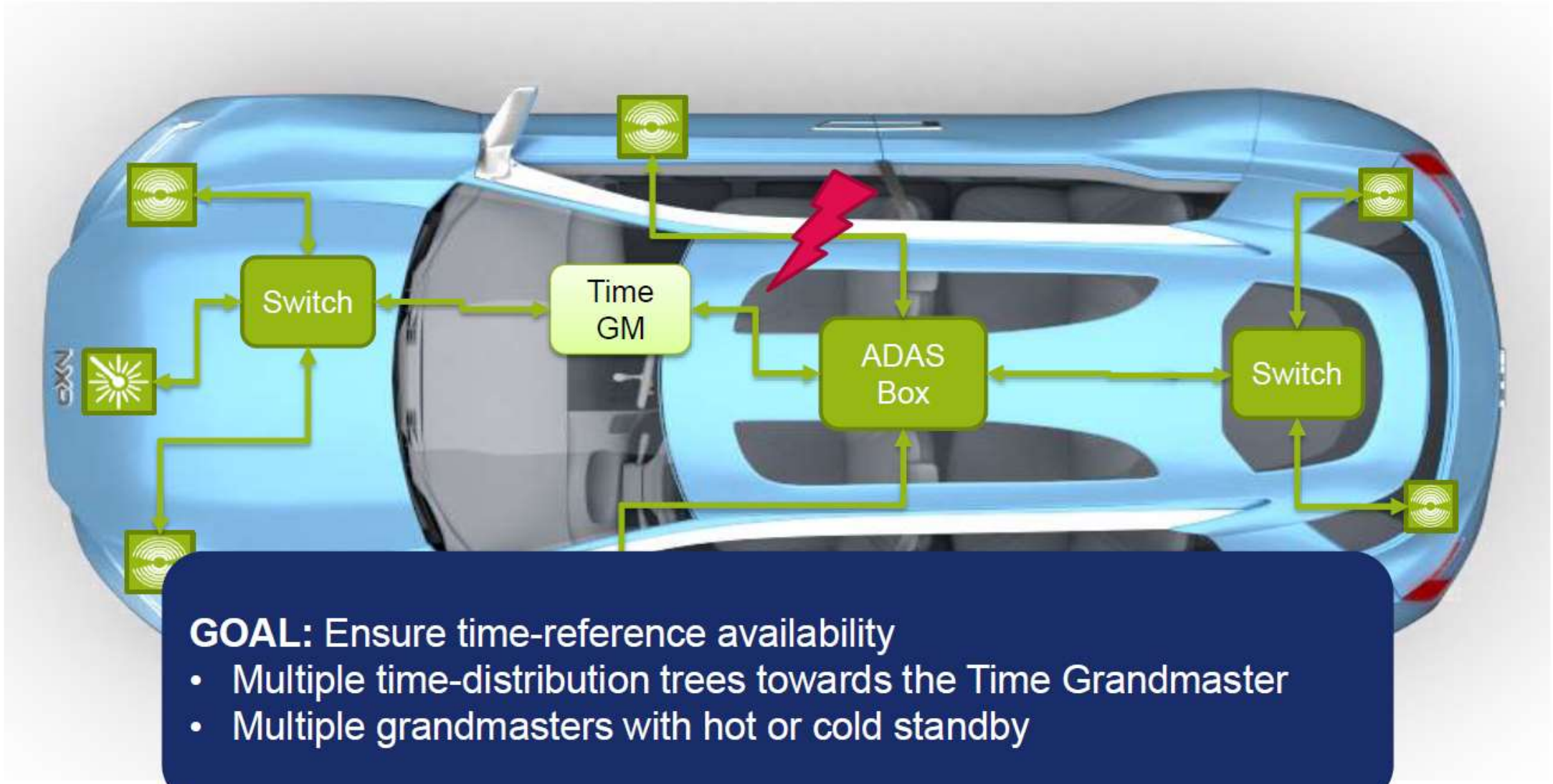
Pros

- Provides a proven and standardized way to implement distributed synchronization
- It relatively simple

Cons

- Requires SW and HW support (now quite common anyhow)
- Requires a specific automotive profile
- Is not designed to be resilient to faults especially of the time grand master

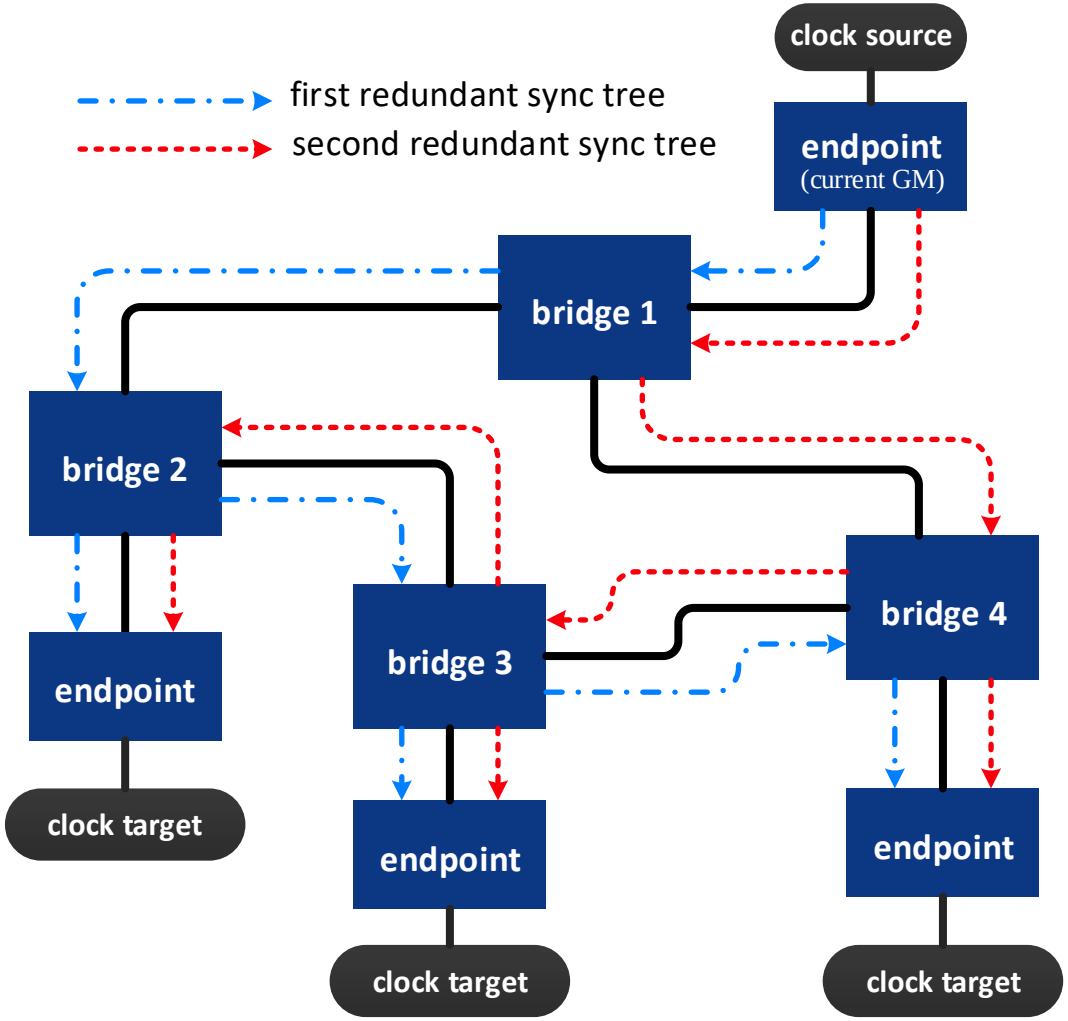
802.1AS-REV: Synchronization for Control Applications



GOAL: Ensure time-reference availability

- Multiple time-distribution trees towards the Time Grandmaster
- Multiple grandmasters with hot or cold standby

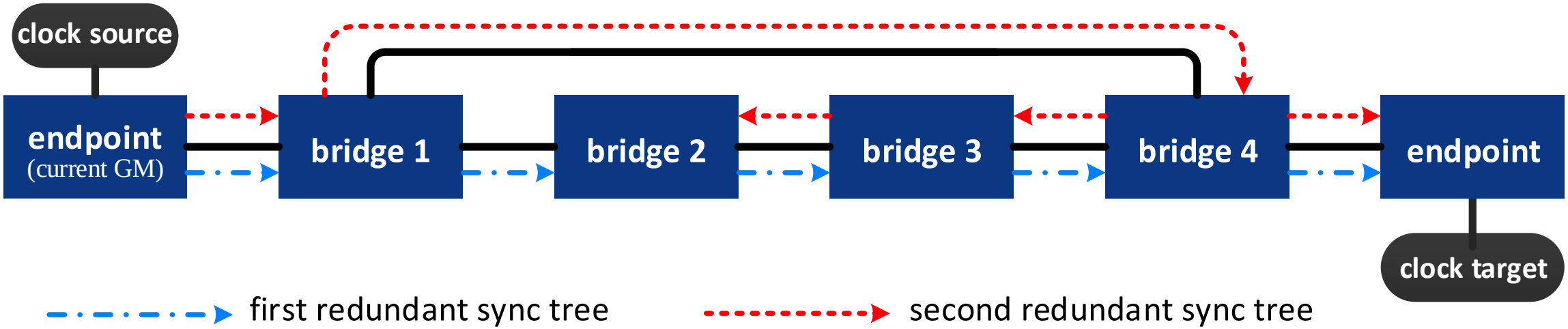
How It Works – 802.1AS-Rev Reliable Time Synchronization



From Figure 7-4, AS-Rev draft 7.0

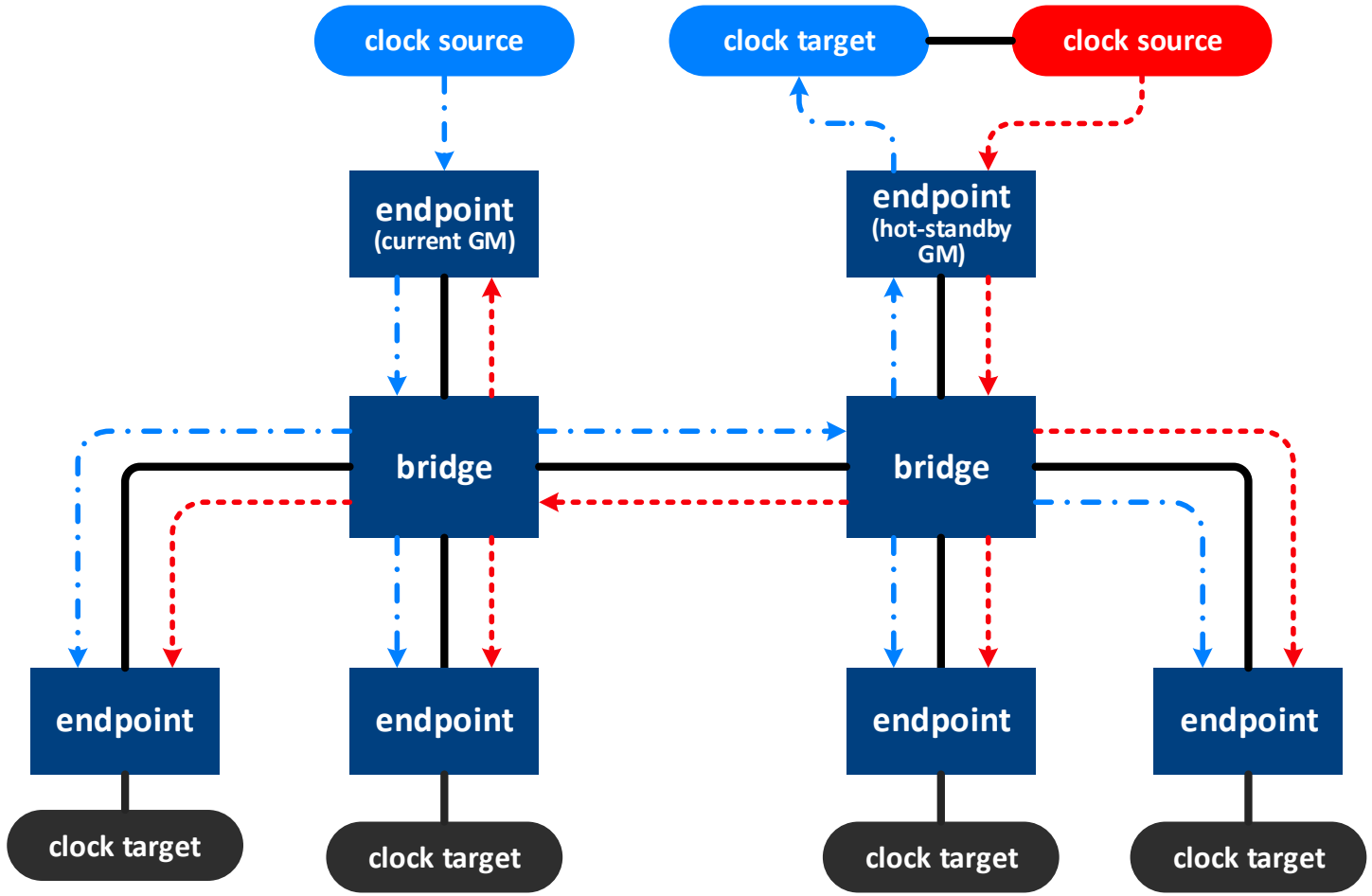
- Previous network is now a ring
- The bridges are connected into a ring with one new link between bridge 1 & bridge 4
- Multiple sync tree paths now connect the clock source to the destinations
  - Redundant paths need to be defined
  - Domain numbers in PTP msg separate sync trees
- Endpoints merge 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 connection!
- Only one Pdelay is done per link (not per domain)
- All other calculations are the same but done per domain per sync tree

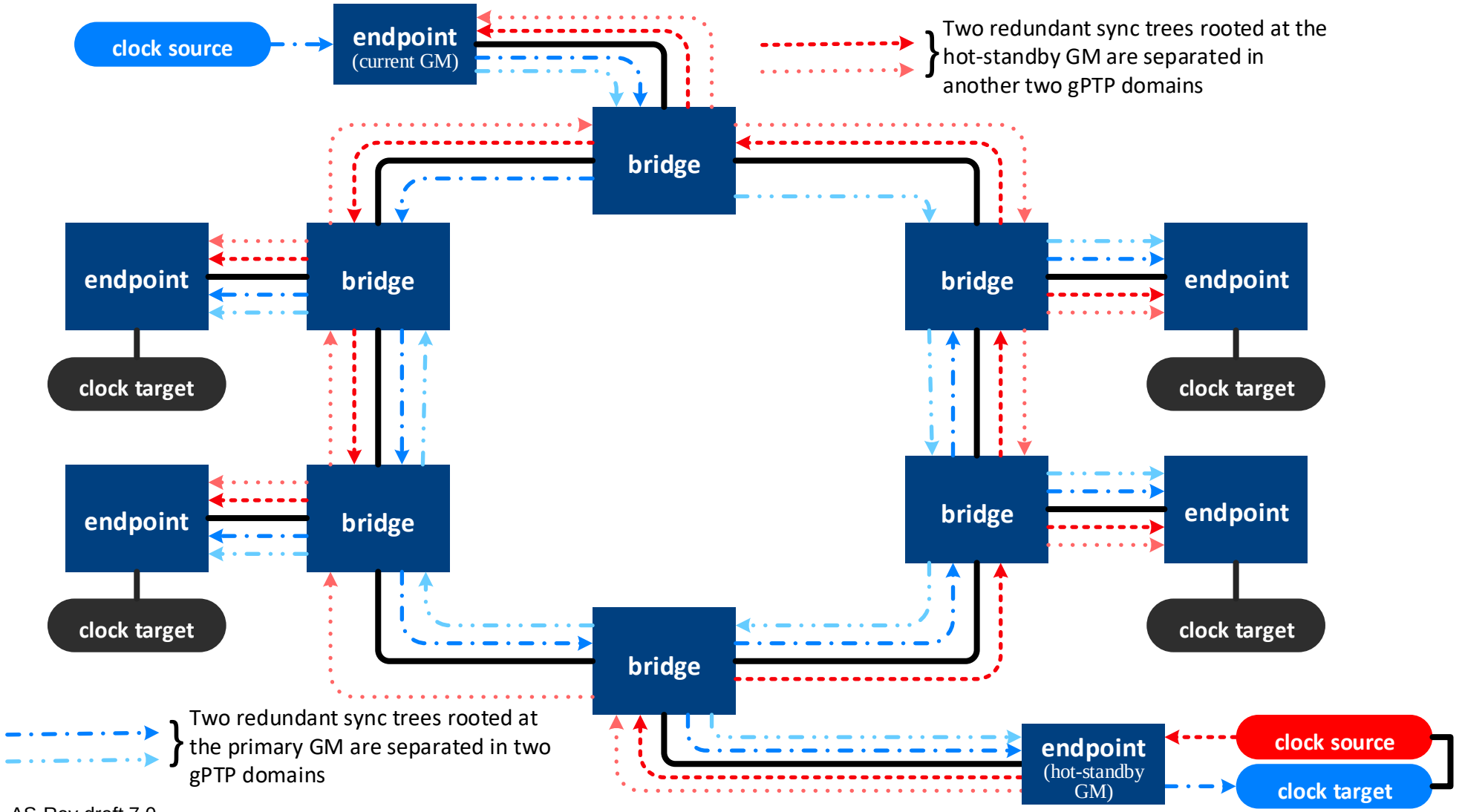
How It Works – AS-Rev Redundant Grand Masters



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

Summarizing 802.1AS

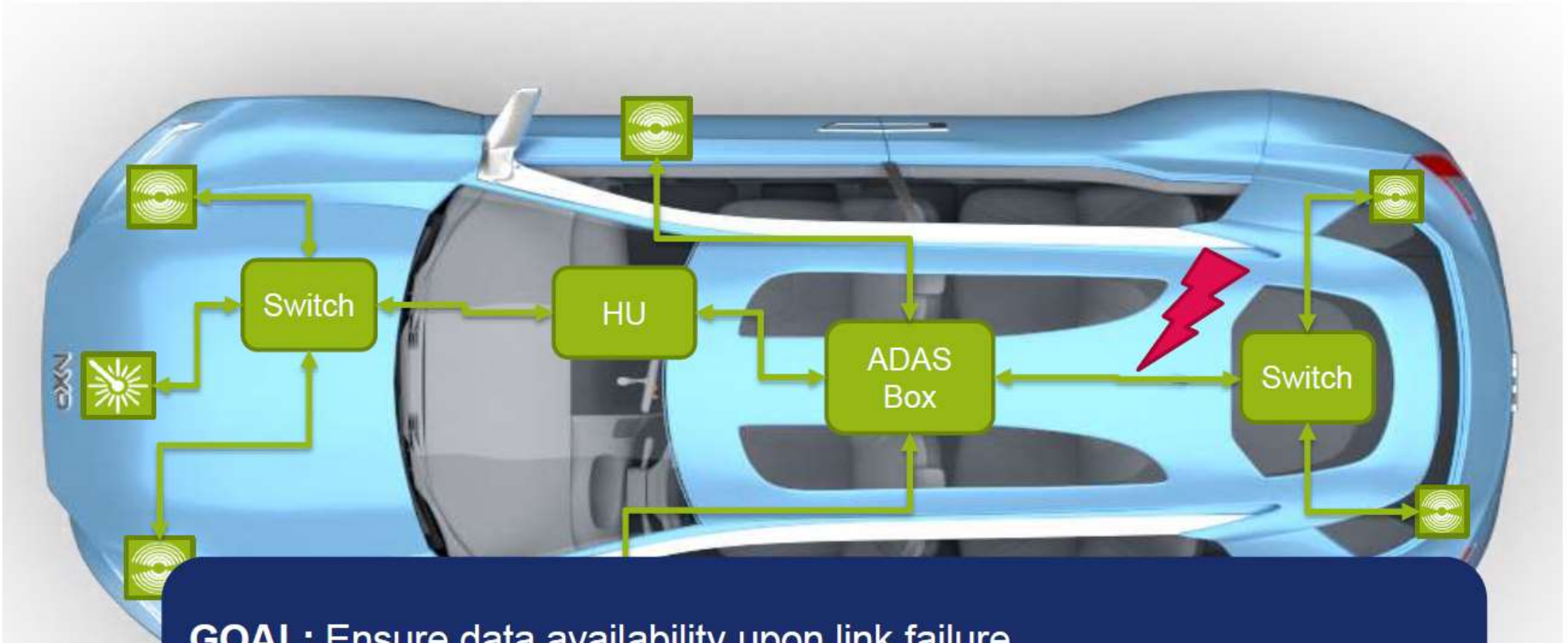
Pros

- Provides a proven and standardized way to implement distributed synchronization
- It relatively simple

Cons

- Requires SW and HW support (now quite common anyhow)
- Requires a specific automotive profile
- Is not designed to be resilient to faults especially of the time grand master

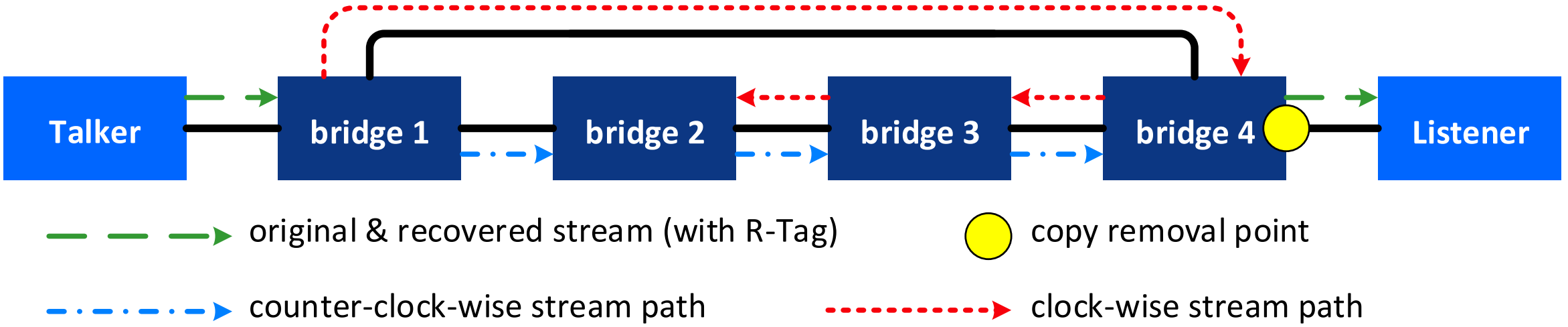
802.1CB Seamless Redundancy



GOAL: Ensure data availability upon link failure

- Send multiple copies of the same data across redundant disjoint paths
- Remove redundant copies without controller support

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

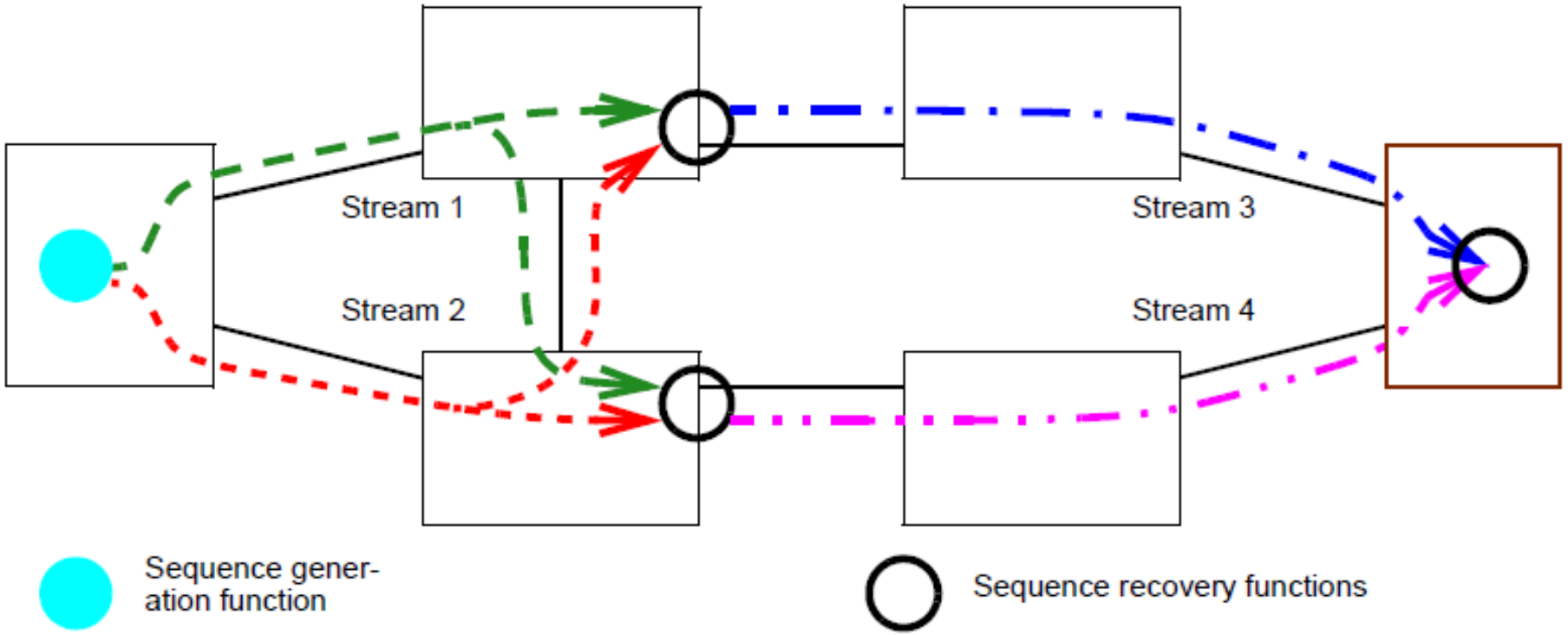


Figure 7-1—Compound Stream built from four Member Streams

From 802.1CB-2017

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

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 connection (link) is needed per ring or ladder rung
  - The same connection 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 – 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

Summarizing 802.1CB

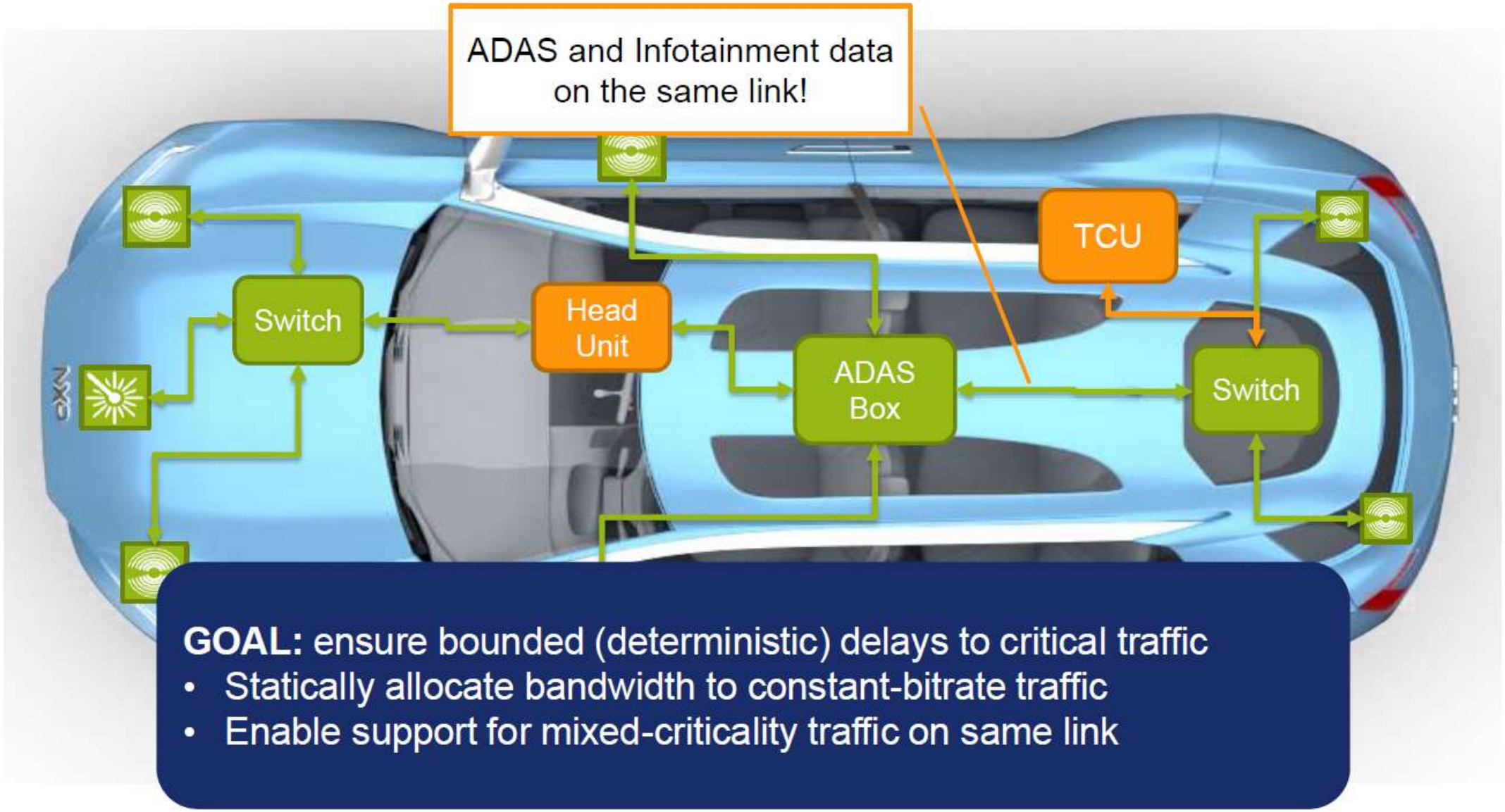
Pros

- Substantially improves the probability of correct data delivery in case of link failure
- Complexity can be fully handled by the switches, no extra HW/SW needed in the end-nodes

Cons

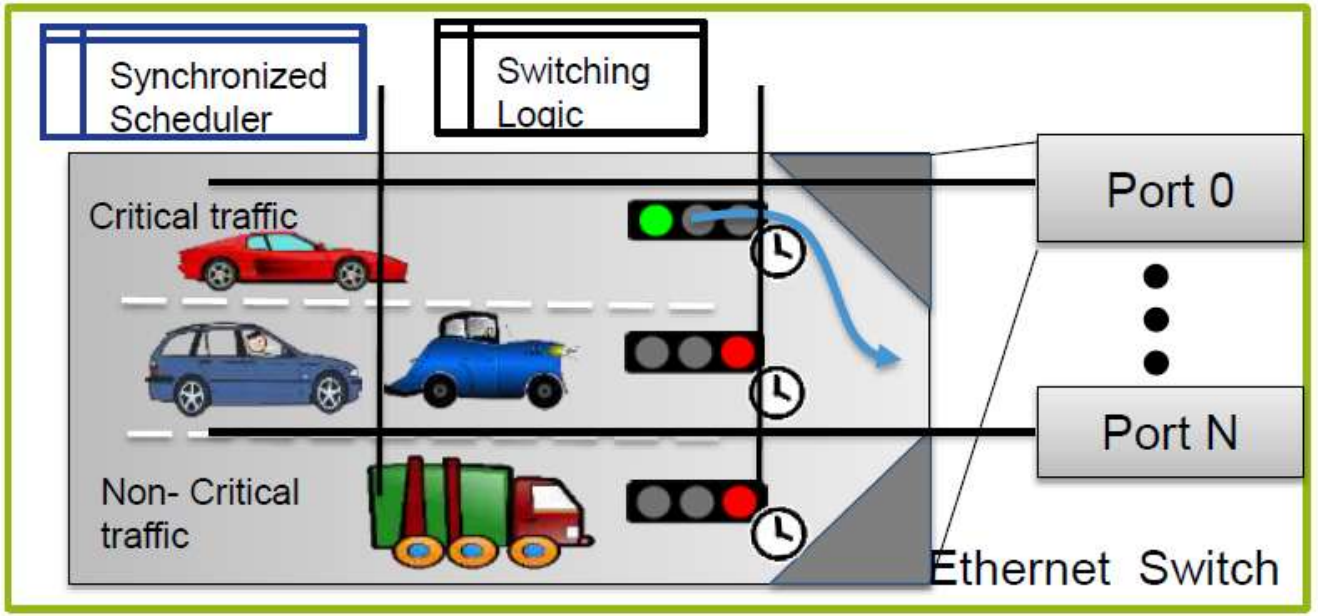
- Requires larger memory and processing power in the switches
- Requires redundant path in the network
- Increased bandwidth needed in the in-vehicle network
- Switch remains a single point of failure
- IEEE standard offers many options and features, automotive profile needed!

802.1Qbv: Enhancements for Scheduled Traffic



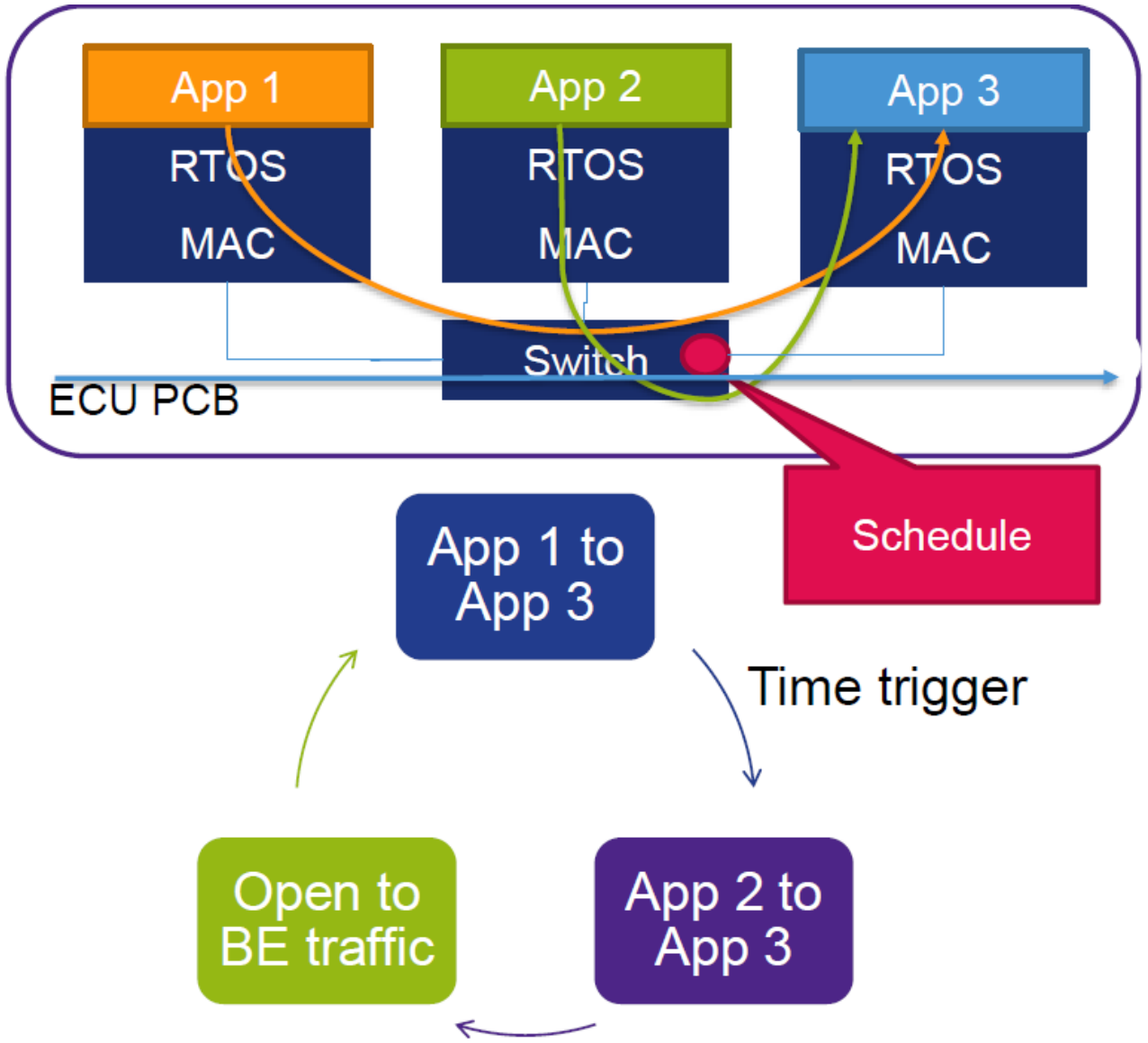
802.1Qbv: Enhancements for Scheduled Traffic

- Time Aware Shaper (TAS)
- Requires open/closing gates egress queues
- Queues are eligible for transmission depending on a time-triggered schedule
  - Based on queue/traffic class
  - In contrast to TTE, FlexRay and so on this is not on message granularity, but on queue/traffic class



802.1Qbv: Enhancements for Scheduled Traffic

- Scheduled gates enable:
  - modular design of complex ECUs
  - Simplify validation of each ECU variant
- Challenges
  - Complex system-level configuration
  - Requires synchronization between end-nodes OS and network time
  - Limited flexibility



Summarizing 802.1Qbv

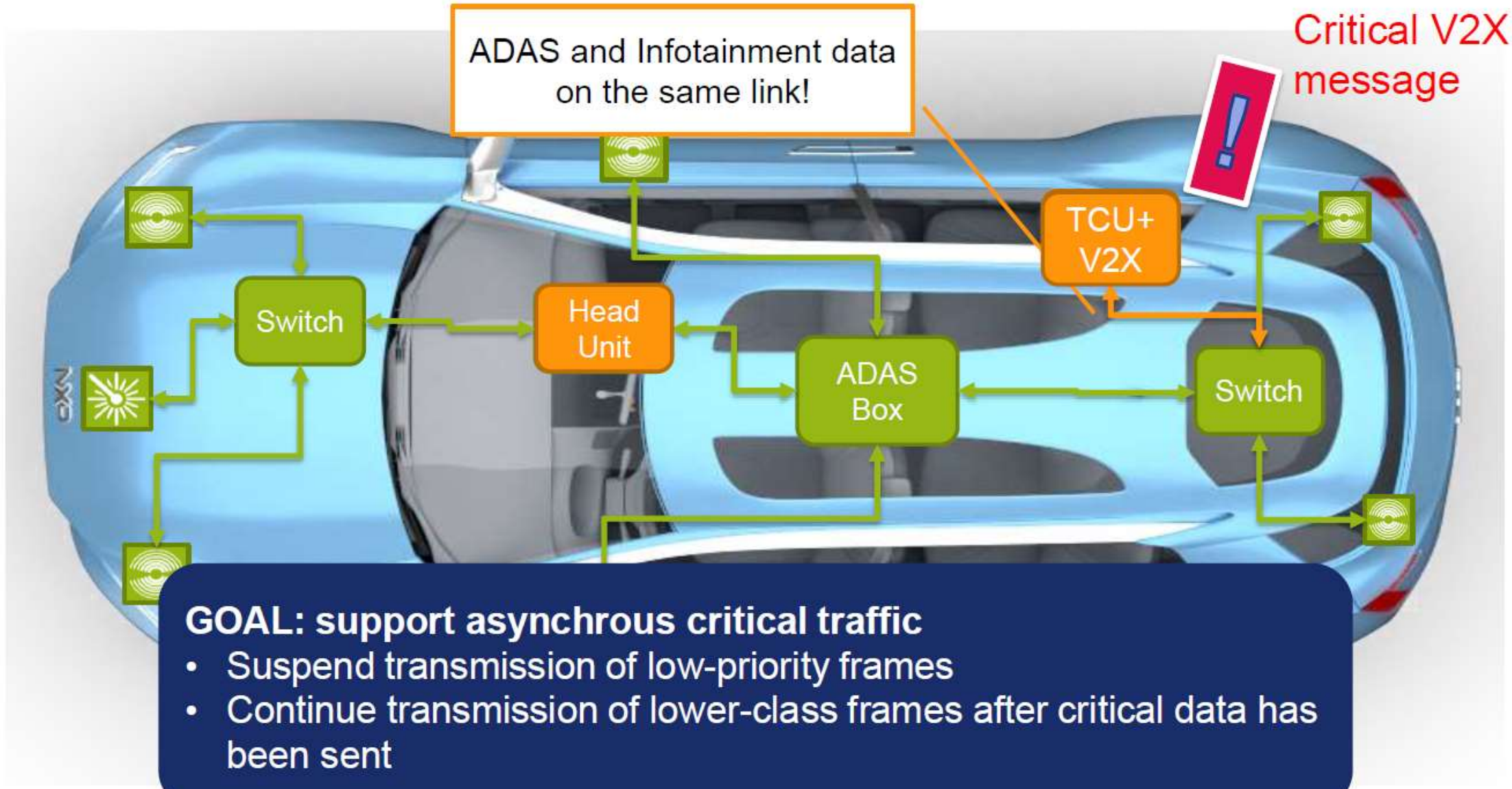
Pros

- Relies on 802.1AS (or similar) synchronization system which is already available
- Enables mixing critical and non critical traffic
- Simplifies modular designs of ECU (e.g. High, mid and low variant)

Cons

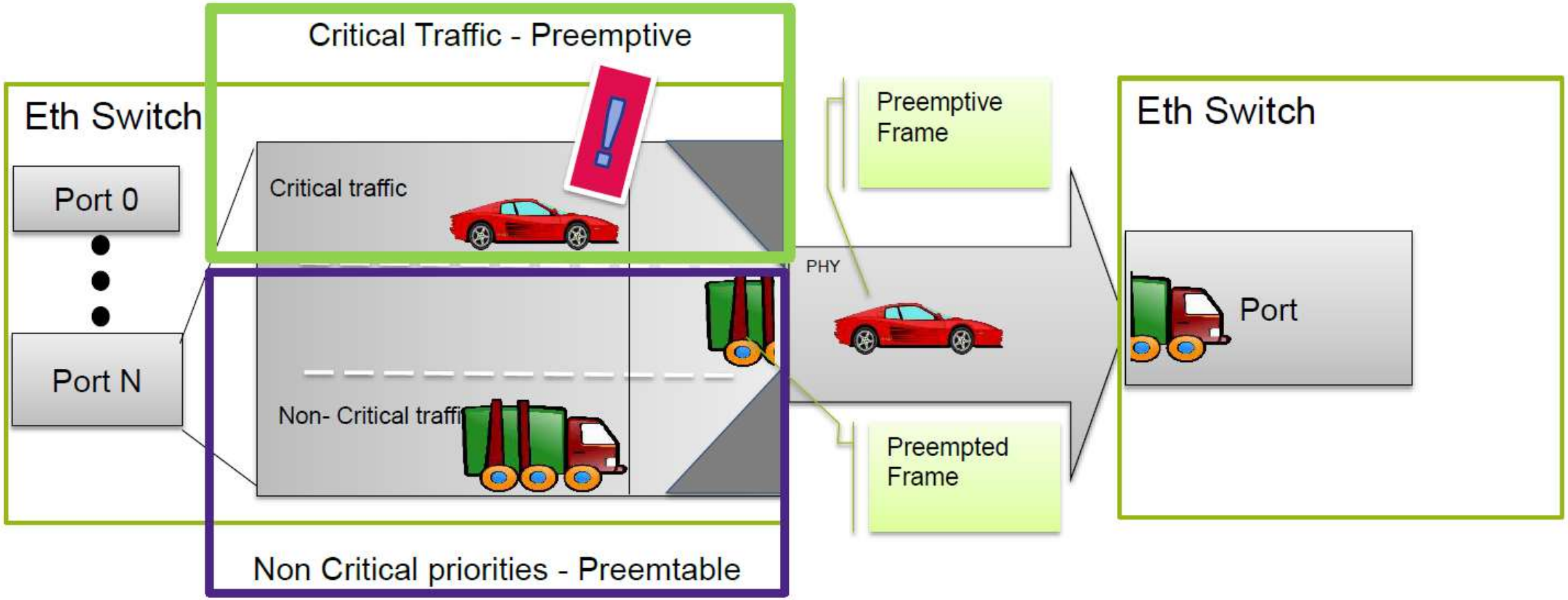
- Complex to configure and update if the network is not trivial
- Gate closure wastes bandwidth to ensure correct function
- Limited flexibility
- Requires a Real-Time OS (RTOS) to operate at full potential

802.1Qbu/802.3br: Frame Preemption



802.1Qbu: Frame Preemption

- Traffic divided into two classes: critical and non-critical
- Only non-critical frames can be preempted, only one level of preemption

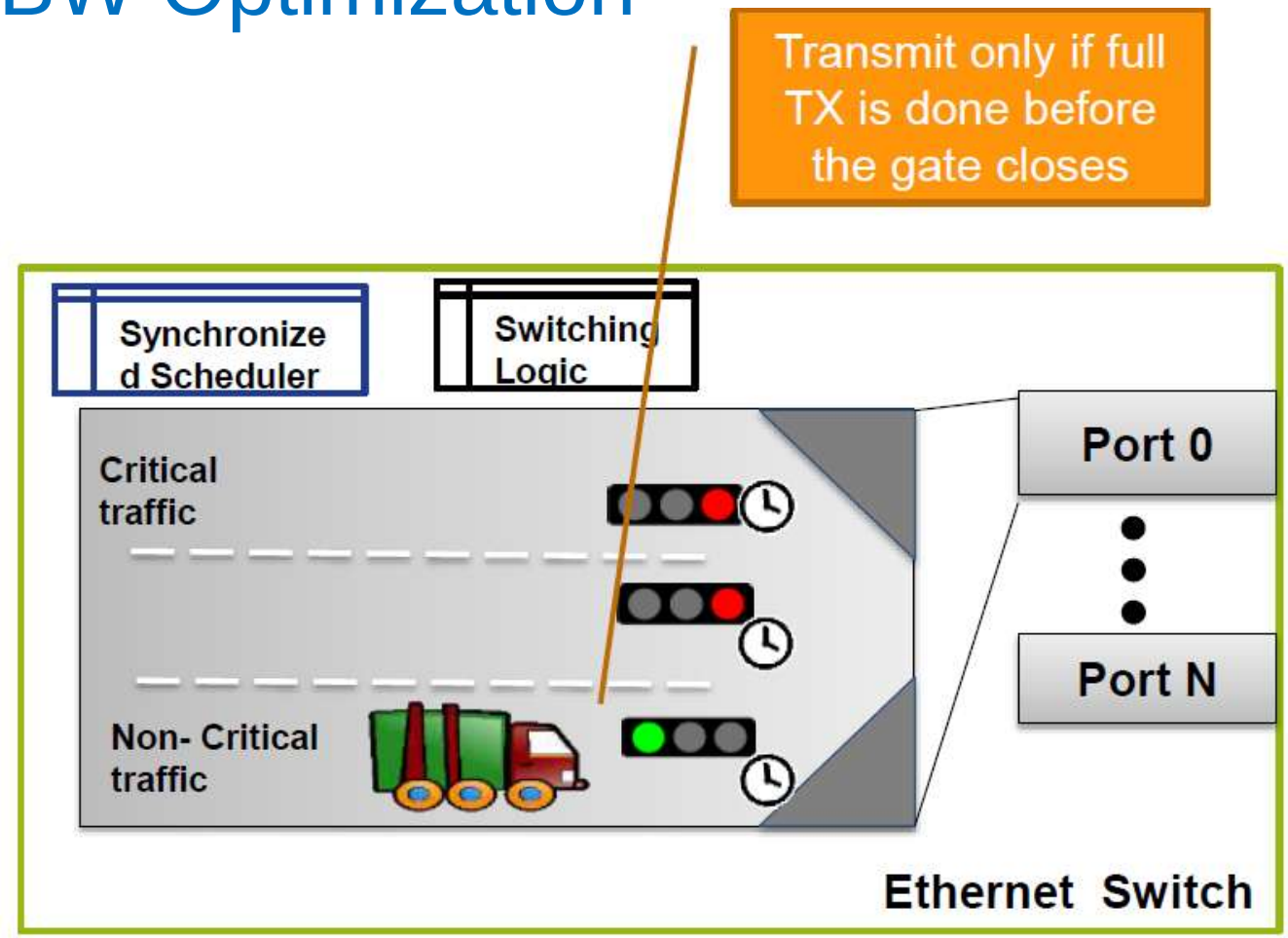


802.1Qbu: Scheduled Traffic BW Optimization

- Gates must be closed only when a PHY is ide: no frames are being transmitted
- If a gate is open, the MAC can transmit a frame only if:

$$\textit{Frame TX time} < \textit{Time to gate closusre}$$

- Time-window gap needed to avoid that a gate is closed while frame is being transmitted
- This is a waste of available BW!
- Preemption reduces this gap because now frames can be preempted to enable gate closure



Summarizing 802.1Qbu

Pros

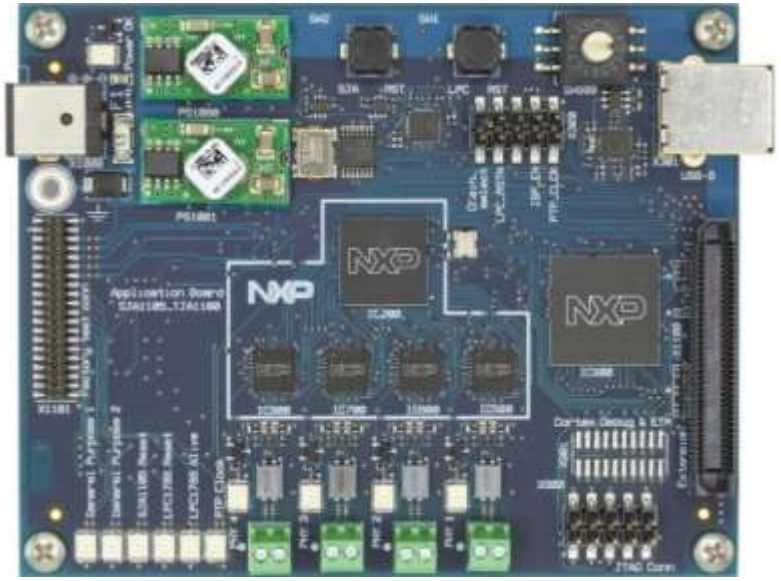
- Reduces network delay of critical traffic in case of exceptional asynchronous events
- Reduces the BW utilization when used with 802.1Qbv
- Simplifies the network bandwidth allocation

Cons

- Requires substantial MAC logic silicon area increase
- Requires larger memory to store preempted frames while preemption is active
- Priority class reduced to preemptive and preemptable traffic

Getting Started

SJA1105EL/TEL Ethernet Switch



Switch

- Released in 2015

Boards

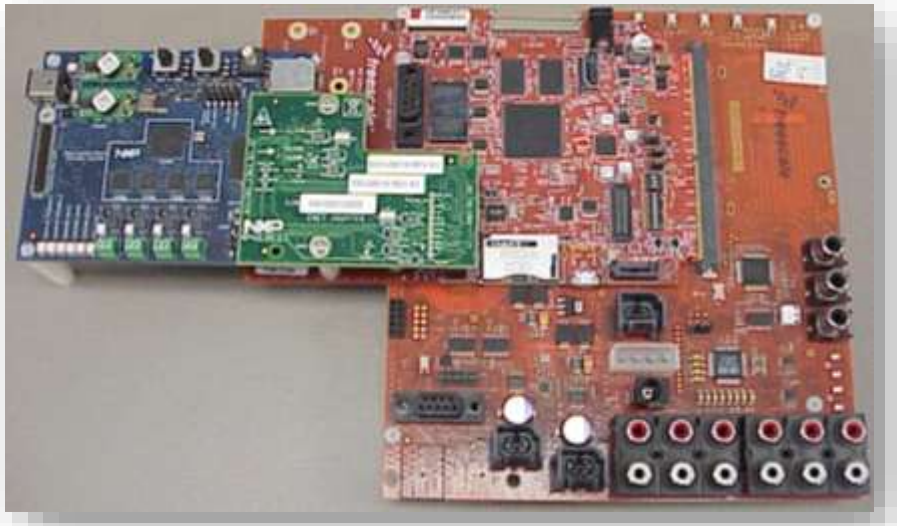
- Switch evaluation board available on NXP.com
- Extra connector board necessary to attach it to i.MX6 Sabre board (green board)
- Small physical modification of the switch board necessary to accommodate the con
  - NXP-modified boards available upon request

Drives

- Linux drivers: available free of charge but with no warranty
- AUTOSAR: drivers available via third parties

AVB SW

MCU/MPU and OS	SJA1105EL/TEL
i.MX6 / OS: Linux	Available now
i.MX8 / OS: Linux	Not planned
MPC574xGxx OS: Autosar OS	Q1 2018
S32K1x OS: Autosar OS	Available



SJA1105PEL/QEL/REL/SEL Ethernet Switch

Switch

- Released in Q4 2017

Boards

- SJA1105Q evaluation board / daughter card
  - available on NXP.com by December 2017
  - compatible with iMX6/8 EVBs and S32K EVB
  - Can run as stand-alone and daughter card for processor board

Drives

- Linux drivers: available (in mid December) free of charge but with no warranty
- AUTOSAR: NXP original AUTOSAR drivers available with license

AVB SW

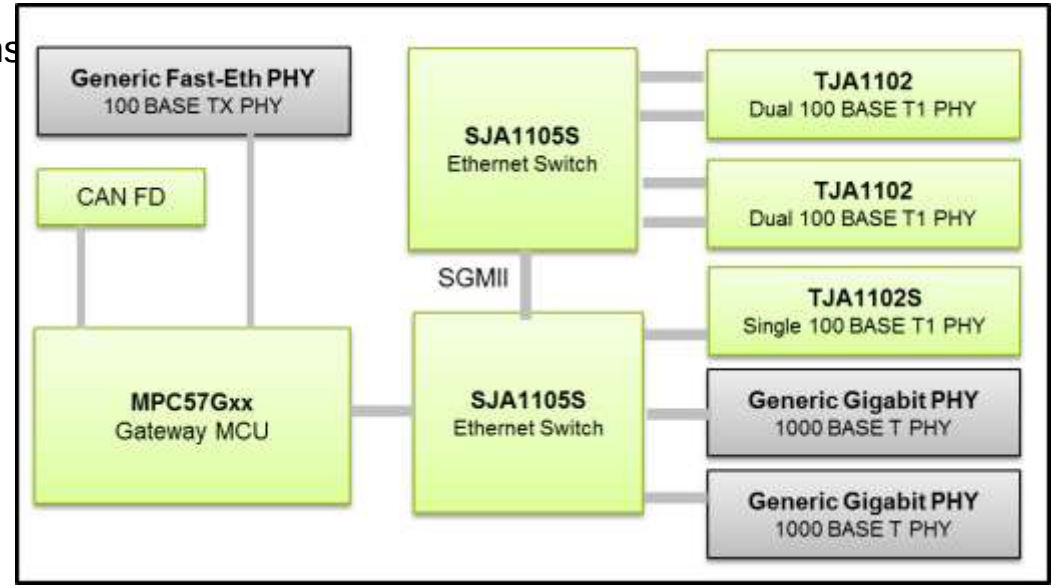
	SJA1105P/Q/R/S
i.MX6 / OS: Linux	Q1 2018
i.MX8 / OS: Linux	Q1 2018
MPC574xGxx OS: Autosar OS	tbc
S32K1x OS: Autosar OS	tbc

NXP Ethernet Gateway Prototyping Platform

- Gateway system solution for fast SW prototyping
- OPEN alliance TC10 Wake-Concept system evaluation
- Ethernet subsystem reference design
- All HW components are in production

NXP COMPONENTS

- SJA1105SEL Automotive Ethernet switch
- TJA1102HN Dual IEEE 100BASE-T1 automotive Ethernet PHY
- TJA1102HNS Single IEEE 100BASE-T1 automotive Ethernet PHY
- MCP5748Gxx Multi-core 32-bit MCU for automotive gateway and body applications
- TJA1145 CAN-FD transceiver



SOFTWARE

- Compatible with NXP production-grade AUTOSAR 4.3 Ethernet Switch & PHY drivers
- Compatible with NXP AVB SW (available Q2 2018)
- Compatible with NXP Design Studio IDE

Available in Q2 2018

www.nxp.com/AutomotiveEthernet

Summary

Summary

- TSN is a large set of standards focusing control application over Ethernet
- While their application in industrial domain is certain, automotive domain is still unclear
- AVnu is the key alliance where specific automotive profiles will be defined
- The NXP SJA1105TEL is already in production and offers support for the full AVB spec and TSN/802.1Qbv

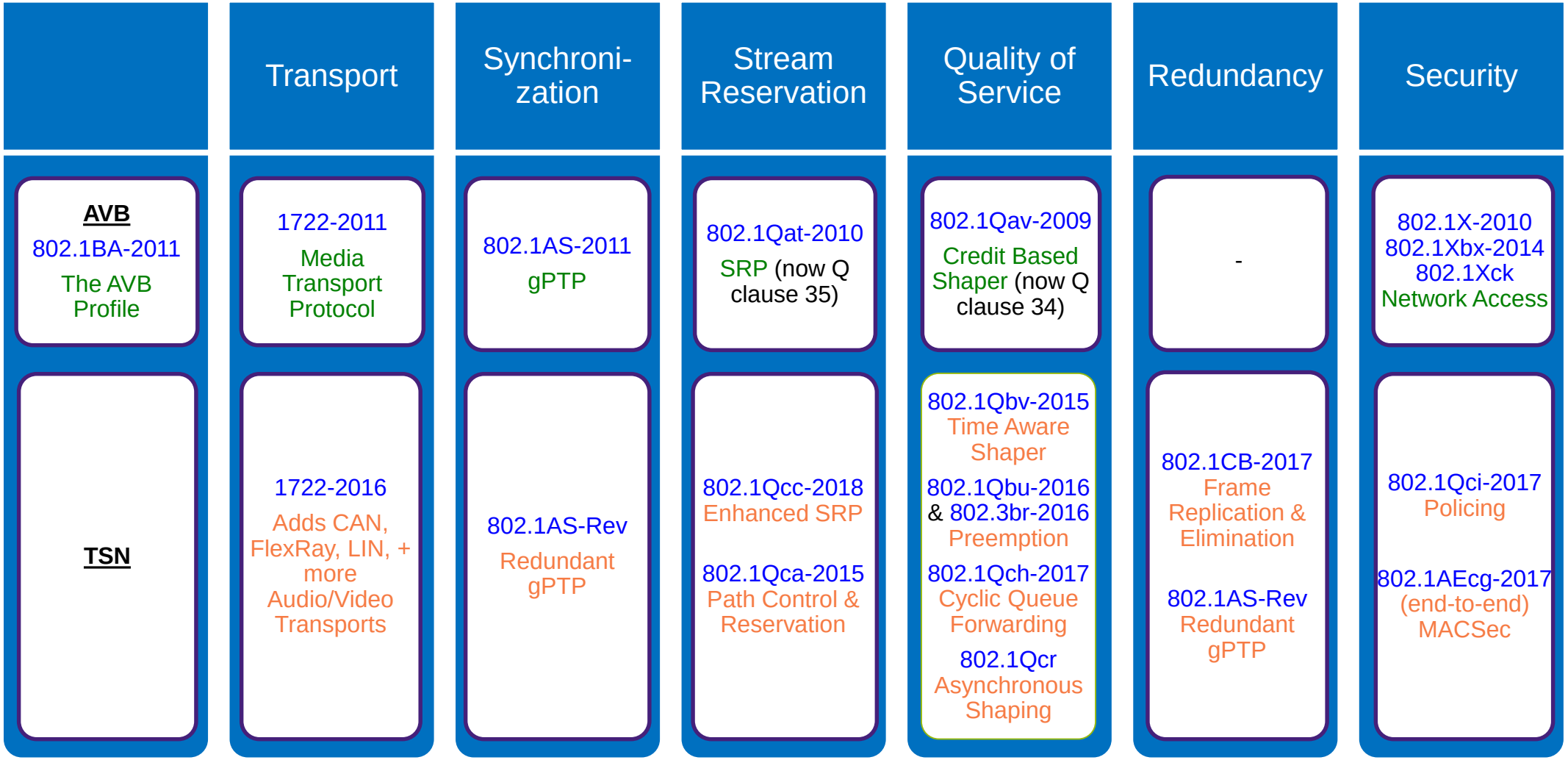
IEEE 802.3 Automotive Ethernet PHY Standards Handout

	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



Standards without an appended year are not completed yet.

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