Time-Sensitive Networking Standardization

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Agenda

- What is Time-Sensitive Networking (TSN)?
- What has been accomplished recently?
- What is next?

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Demystifying TSN

- **What is TSN?**
- **Essentially, TSN is VLAN bridging [802.1Q]**
  - TSN is the newest part of VLAN* bridging
- **No MUST in the TSN toolbox**
  - Case-by-case TSN tool(s) (icing on the cake)
  - Best to refer to the specific TSN tool(s)
  - For instance, strict priority with proper Traffic Engineering (TE) is TSN, see, e.g., 802.1CM
- **To address some common misunderstandings:**
  - TSN ≠ time synchronization
  - TSN ≠ Time Aware Shaper (TAS) [802.1Qbv]
  - TSN ≠ new bridging

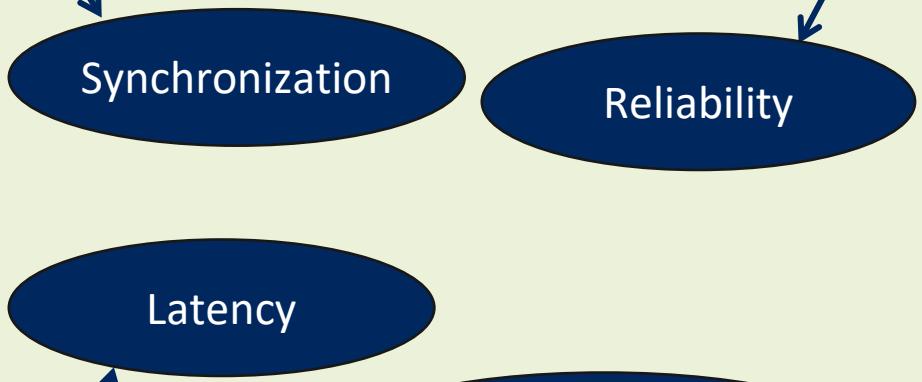
The *icing*/*crème* *is* on top of the cake, *not on its own*!

*VLAN: Virtual Local Area Network

Time-Sensitive Networking (TSN) Profiles (Selection and Use of TSN tools)

Audio Video Bridging [802.1BA]	Fronthaul [802.1CM/de]	Industrial Automation [IEC/IEEE 60802]	Automotive In-Vehicle [802.1DG]	Aerospace Onboard [IEEE 802.1DP / SAE AS6675]

TSN Components
(Tools of the TSN toolset)



Time synchronization:
Timing and Synchronization [802.1AS-2020]
(a profile of IEEE 1588)
Hot Standby [802.1ASdm]
YANG [802.1ASdn]
Inclusive Terminology [802.1ASdr]
Support for half-duplex [P802.1ASds]
Optional Announce [P802.1ASeb]
Fault-Tolerant Timing [P802.1ASed]

High availability / Ultra reliability:
Frame Replication and Elimination [802.1CB]
Sequence Recovery Configuration [P802.1CBec]
Path Control and Reservation [802.1Qca]
Per-Stream Filtering and Policing [802.1Qci]

Bounded low latency:
Credit Based Shaper [802.1Qav]
Frame Preemption [802.1Qbu & 802.3br]
Scheduled Traffic [802.1Qbv]
Cyclic Queuing and Forwarding [802.1Qch]
Asynchronous Traffic Shaping [802.1Qcr]
Shaper Parameter Settings [P802.1Qdq]
Enhancements to CQF [P802.1Qdv]
QoS Provisions [802.1DC]
Cut-Through Forwarding [P802.1DU]

Zero congestion loss = Bounded latency

Dedicated resources & API:
Stream Reservation Protocol [802.1Qat]
Link-local Registration Protocol [802.1CS]
TSN Configuration [802.1Qcc]
TSN Configuration Enhancements [802.1Qdj]
Traffic Engineering for Wireless [P802.1Qee]
Foundational Bridge YANG [802.1Qcp]
YANG for CFM [802.1Qcx]
YANG for 802.1Qbv/Qbu/Qci [802.1Qcw]
YANG for CBS [802.1Qdx]
YANG for MSTP [802.1Qdy]
YANG for LLDP [802.1ABcu]
YANG for LAG [802.1AXdz]
YANG & MIB for FRER [802.1CBcv]
Extended Stream Identification [802.1CBdb]
LLDPv2 for Multiframe Data Units [802.1ABdh]
Resource Allocation Protocol [P802.1DD]

Note: A ‘P’ in front of ‘802.1’ indicates an ongoing Project.

more on TSN standards and ongoing projects at: https://www.ieee802.org/1/tsn

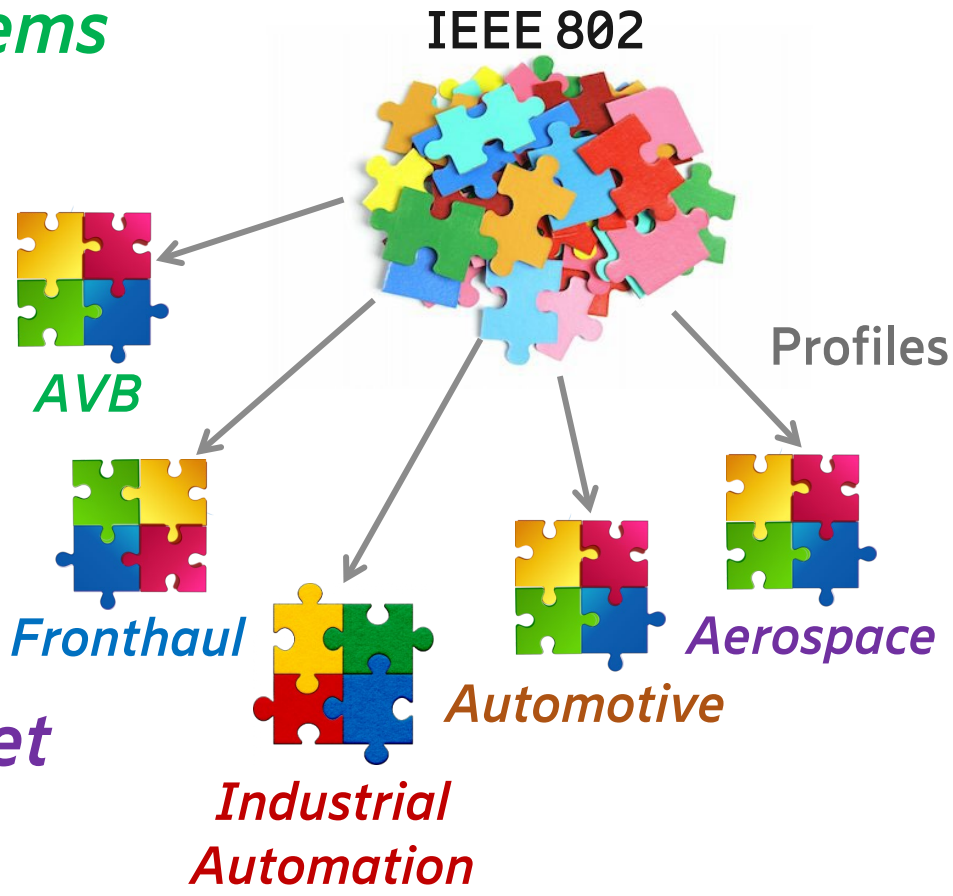
Base Standards

- 802: Overview and Architecture
- 802.1Q: Bridges and Bridged Networks
- 802.1AB: Station and Media Access Control Connectivity Discovery (Link Layer Discovery Protocol (LLDP))
- 802.1AC: MAC Service Definition
- 802.1AS: Timing and Synchronization for Time-Sensitive Applications
- 802.1AX: Link Aggregation (LAG)
- 802.1CB: Frame Replication and Elimination for Reliability (FRER)
- 802.1CS: Link-local Registration Protocol (LRP)

Profile Specifications

Select features, options, defaults to ease interoperability and deployment

- 802.1BA: *Audio-Video Bridging (AVB) Systems*
- 802.1CM: *TSN for Fronthaul*
- IEC/IEEE 60802:
  TSN Profile for Industrial Automation
- 802.1DG: *TSN Profile for Automotive In-Vehicle Ethernet Communications*
- IEEE 802.1DP / SAE AS6675:
  TSN Profile for Aerospace onboard Ethernet



IEEE SA Emerging Technology Award

- The IEEE 802.1 Working Group was awarded the 2020 IEEE SA Emerging Technology Award — *for the development of IEEE Std 802.1CM™-2018* ***Time-Sensitive Networking for Fronthaul*** *as amended by IEEE Std 802.1CMde™-2020, the first IEEE standard to connect a cellular network's radio equipment to its remote controller via a packet network, in particular, over a bridged IEEE 802.3™ Ethernet network.*

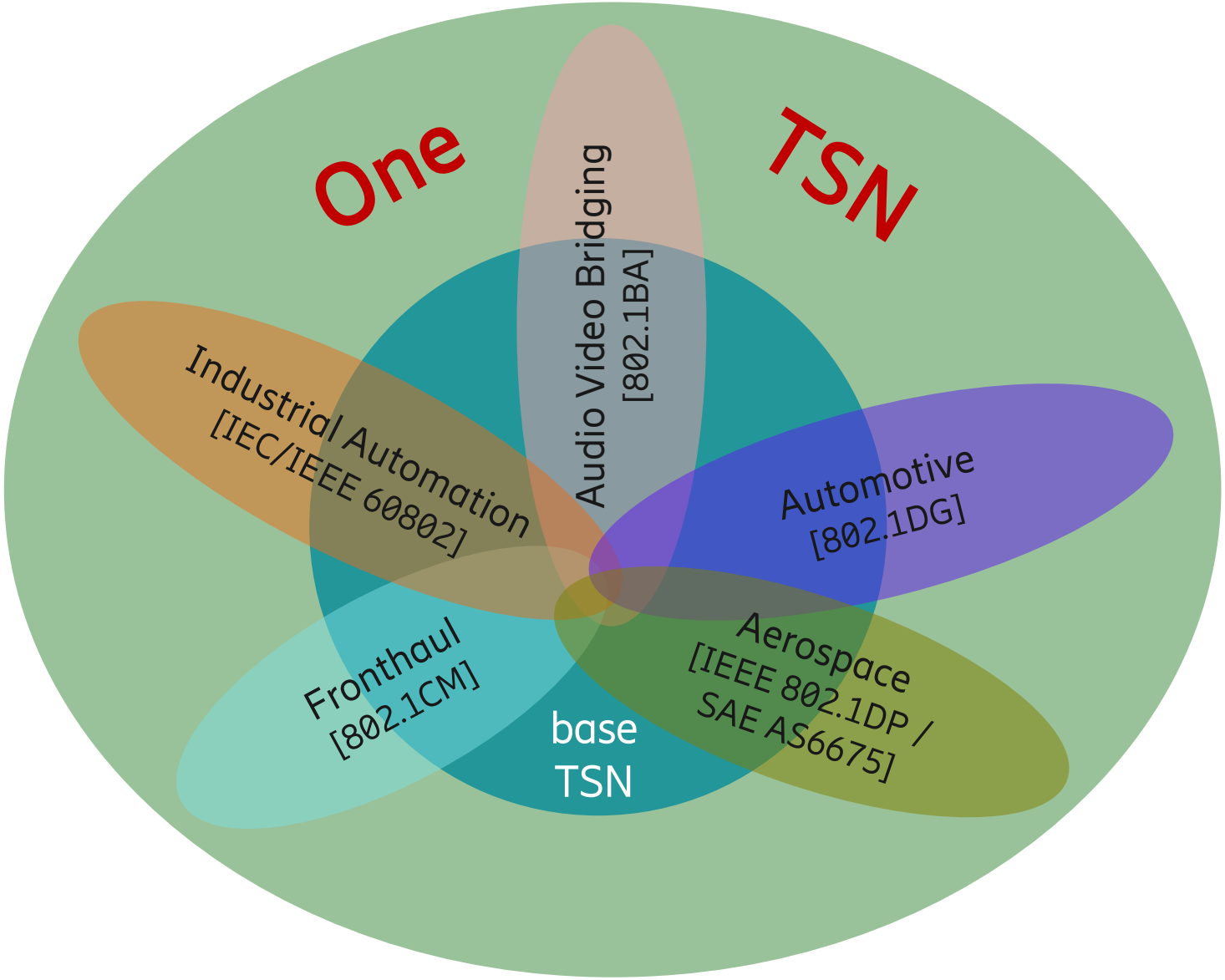
- IEEE SA blogpost: https://standards.ieee.org/beyond-standards/how-time-sensitive-networking-benefits-fronthaul-transport/

Benefits of Collaborative Efforts for Profiles

There Is Only One Common TSN

- **The very same One TSN for all Profiles!**
- **As unified as possible**

- Common:
  - Silicon
  - Bridges
  - Infrastructure



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Profile Specifications Recently Done

- **Automotive – IEEE Std 802.1DG**
  "TSN Profile for Automotive In-Vehicle Ethernet Comms."
  published: 2025-06-06
- **Aerospace – IEEE 802.1DP / SAE AS6675**
  "TSN for Aerospace Onboard Ethernet Communications"
  approved draft standard, approved both by IEEE SA and SAE
- **Industrial Automation – IEC/IEEE 60802**
  "TSN Profile for Industrial Automation"
  technically done, submitted to IEEE SA RevCom & IEC final ballot
- **They provide solid grounds for test and certification efforts**
- **They set the stage for adoption and success of TSN**

TSN Profiles identified to date are DONE and READY!

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IEEE Std 802.1BA

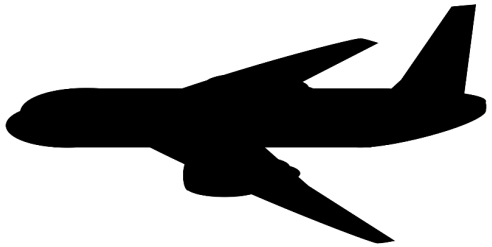
IEEE Std 802.1CM

IEC/IEEE 60802

IEEE 802.1DP / SAE AS6675

IEEE Std 802.1DG

Wide Range of Aerospace and Defense Use Cases



Commercial / Civil Aircraft

- Aircraft Control Domain Network
  small and large passenger aircraft
- Cabin Network
  large passenger aircraft

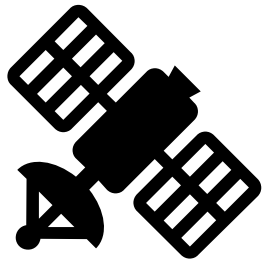
Fixed Wing Military Aircraft

- Mission Network (small, combat, large)
- Flight Network
- Fiber Channel over TSN (convergence)

Rotary Wing Military Aircraft

- Mission Network
- Flight Network

Unmanned Military Aircraft Network



Satellite

- Platform Network
- Payload Network

Ground Vehicles

- Vehicle Electronics

source: Abdul Jabbar, "*IEEE 802.1DP / SAE AS6675 Update*", 2025-09-18 (https://adtsummit.com)

TSN Enables Transition to Zonal Architecture for Aerospace

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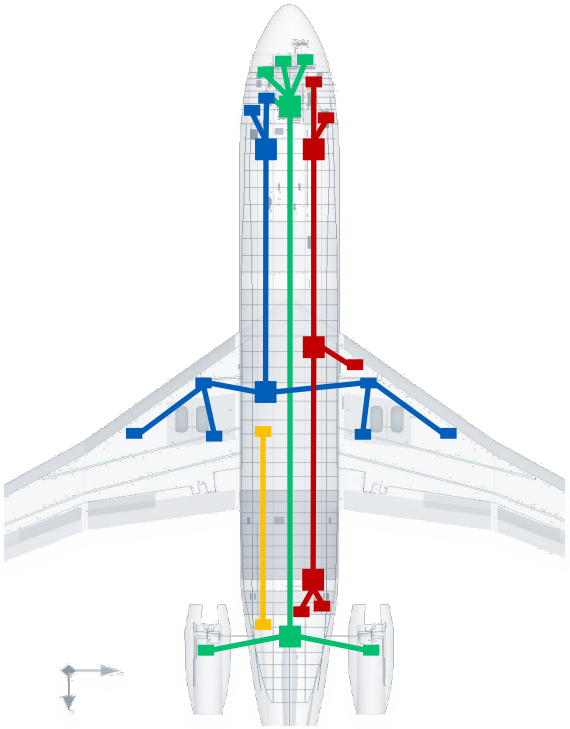
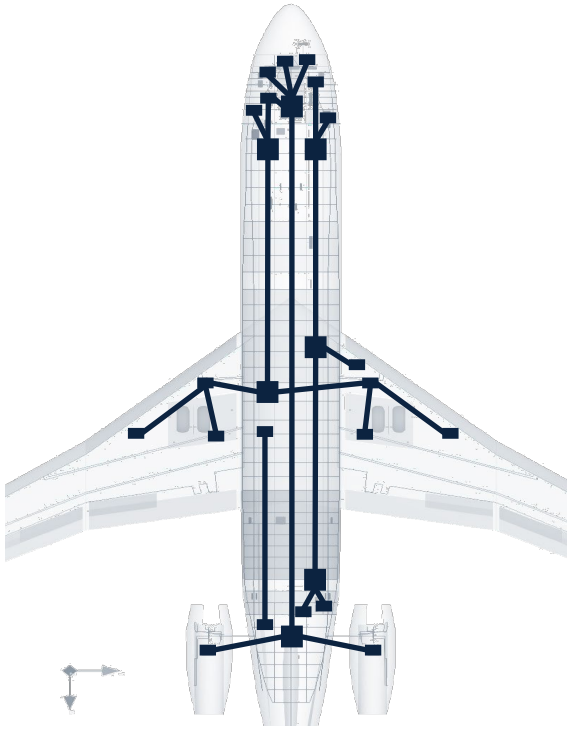
Domain-based Architecture

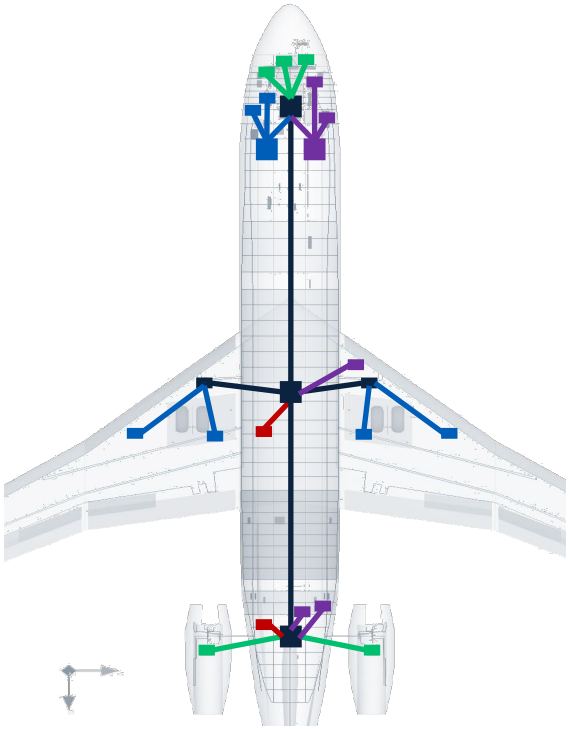


Segregated Network
Many Bus Types

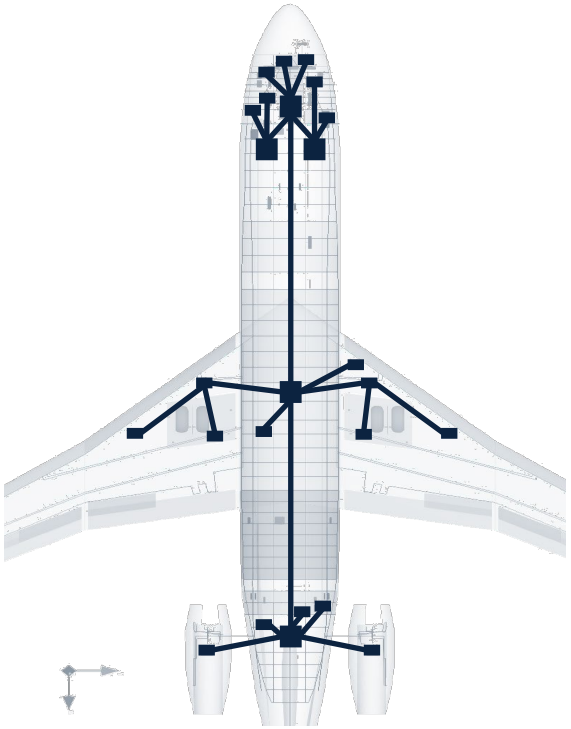


Segregated Network
Fewer Bus Types

Zonal Architecture



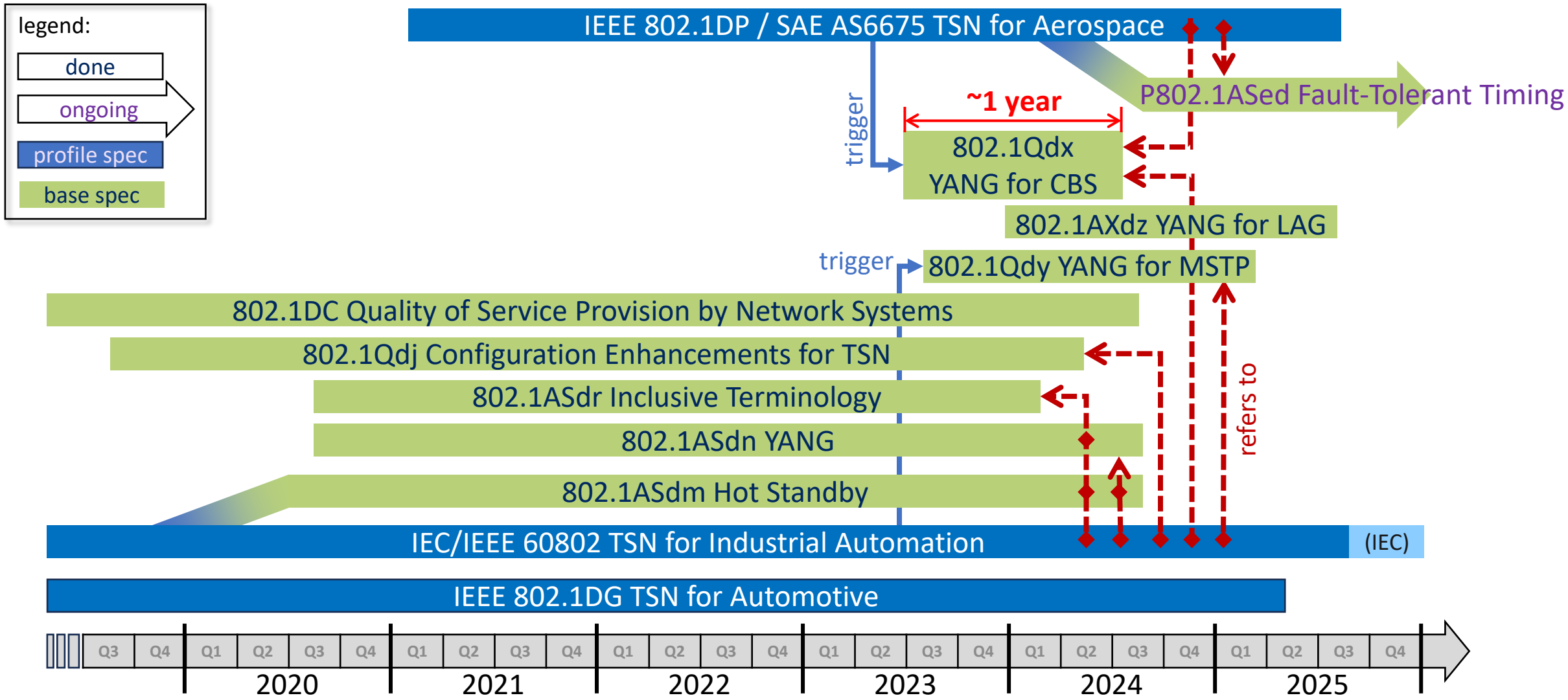
Converged Network
Many Bus Types



Converged Network
Fewer Bus Types

source: IEEE Time-Sensitive Networking Webinar Series: "*Time-Sensitive Networking for Aerospace*", 2024-09-12

Recent Developments



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Ongoing Revision Projects

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Revisions of base standards incorporate outstanding amendments

- P802.1Q-2022-Revision – *Bridges and Bridged Networks*
- P802.1AB-2016-Revision – *Station and MAC Connectivity Discovery*
- P802.1AC-2016-Revision – *MAC Service Definition*
- P802.1AS-2020-Revision – *Timing and Synchronization*
- P802.1CB-2017-Revision – *Frame Replication and Elimination for Reliability*

Security:

- P802.1X-2020-Revision – *Port-Based Network Access Control*
- P802.1AE-2018-Revision – *MAC Security*
- P802.1AR-2018-Revision – *Secure Device Identity*

Ongoing Projects

- **P802.1DD** – *Resource Allocation Protocol* (P802.1Qdd "rebranded")
- **P802.1DU** – *Cut-Through Forwarding Bridges and Bridged Networks*
- **P802.1Qdq** – *Shaper Parameter Settings for Bursty Traffic Requiring Bounded Latency*
- **P802.1Qdt** – *Priority-based Flow Control Enhancements*
- **P802.1Qdv** – *Enhancements to Cyclic Queuing and Forwarding*
- **P802.1Qdw** – *Source Flow Control*
- **P802.1Qee** – *Traffic Engineering for Bridged Networks with Wireless Technologies*
- **P802.1ASds** – *Support for the IEEE Std 802.3 Clause 4 MAC operating in half-duplex*
- **P802.1ASeb** – *Optional Announce*
- **P802.1ASed** – *Fault-Tolerant Timing with Time Integrity*
- **P802.1CBec** – *Guidance for Sequence Recovery Function Parameter Configuration*
  (being extended to be able to refine the Sequence Recovery Function)

Farther Future Work

- Some individual ideas, proposals – **No group consensus yet!**
- Industrial Automation
  - started brainstorming on next steps, some candidate topics identified
  - incl. virtualization, wireless, and potentially multiple configuration domains
  - see more, e.g., at the May Interim, July Plenary, September Interim
- Automotive
  - amending 802.1 DG with time synchronization profile
- Aerospace
  - terrestrial space and multi-orbits satellite-to-satellite communications
- See the TSN agendas for what is going on

Further Information

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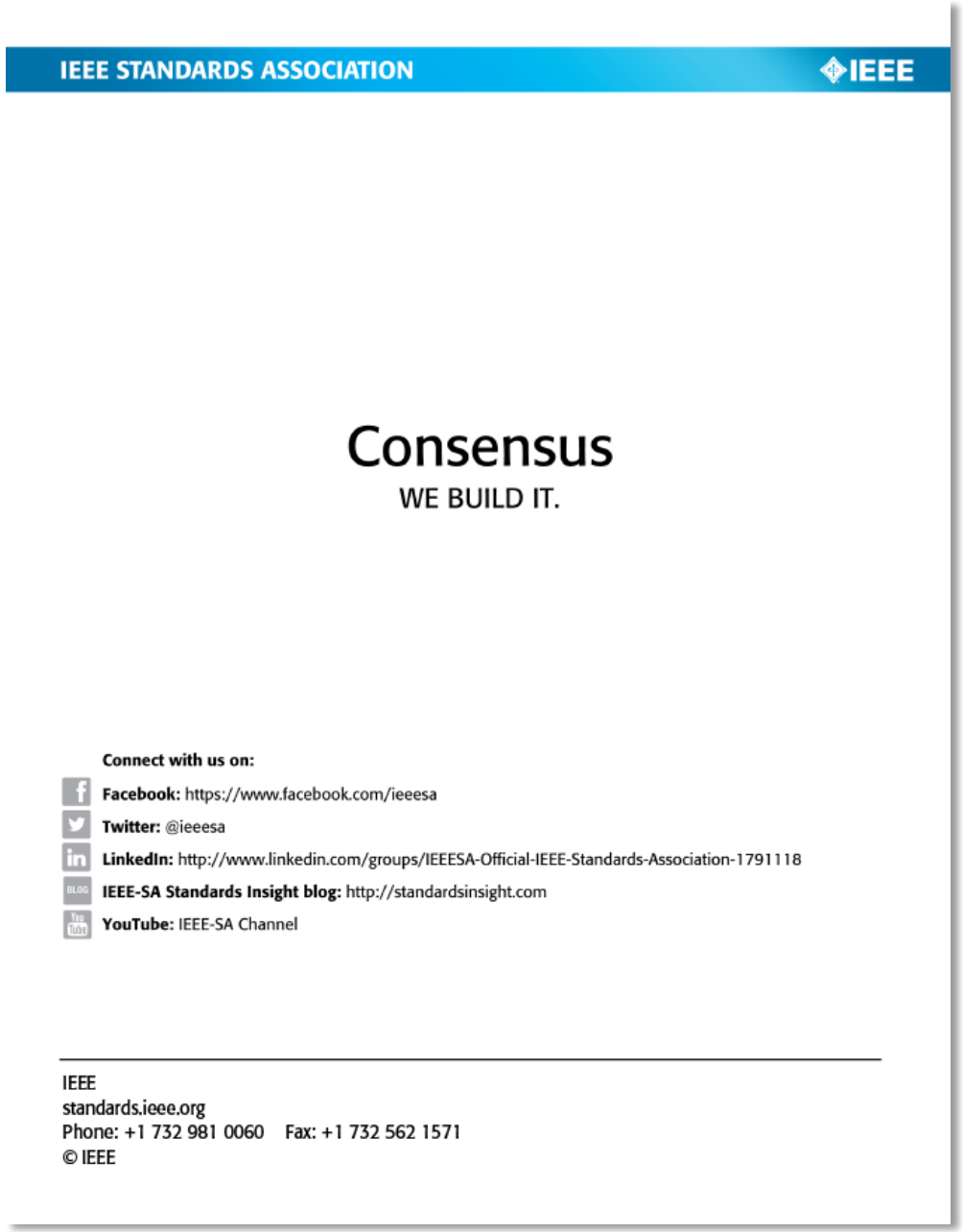
- http://www.ieee802.org/1 / https://1.ieee802.org/
- http://ieee802.org/1/tsn / https://1.ieee802.org/tsn/
- Tutorial – Time-Sensitive Networking For New Ethernet Bridging Applications https://1.ieee802.org/tutorial-tsn-for-ethernet-bridging/
- Time-Sensitive Networking Webinar Series https://engagestandards.ieee.org/TSN-Webinar-Series.html (https://1.ieee802.org/?s=webinar)
- Software Defined Networking (SDN) supported by IEEE 802.1Q

  https://www.ieee802.org/1/files/public/docs2014/Q-farkas-SDN-support-0314-v01.pdf, https://arxiv.org/abs/1405.6953
- TSN/A Conference: https://tsnaconference.de
- and more, e.g., at the end of https://www.ieee802.org/1/files/public/docs2018/detnet-tsn-farkas-tsn-overview-1118-v01.pdf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