DRIVING DIGITAL TRANSFORMATION THROUGH IEEE 802.1 TSN

IEEE TIME-SENSITIVE NETWORKING WEBINAR SERIES: AN OVERVIEW OF TIME-SENSITIVE NETWORKING

SPEAKER: JÁNOS FARKAS, PRINCIPAL RESEARCHER, ERICSSON

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2 December 2021

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SPEAKER – JÁNOS FARKAS

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Principal Researcher – Deterministic Networking, Ericsson

Dr. János Farkas is a principal researcher in the area of deterministic networking at Ericsson Research. He is active in standardization of deterministic networking technologies in packet networks, for which he received the IEEE Standards Association Medallion. He serves as the Chair of the IEEE 802.1 Time-Sensitive Networking Task Group, and as a Co-Chair of the IETF Deterministic Networking Working Group.

He holds Ph.D. and M.Sc. degrees in electrical engineering from the Budapest University of Technology and Economics, Hungary.

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TSN Time Sensitive Networking Powered by IEEE 802

DRIVING DIGITAL TRANSFORMATION THROUGH IEEE 802.1 TSN

AN OVERVIEW OF TIME-SENSITIVE NETWORKING

2 December 2021

IEEE

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Outline

FOUNDATIONAL TECHNOLOGIES

Introduction

TSN components

TSN profiles

Summary

INTRODUCTION

DIGITAL TRANSFORMATION THROUGH IEEE 802.1 TSN

FOUNDATIONAL TECHNOLOGIES

Some Use Cases (incomplete)

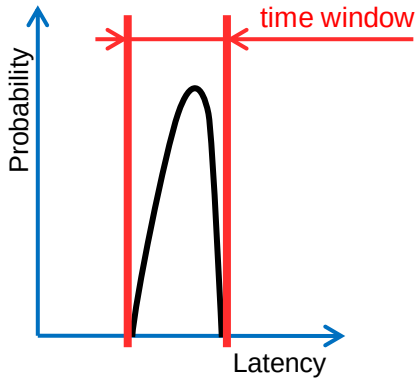
IEEE 802.1 TIME-SENSITIVE NETWORKING (TSN)

FOUNDATIONAL TECHNOLOGIES

The Right Packet at The Right Time

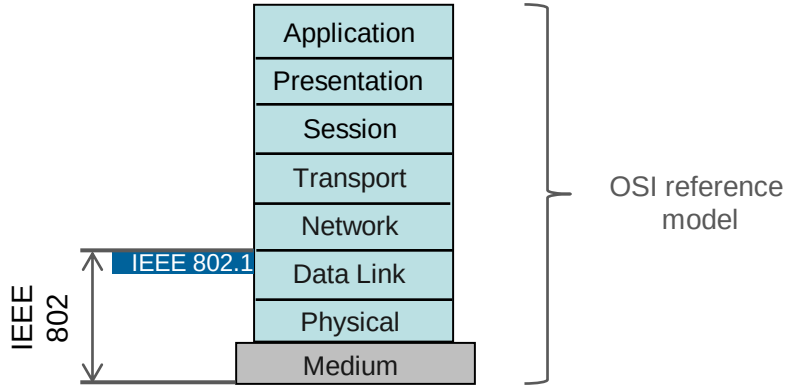
Deterministic data packet delivery

- Data packet delivery within a time window without loss or delay due to congestion or errors



TSN is a set of standards specified by IEEE 802 to provide deterministic data transfer in packet networks, e.g., in Layer 2 bridged networks

- All the benefits of open IEEE SA standards
- Standard Ethernet: IEEE Std 802.3

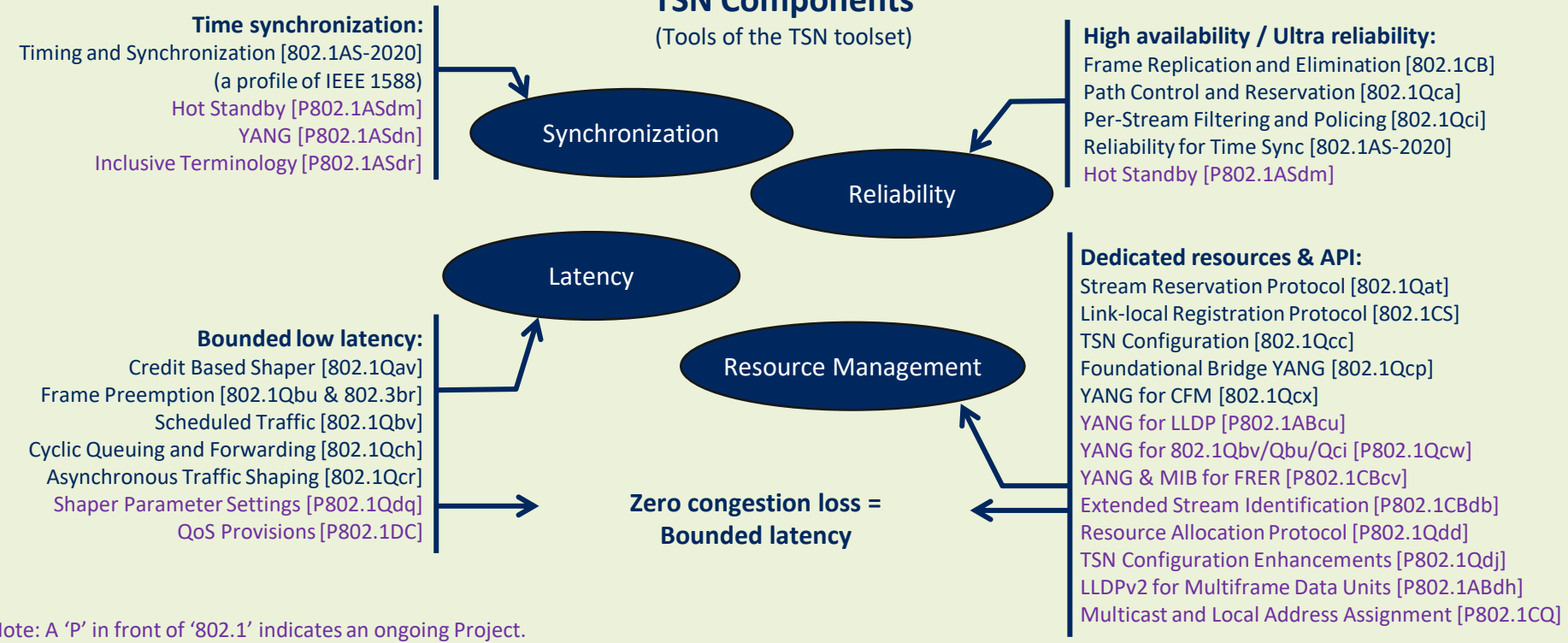


Time-Sensitive Networking (TSN) Profiles (Selection and Use of TSN tools)

Audio Video Bridging [802.1BA/Revision]	Fronthaul [802.1CM/de]	Industrial Automation [IEC/IEEE 60802]	Automotive In-Vehicle [P802.1DG]	Service Provider [P802.1DF]	Aerospace Onboard [IEEE P802.1DP / SAE AS6675]

TSN Components

(Tools of the TSN toolset)



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

TSN PROFILES

An IEEE 802.1 TSN Profile specification

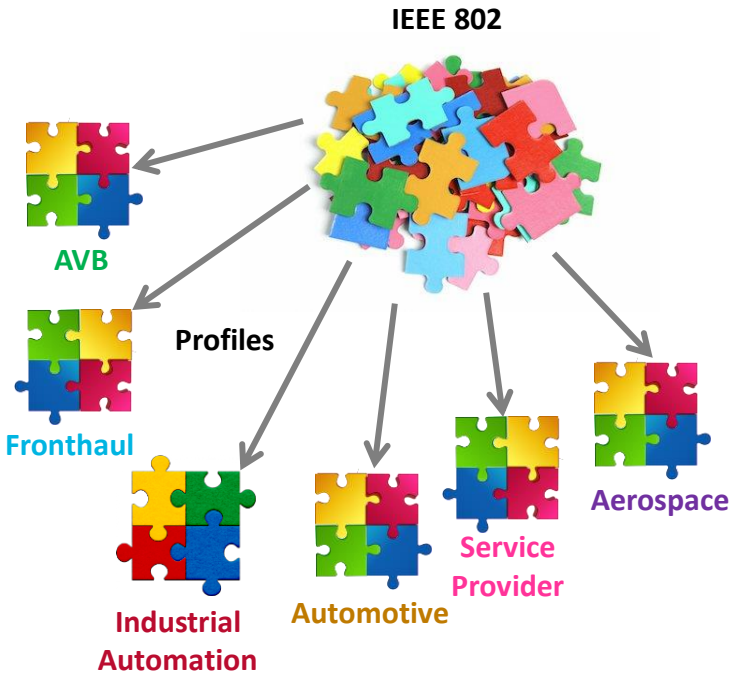
- Selects features, options, defaults, protocols, and procedures

Published IEEE 802.1 TSN profile standards:

- IEEE Std 802.1BA for Audio-Video Bridging (AVB) networks
- IEEE Std 802.1CM TSN for Fronthaul
- IEEE Std 802.1CMde Amendment on enhancements

Ongoing IEEE 802.1 TSN profile projects:

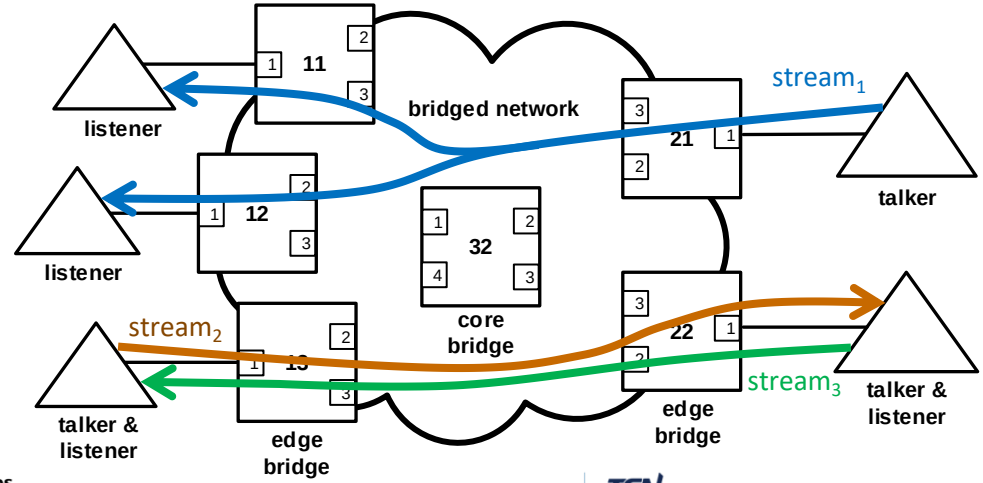
- IEC/IEEE 60802 TSN Profile for Industrial Automation
- P802.1DG TSN Profile for Automotive In-Vehicle Ethernet Communications
- P802.1DF TSN Profile for Service Provider Networks
- P802.1DP / AS6675 TSN Profile for Aerospace onboard Ethernet

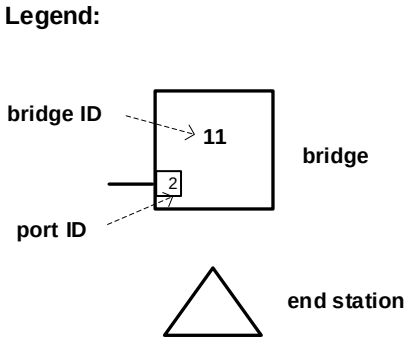


NOMENCLATURE

FOUNDATIONAL TECHNOLOGIES

- IEEE 802.1Q distinguishes two types of devices: **bridge**s and **end station**s
- **Talker**: An end station that is the source or producer of a stream
- **Listener**: An end station that is the destination, receiver, or consumer of a stream
- **Stream**: A unidirectional flow of data from a Talker to one or more Listeners





TSN COMPONENTS

SYNCHRONIZATION

TIMING AND SYNCHRONIZATION [802.1AS]

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IEEE Std 802.1AS

- specifies the generalized Precision Time Protocol (gPTP)
- is a proper profile of the IEEE Std 1588 Precision Time Protocol (PTP)
- includes protocol features additional to PTP
- includes performance requirements
- provides transport of time synchronization
- specifies the Best Master Clock Algorithm

The 2020 revision [802.1AS-2020] adds

- multiple gPTP domains
- external port configuration
- basic redundancy
- and more …

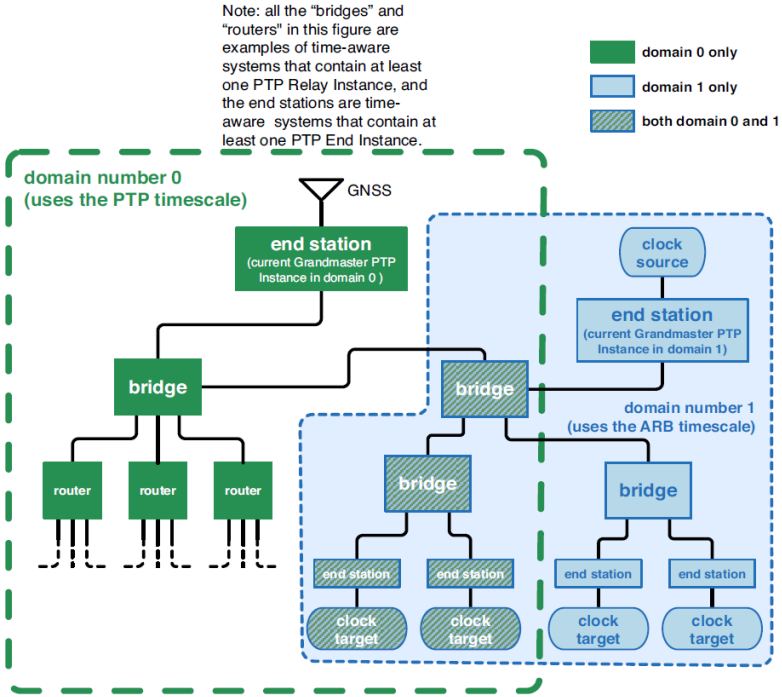


Figure 7-3—Time-aware network example for multiple gPTP domains

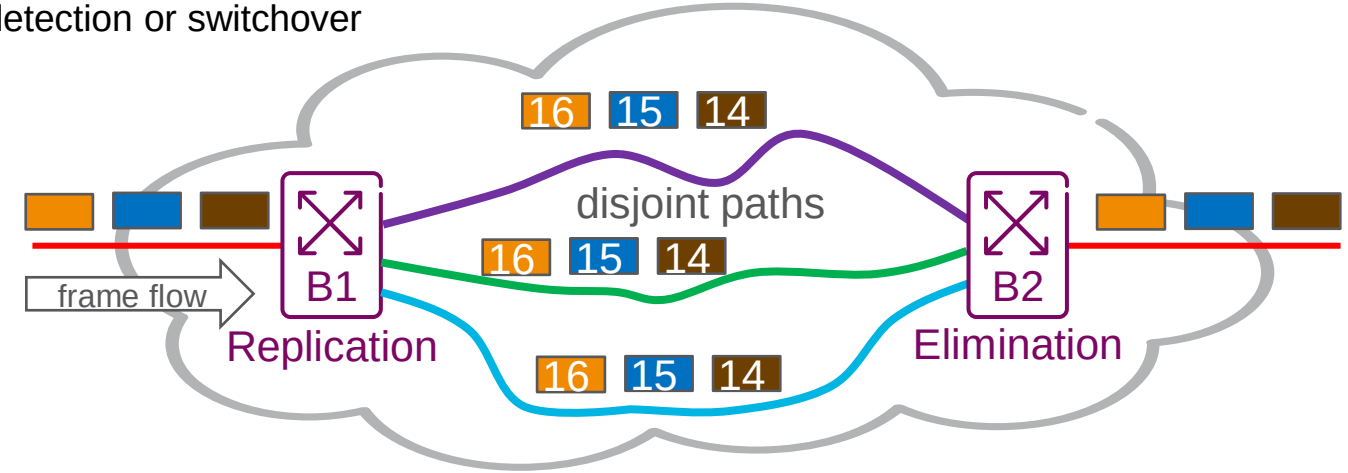
TSN COMPONENTS

RELIABILITY

FRAME REPLICATION AND ELIMINATION FOR RELIABILITY [802.1CB]

Avoids frame loss due to equipment failure

- Send frames on multiple maximally disjoint paths, then combine and delete extras
- A per-frame 1+n redundancy
- NO failure detection or switchover



TSN COMPONENTS

LATENCY

BRIDGE FORWARDING PROCESS [802.1Q]

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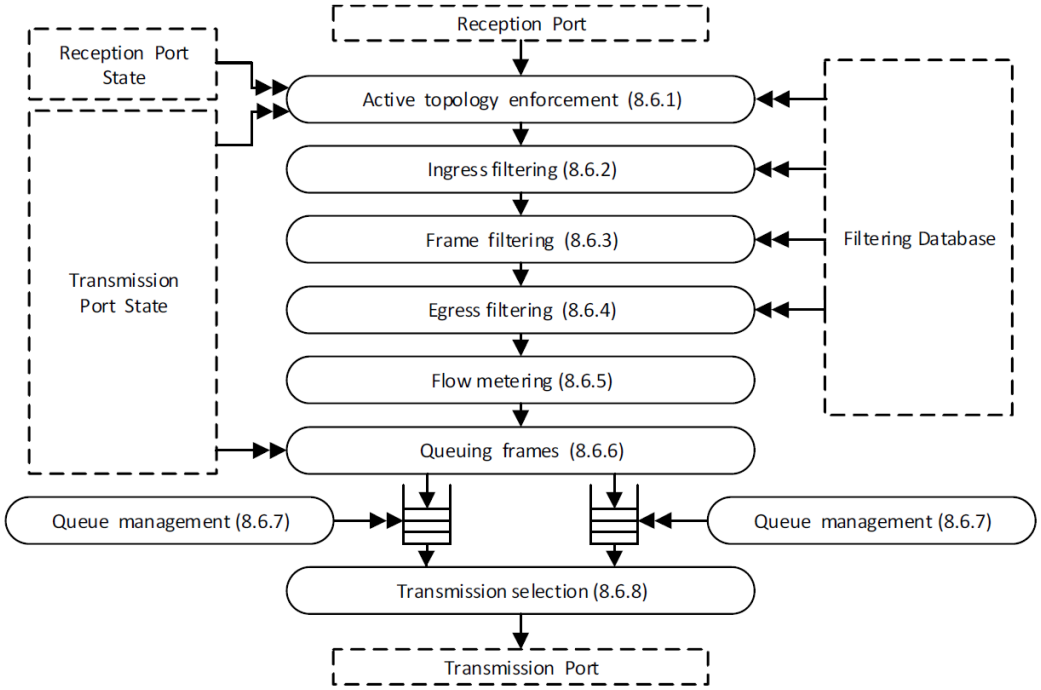
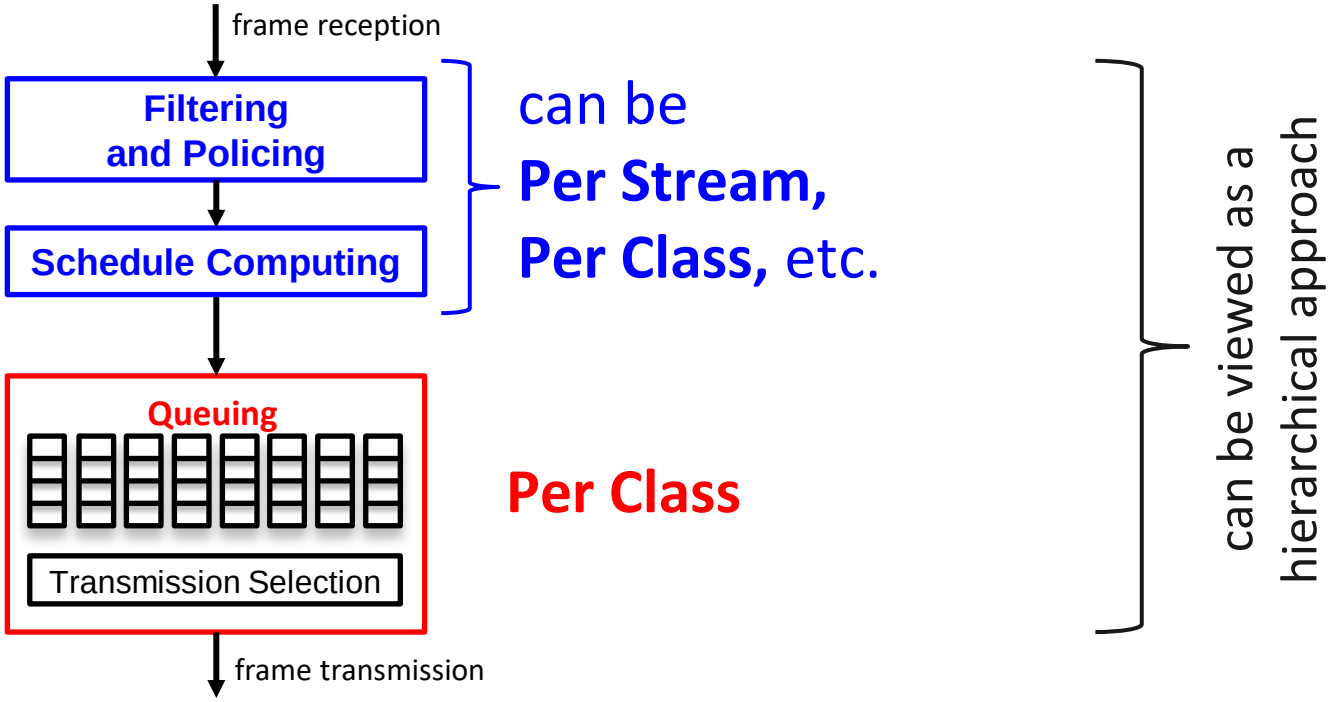


Figure 8-12—Forwarding process functions

ILLUSTRATION OF QOS FUNCTIONS

FOUNDATIONAL TECHNOLOGIES



note: other functions are not shown in this figure, e.g., relay, reliability

SCHEDULED TRAFFIC [802.1Qbv]

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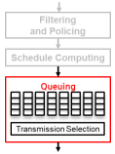
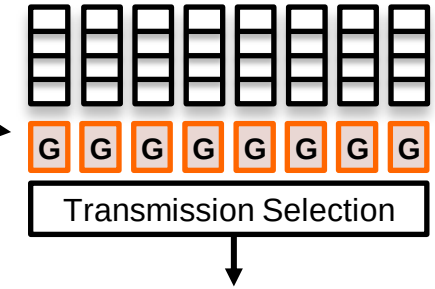


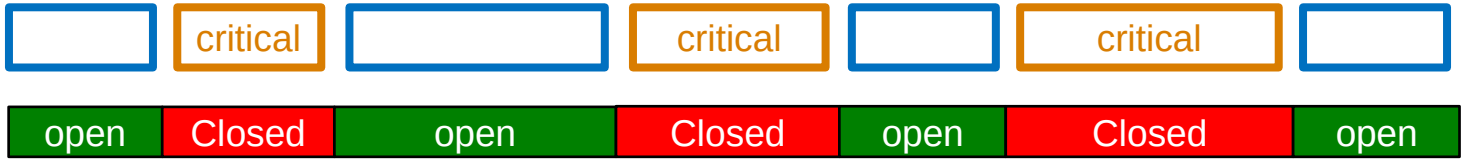
Reduces latency variation for frames with known timing

- Time-based control and programming of the bridge queues
- Time-Gated queues
- Transmission Gate (G): open or Closed
- Periodically repeated time schedule (gate control list)
- Time synchronization is needed
- 802.1Qbv is part of 802.1Q-2018



Gate control list

```
T00: oCooCooo
T01: CoCooCCo
T02: oCooCooo
T03: ooCooCCo
T04: oCooCooo
.............
T78: oCooCooo
T79: CoCooCCC
```



frame transmitted: critical / non-critical

gate(s) for non-critical traffic

Note: gate of non-critical data can be closed in advance to protect critical data

INTERSPERSING EXPRESS TRAFFIC [802.3br]

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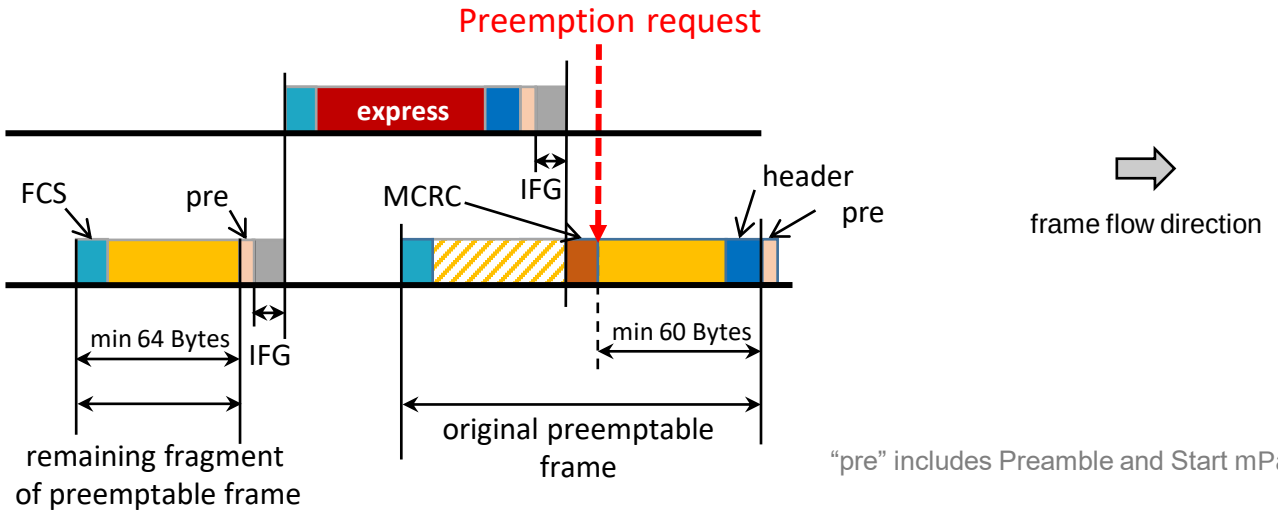
(Frame Preemption)

Express frames can suspend the transmission of preemptable frames while one or more time-critical frames are transmitted

- link local, per hop (it is not IP fragmentation)



"pre" includes Preamble and Start mPacket delimiter (SMD)

SCHEDULED TRAFFIC AND FRAME PREEMPTION

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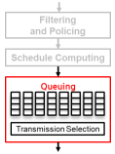
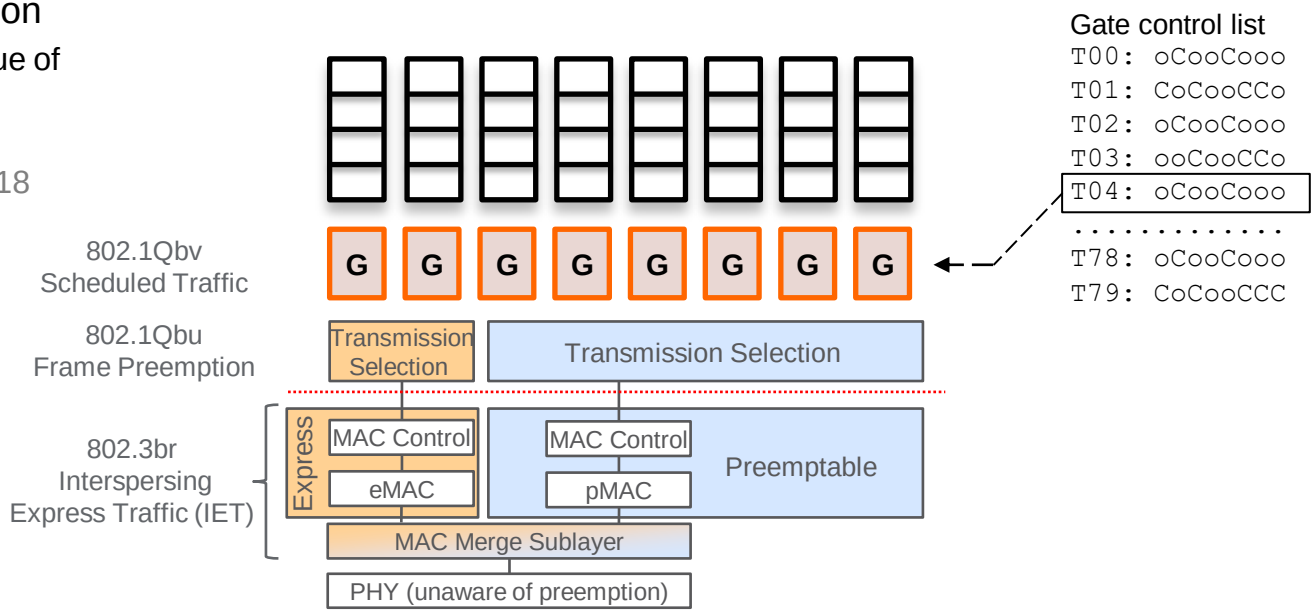


Frame Preemption can be combined with Scheduled Traffic

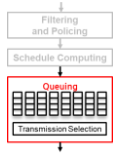
802.1Qbu Frame Preemption

- each queue is assigned a value of frame preemption status: ***express*** or ***preemptable***
- 802.Qbu is part of 802.1Q-2018



BENEFITS OF FRAME PREEMPTION

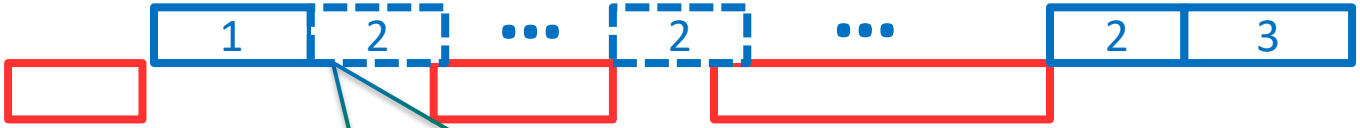
FOUNDATIONAL TECHNOLOGIES



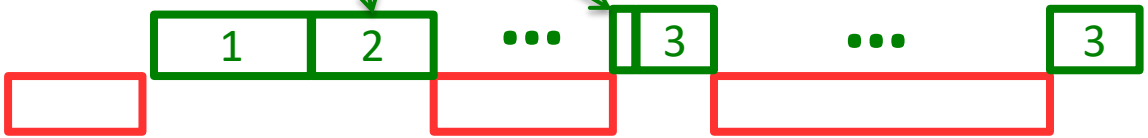
Decreases delay variation for express traffic, and increases bandwidth for preemptable non-critical traffic, whose packet size does not need to be considered when engineering

- Scheduled rocks of critical packets in each cycle:

- Conflict excessively with non-critical packet rocks:

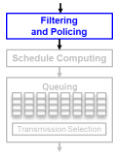


- Problem solved by converting non-critical packets to preemptable sand between the scheduled rocks:



PER-STREAM FILTERING AND POLICING [802.1Qci]

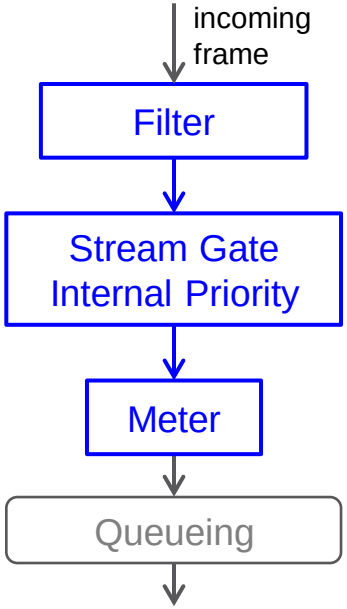
FOUNDATIONAL TECHNOLOGIES



Protection against bandwidth violation, malfunctioning, attacks, etc.

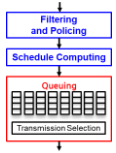
Decisions on per-stream, per-priority, etc.

- Filter
  - Filters, Counters
- Stream Gate
  - Time-scheduled gate
  - open or Closed
- Internal Priority Value (IPV)
  - Bridge internal traffic class of the frame
- Meter
  - Bandwidth Profile of MEF 10.3
  - Red/Yellow/Green Marking
- 802.Qci is part of 802.1Q-2018



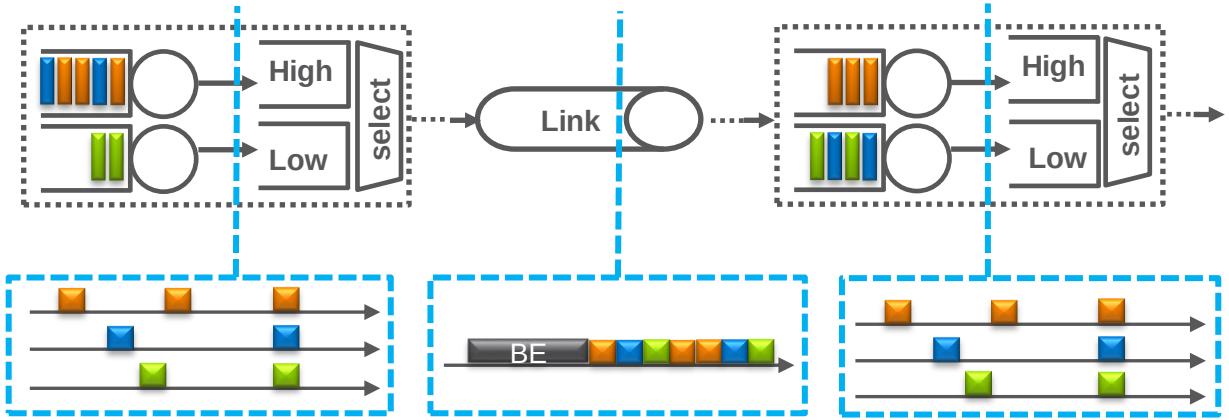
ASYNCHRONOUS TRAFFIC SHAPING (ATS) [802.1Qcr]

FOUNDATIONAL TECHNOLOGIES



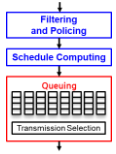
Zero congestion loss without time synchronization

- Similar to per-flow IntServ shaping, except that:
  - All streams from one input port to the same output port share the same queue
- A shaper state machine for a set of streams of the queue
- Smoothen traffic patterns by re-shaping per hop
- Prioritize urgent traffic over relaxed traffic
- 802.Qcr is being added to 802.1Q-2022

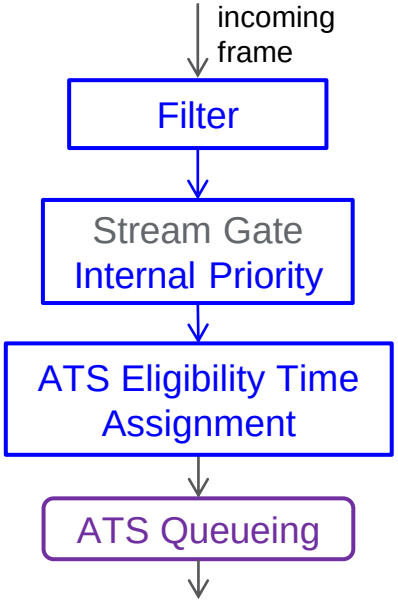


ATS COMPONENTS [802.1Qcr]

FOUNDATIONAL TECHNOLOGIES

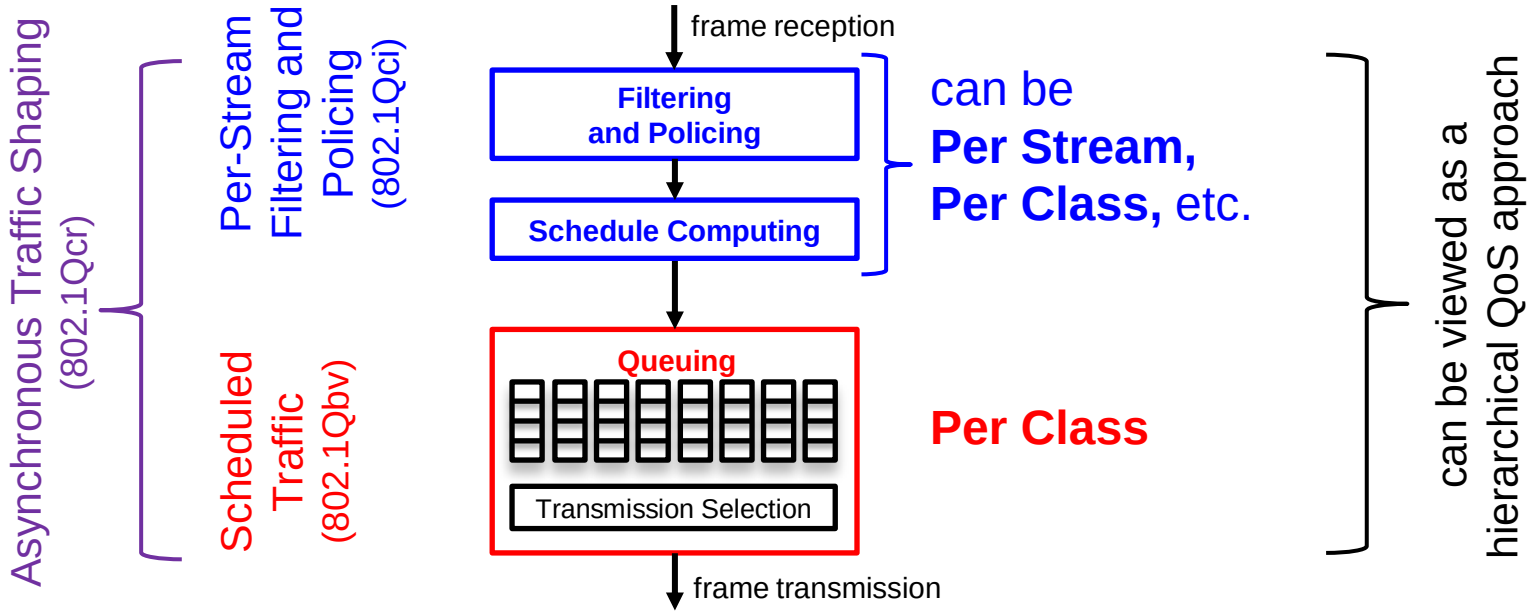


- Filter
  - Selects treatment for frames of a stream, e.g., IPV, shaper
- Internal Priority Value (IPV)
  - Bridge internal traffic class of the frame
  - Used for ATS operations
- ATS Shaper
  - Applies a token bucket algorithm
  - Uses bridge local time variables
  - Pre-computes and assigns local eligibility times to frames
  - Eligibility time becomes effective in the queueing
  - Transmit frames that reached their Eligibility Time



SUMMARY OF QOS FUNCTIONS

FOUNDATIONAL TECHNOLOGIES



note: other functions are not shown in this figure, e.g., MAC relay, reliability

TSN COMPONENTS

RESOURCE MANAGEMENT

TSN CONFIGURATION [802.1Qcc]

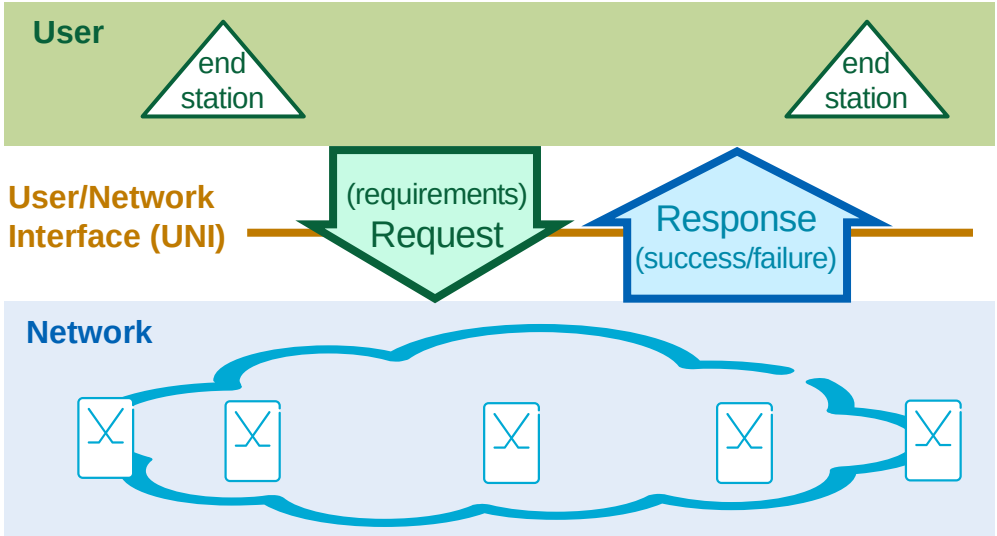
FOUNDATIONAL TECHNOLOGIES

TSN configuration models and principles are specified by 802.1Qcc

- The network obtains requirements from users
- The network configures the bridges to meet user requirements
- The network returns the success or failure to the user
- Configuration information is exchanged over the User/Network Interface (UNI)
- Variolous protocols can be used to exchange the configuration information, e.g.:
  - remote network management protocols
  - signaling protocols
- The user/network configuration information is specified in a manner that is independent of schema, encoding, or protocol.

Three configuration models are defined by 802.1Qcc as described in the following

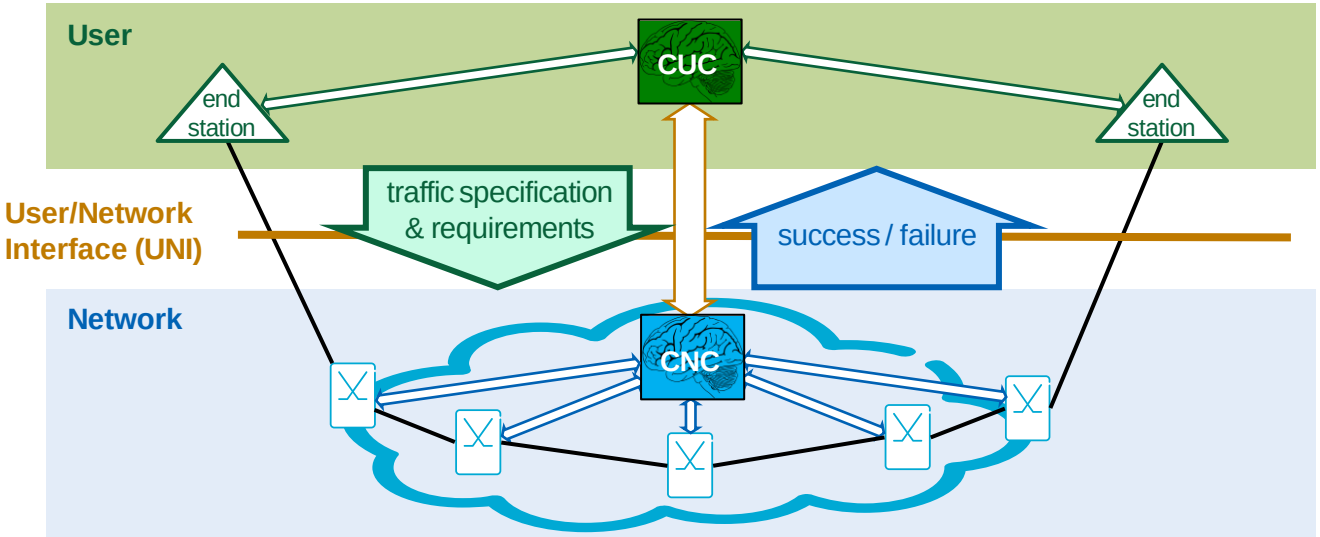
- 802.Qcc is being added to 802.1Q-2022



FULLY CENTRALIZED CONFIGURATION MODEL

FOUNDATIONAL TECHNOLOGIES

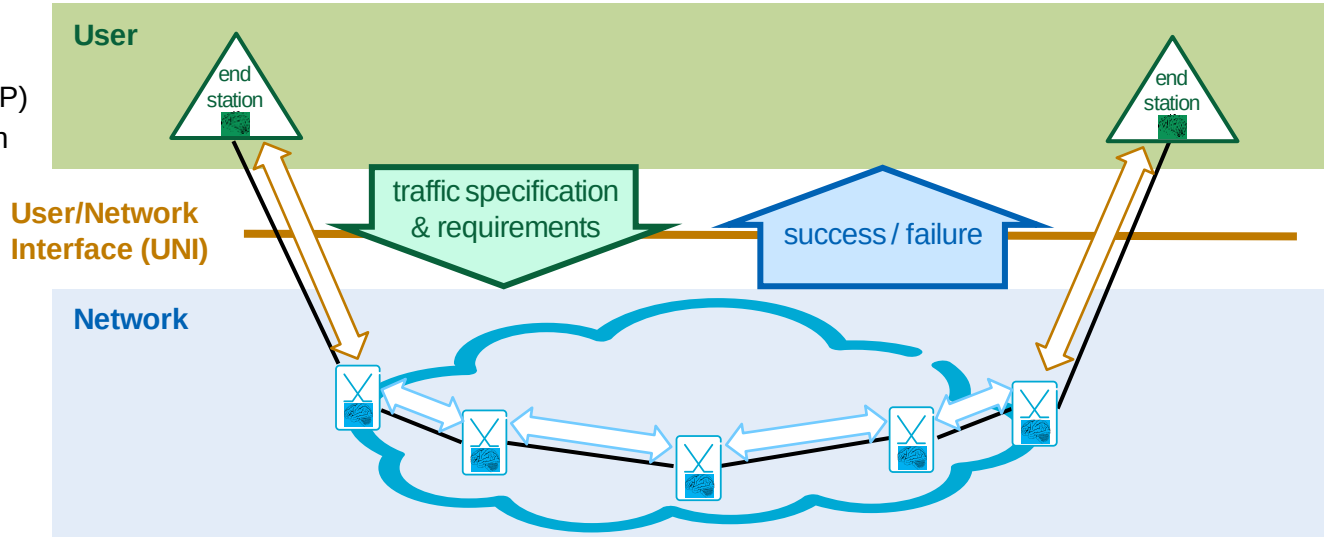
- Central intelligence (can be implemented in cloud)
  - Central User Configuration (CUC)
  - Central Network Configuration (CNC)
- Simple devices
  - No need to implement signaling protocol, etc.



FULLY DISTRIBUTED CONFIGURATION MODEL

FOUNDATIONAL TECHNOLOGIES

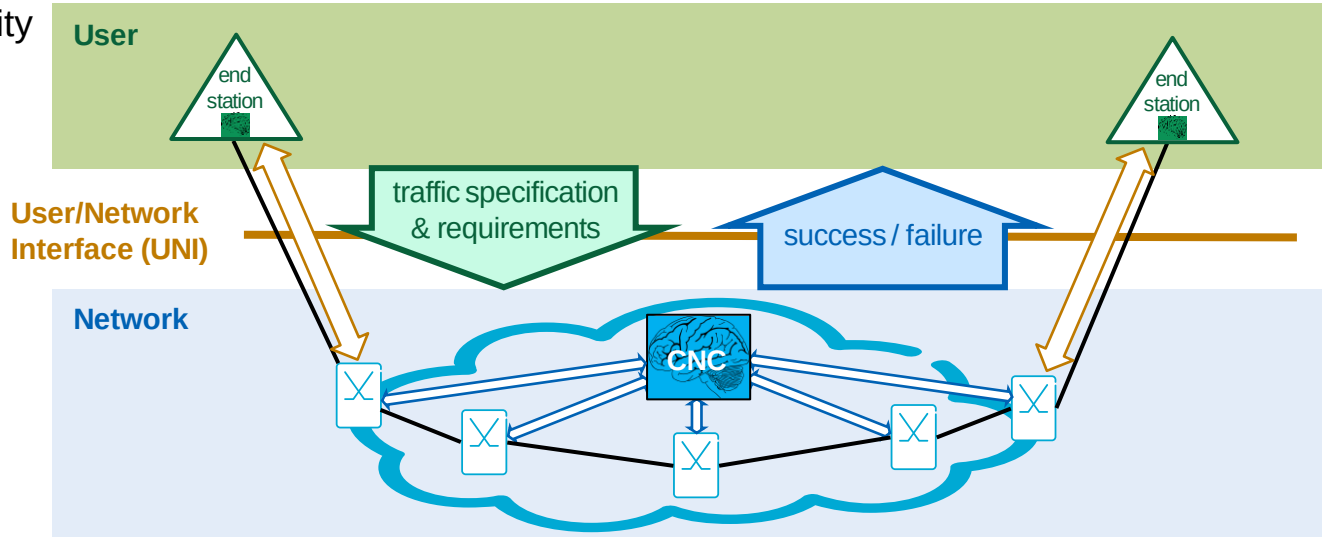
- No central entity at all
- More complex devices
  - Implement distributed protocols, e.g.:
    - Rapid/Multiple Spanning Tree Protocol (RSTP/MSTP)
    - Multiple VLAN Registration Protocol (MVRP)
    - Stream Reservation Protocol (SRP) or Resource Allocation Protocol (RAP)



CENTRALIZED NETWORK/DISTRIBUTED USER MODEL

FOUNDATIONAL TECHNOLOGIES

- Central intelligence in the network (can be implemented in cloud)
  - Central Network Configuration (CNC)
  - Simple bridges
- User has no central entity
  - Signaling protocol at the UNI, e.g.,:
    - Stream Reservation Protocol (SRP) or Resource Allocation Protocol (RAP)



ANOTHER POSSIBLE MIXED CONFIGURATION

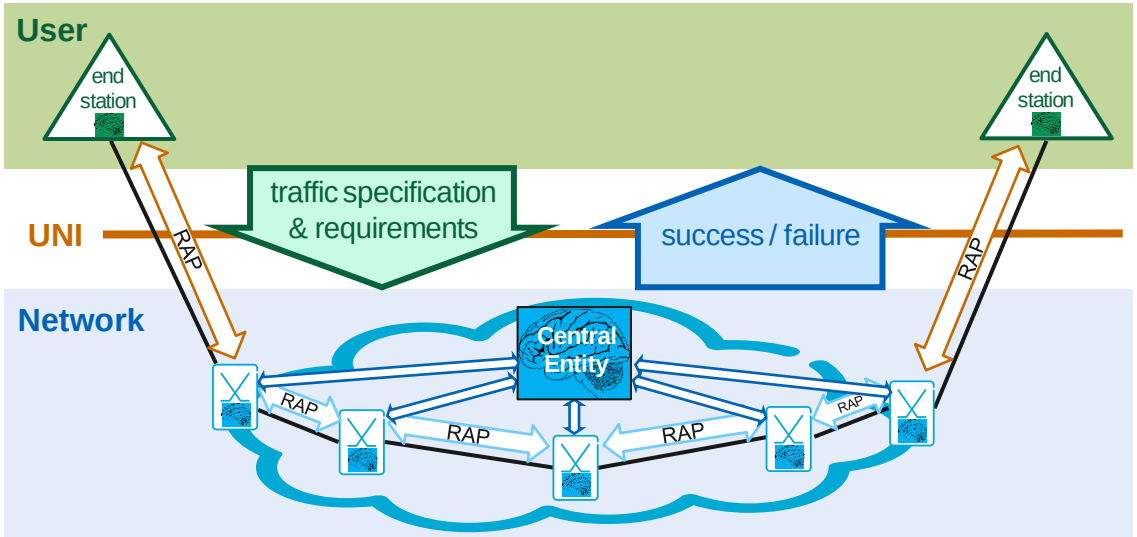
FOUNDATIONAL TECHNOLOGIES

Not mentioned in 802.1Qcc

Distributed reservation with some centralized network configuration

Note that P802.1Qdd Resource Allocation Protocol (RAP) is an ongoing project work in progress

- User has no central entity
  - RAP at the UNI
- Network has central entity
  - Central entity (CNC) configures
    - Resource Allocation (RA) classes
    - Traffic classes
    - Potentially:
      - Transmission gate schemes
      - VLANs, active topologies, MSTIDs
      - Synchronization
      - TSN domains
  - RAP performs resource allocation on top



TSN PROFILES

DIFFERING PROFILES

FOUNDATIONAL TECHNOLOGIES

- IEEE Std 802.1BA for Audio-Video Bridging (AVB) networks
  - Plug & Play → defaults are essential
- IEEE Std 802.1CM TSN for Fronthaul
  - Fully engineered
  - Profile includes configuration guidelines
- IEC/IEEE 60802 TSN Profile for Industrial Automation
  - Plug & Produce
  - Engineering
- IEEE Std 802.1DF TSN Profile for Service Provider Networks
  - Fully engineered
- IEEE P802.1DG TSN Profile for Automotive In-Vehicle Ethernet Communications
  - Fully engineered
- IEEE P802.1DP / SAE AS6675 TSN Profile for Aerospace Onboard Ethernet Communications
  - Fully engineered

COLLABORATIVE EFFORT

FOUNDATIONAL TECHNOLOGIES

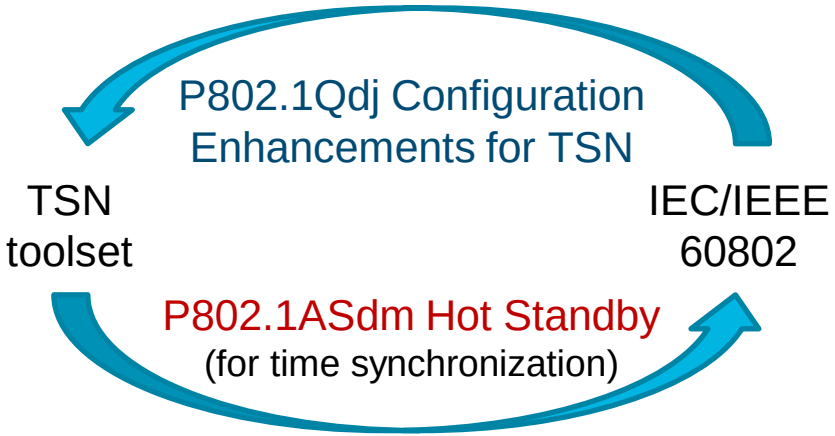
- Bring experts together
- Experts of the application area / use case
- Experts of the technology: TSN

→ Mutual benefits

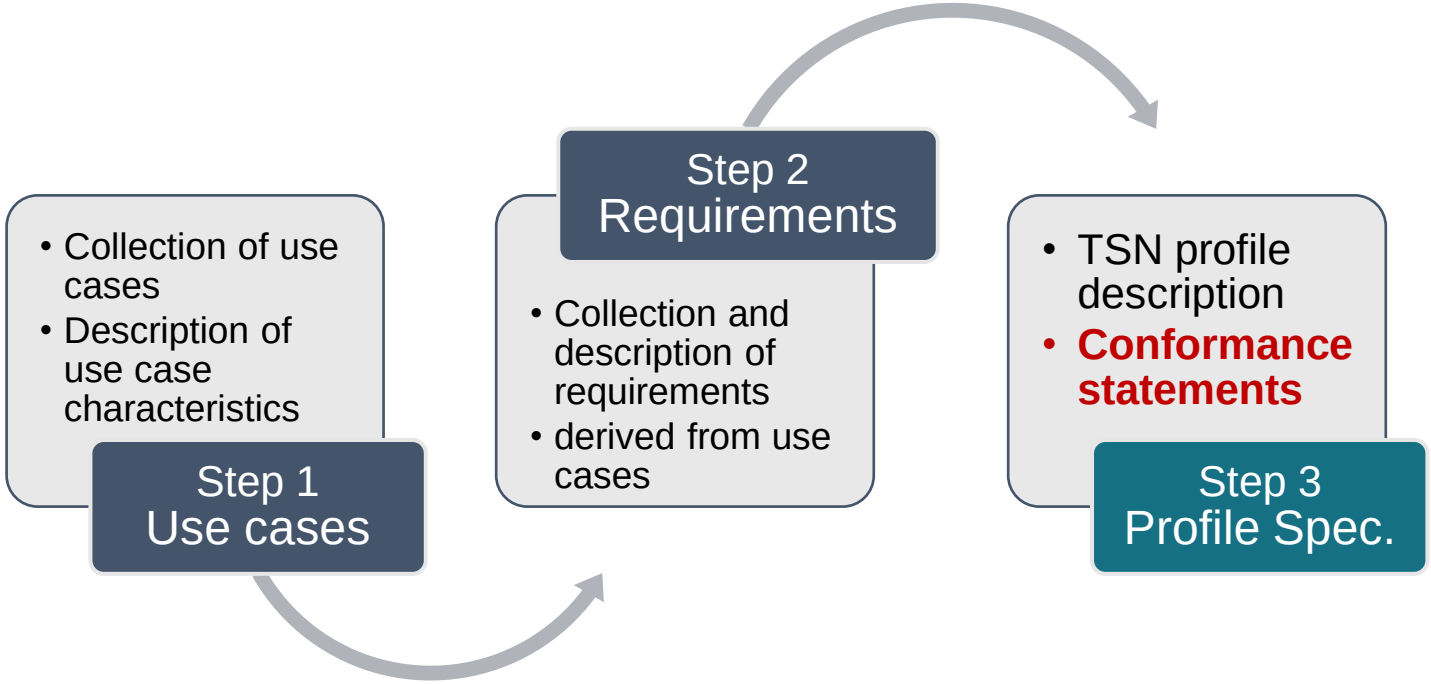
→ Solid outcome

- Joint efforts
  - IEEE 802.1CM/de with CPRI Cooperation and ITU-T SG15/Q13
  - IEC/IEEE 60802
  - IEEE P802.1DP / SAE AS6675

For example:



TYPICAL PROFILE WORKFLOW



KEY PARTS OF A PROFILE

FOUNDATIONAL TECHNOLOGIES

Conformance Clause

(typically Clause 5)

- Collects the mandatory and the optional requirements that a bridge or end station claiming conformance to the standard has to meet
- Textual description
- Uses conformance language: Shall, May, (Should)

Profile Conformance Statements (PCS)

(typically Annex A)

- Matches Conformance Clause
- The supplier of an implementation that is claimed to conform to a particular Profile shall complete the corresponding PCS proforma
- Tabular format
- **Important: Who fills the PCS in and when**

Examples from IEEE Std 802.1CM

5.5 End station requirements

This subclause defines the conformance requirements for end station implementations claiming conformance to this standard. An end station implementation that conforms to the provisions of this standard shall:

a) Support priority-tagged (see 3.184 of IEEE Std 802.1Q-2018) or VLAN-tagged frames on all ports;

b) Support a minimum of three traffic classes on all ports.

Item	Feature	Status	References	Support
E-Q-1	Does the end station support untagged frames on all ports?	E-S-1:M	Q:3.249, 5.6, 5.6.1: a), Clause 8	Yes [ ] No [ ]
E-Q-2	Does the end station support priority-tagged frames on all ports?	O.5	Q:3.158, 5.5: a), Clause 8	Yes [ ] No [ ]
E-Q-3	Does the end station support VLAN-tagged frames on all ports?	O:5	Q:9, 5.5: a), Clause 8	Yes [ ] No [ ]
E-Q-4	Does the end station support at least three traffic classes on all ports?	M	Q:3.239, 5.5: b), Clause 8	Yes [ ]

SUMMARY

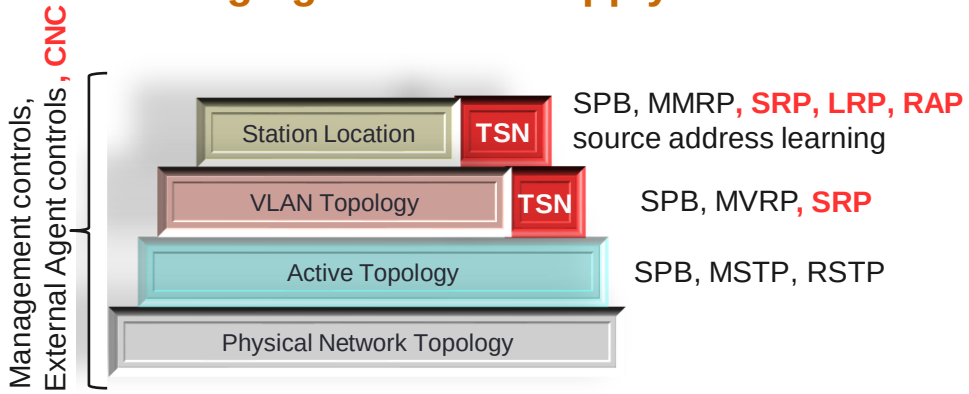
GOOD TO BEAR IN MIND

FOUNDATIONAL TECHNOLOGIES

TSN is an Add-on to VLAN Bridging (see first webinar)

TSN extends IEEE 802.1 bridging

Bridging basics still apply!



SRP: Stream Reservation Protocol
LRP: Link-local Registration Protocol
RAP: Resource Allocation Protocol

RSTP: Rapid Spanning Tree Protocol
MSTP: Multiple Spanning Tree Protocol
SPB: Shortest Path Bridging
MVRP: Multiple VLAN Registration Protocol
MMRP: Multiple MAC Registration Protocol

SUMMARY

FOUNDATIONAL TECHNOLOGIES

- TSN provides bounded latency (upper and lower bound), bounded packet delay variation (jitter), low packet loss, and high availability/reliability
  - TSN is evolving, the toolset is being extended
- TSN is applicable in various use cases
  - Profile specifications address application areas
- IEEE 802.1 is individual-based and open to all

WELCOME TO JOIN THE EFFORT!

http://ieee802.org/1/tsn

2020 IEEE SA Emerging Technology Award

FURTHER INFORMATION

FOUNDATIONAL TECHNOLOGIES

[TSN webinar series](), including the [first webinar]()

802.1 TSN TG page: http://www.ieee802.org/1/tsn

Fronthaul blog: https://beyondstandards.ieee.org/how-time-sensitive-networking-benefits-fronthaul-transport/

[TSN feature topic]() of the [June 2018 Issue of IEEE Communications Standards Magazine]()
https://ieeexplore.ieee.org/document/8412457

Tutorial on TSN at IETF 99
https://datatracker.ietf.org/meeting/99/materials/slides-99-edu-sessf-time-sensitive-networking-tutorial-english-language-janos-farkas-norman-finn-patricia-thaler

Tutorial on IEEE 802 Ethernet Networks for Automotive
http://www.ieee802.org/802_tutorials/2017-07/tutorial-Automotive-Ethernet-0717-v02.pdf

"Heterogeneous Networks for Audio and Video: Using IEEE 802.1 Audio Video Bridging"
http://ieeexplore.ieee.org/xpl/articleDetails.jsp?arnumber=6595589

Tutorial on IEEE 802.3br Interspersing Express Traffic (IET) and IEEE 802.1 Time-Sensitive Networking
http://www.ieee802.org/802_tutorials/2015-03/8023-IET-TF-1501-Winkel-Tutorial-20150115_r06.pptx

Tutorial on Deterministic Ethernet http://www.ieee802.org/802_tutorials/2012-11/8021-tutorial-final-v4.pdf

Tutorial on IEEE 802.1Q at IETF 86 https://www6.ietf.org/meeting/86/tutorials/86-IEEE-8021-Thaler.pdf

Paper on 802.1Q bridging https://www.ieee802.org/1/files/public/docs2014/Q-farkas-SDN-support-0314-v01.pdf

Q&A

UPCOMING WEBINARS

Time Synchronization – IEEE Std 802.1AS (Q1 2022)
Audio Video Bridging – IEEE Std 802.1BA
Fronthaul – IEEE Std 802.1CM
Industrial Automation – IEC/IEEE 60802
Automotive Ethernet – IEEE P802.1DG
Aerospace Ethernet – IEEE P802.1DP / SAE AS6675

THANK YOU

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IEEE 802.1: http://www.ieee802.org/1
Foundational Technologies: https://standards.ieee.org/practices/foundational/index.html
Standards Home Page: https://standards.ieee.org