IEEE 802.1 Time-Sensitive Networking (TSN)

János Farkas, Norman Finn, Patricia Thaler
Ericsson Huawei Broadcom

Outline

- Introduction
- Reliability
- Deterministic latency
- Resource management
- Summary

INTRODUCTION

Potential Markets (not comprehensive)

Industrial Automation

Wind

Nuclear

Power Gen

High Traffic Mix, Deterministic, Low Latency, Secure, Reliable, High Throughput

5G

Healthcare

Oil & Gas

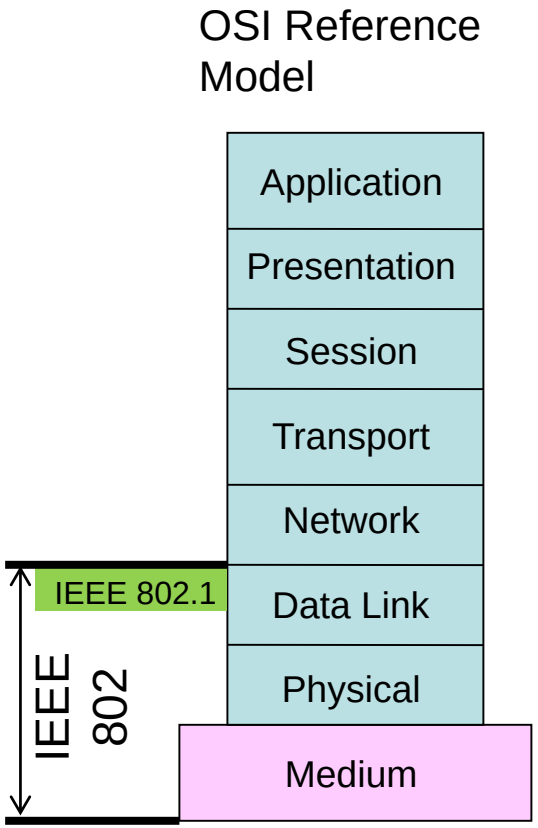
Water

Aviation

Transportation

IEEE 802 and 802.1

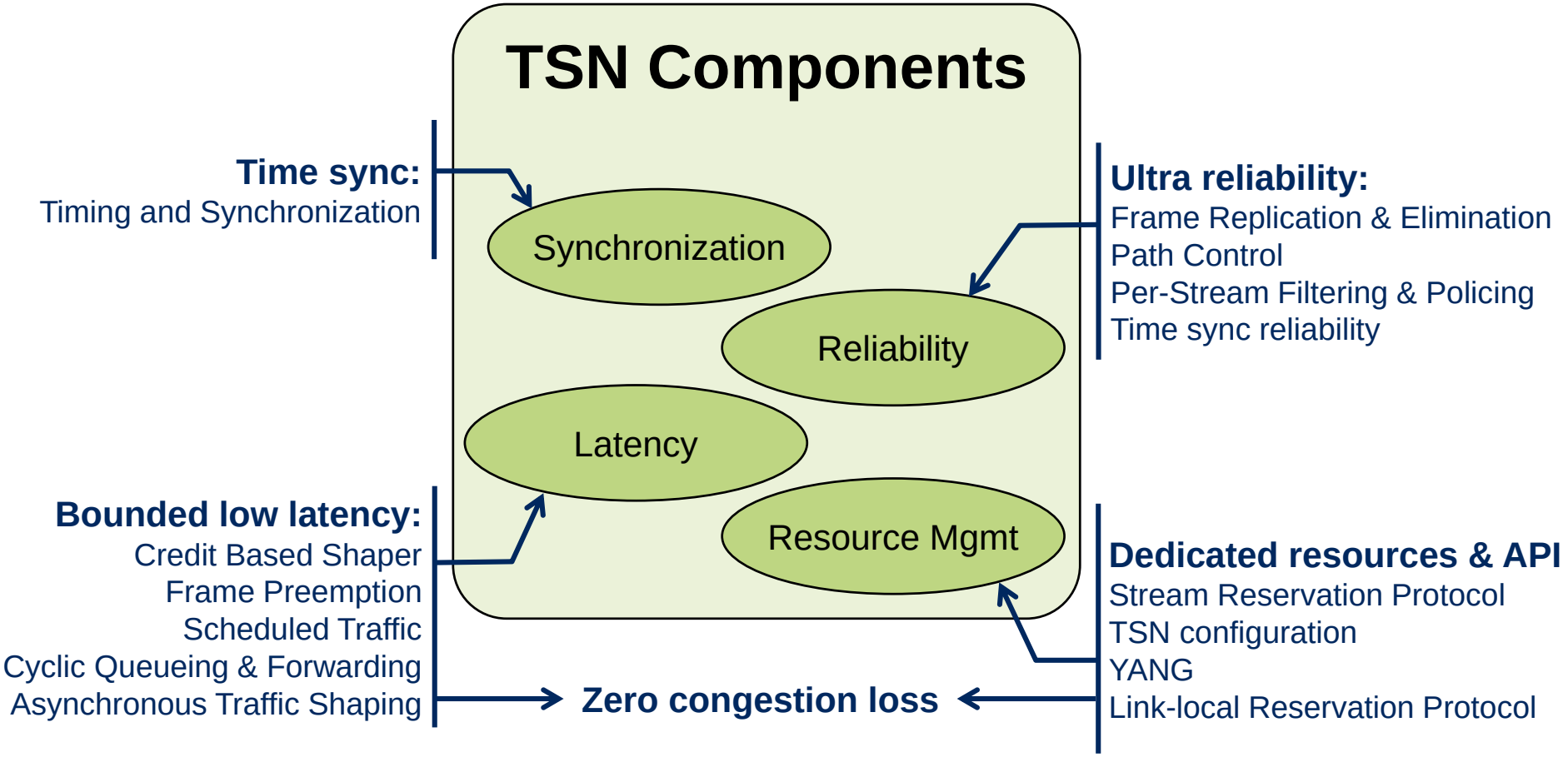
- IEEE 802 LAN/MAN Standards Committee (aka IEEE 802 or LMSC)
  - Develop LAN and MAN standards
  - Mainly for link and physical layers of the network stack
- IEEE 802.1
  - 802 LAN/MAN architecture
  - Internetworking among 802 LANs, MANs, and other wide area networks
  - 802 Security
  - 802 overall network management, and protocol layers above the MAC & LLC layers.



From AVB to TSN

- IEEE 802.1 Audio Video Bridging (AVB) Task Group (TG)
  - Started in 2005
  - Address professional audio, video market
  - Consumer electronics
  - Automotive infotainment
  - Avnu Alliance: associated group for compliance and marketing
- IEEE 802.1 Time-Sensitive Networking (TSN) TG
  - AVB features become interesting for other use cases, e.g.
    - Industrial
    - Automotive
  - AVB was not an appropriate name to cover all use cases
  - AVB TG was renamed to TSN TG in 2012
  - Interworking TG and TSN TG were merged in 2015

Time-Sensitive Networking

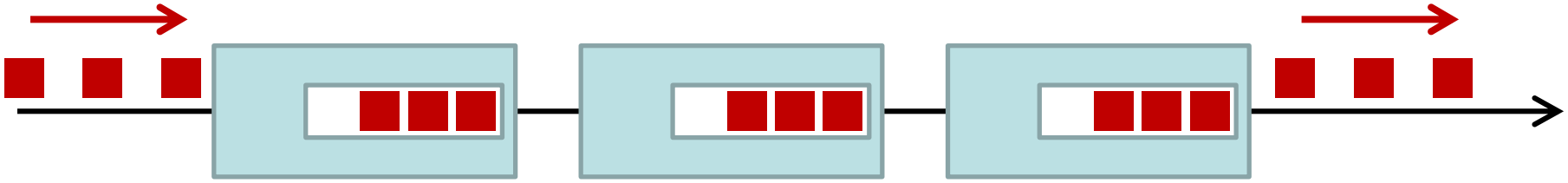


Guaranteed data transport with bounded low latency, low delay variation, and extremely low loss

Bounded Latency

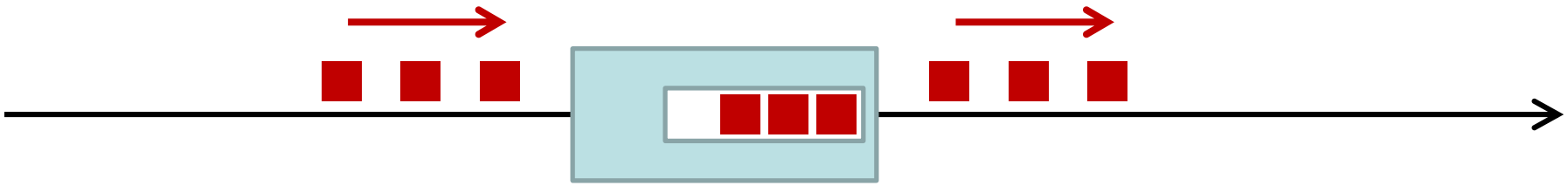
- TSN's target applications, real-time networks, require a **guaranteed not-to-exceed end-to-end latency** for critical data
- Average/mean/best-case latencies are irrelevant
- Many ways to accomplish bounded latency:
  - ~~Throw away late packets; grossly overprovision the network; intensive engineering and testing.~~
  - **Provide zero congestion loss**

0 Loss = Bounded Latency



- Given:
  - Constant input rate
  - Finite buffer capacity
  - 0 packets lost
- End-to-end latency is bounded

How to Get 0 Congestion Loss

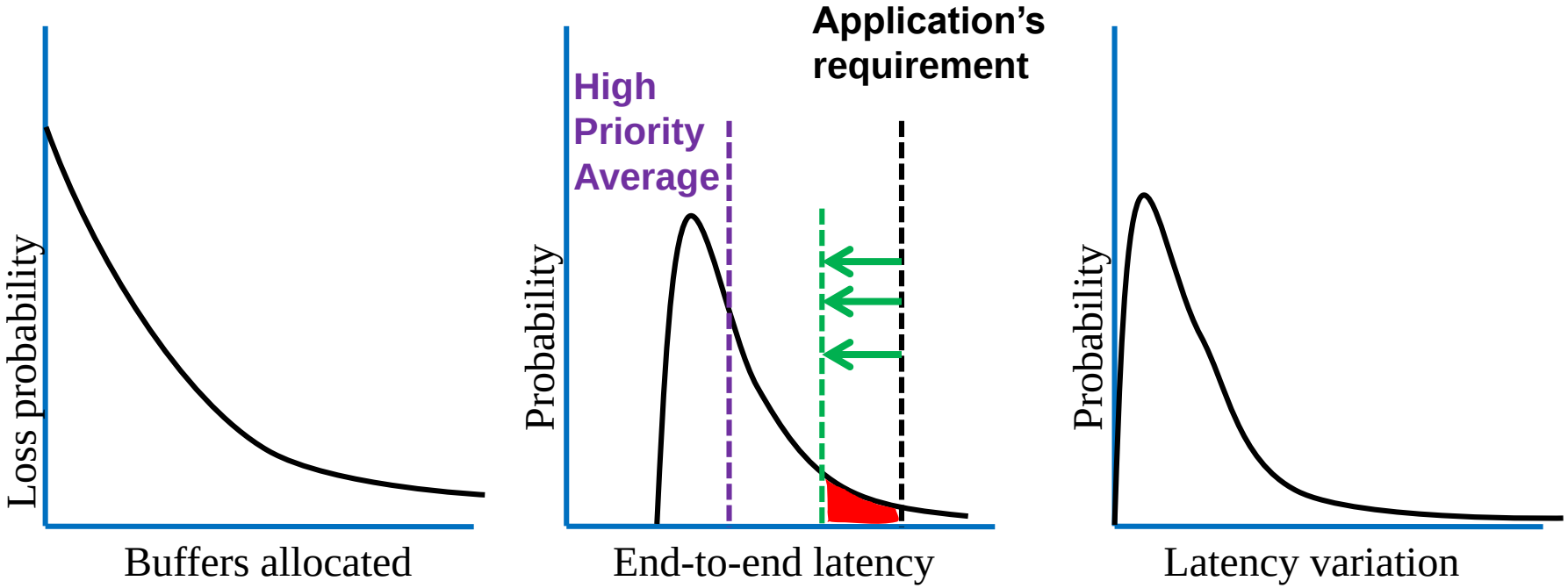


- At **every hop**:
  - **Packets/interval in == packets/interval out**
- But:
  - Packetized data is not a constant-rate bit stream
  - Different flows' optimal transmit times can conflict
- So, gaps and bursts are inevitable

Gaps and Bursts

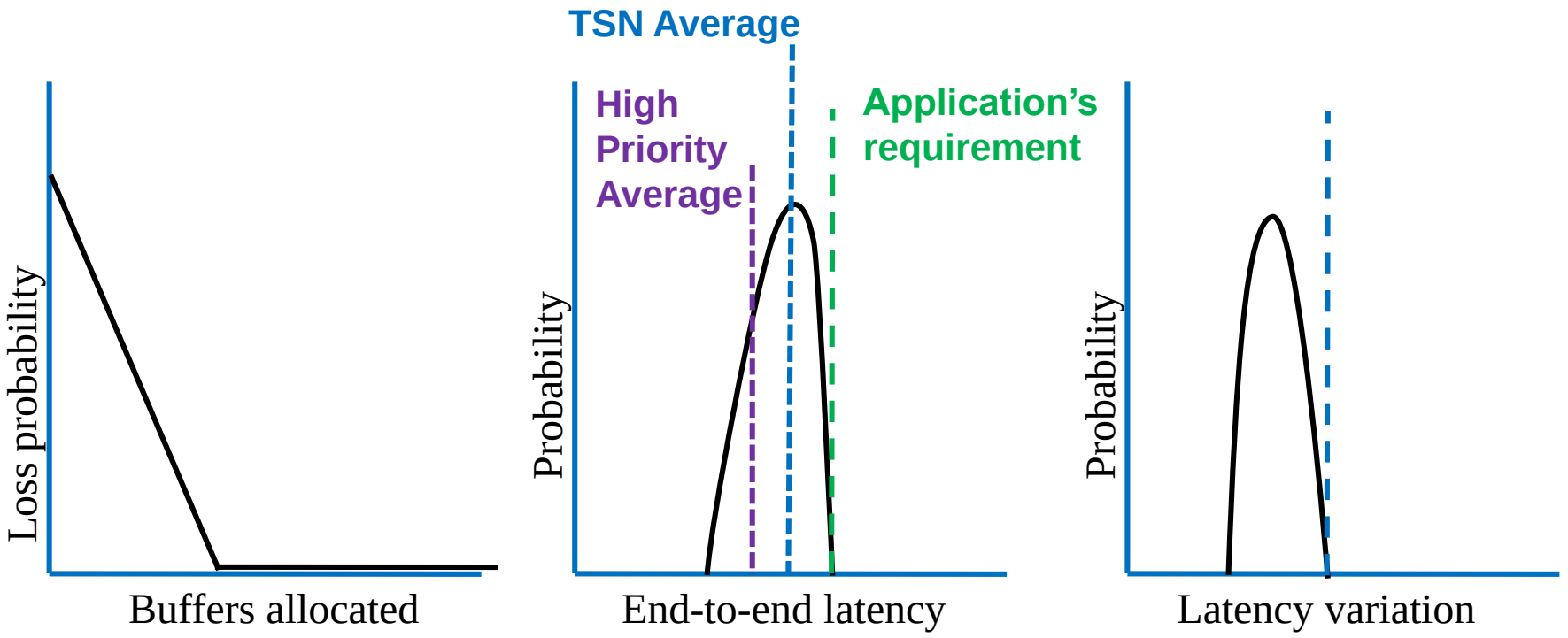
1. Reserve buffer space and bandwidth resources before the critical flow starts
2. Use queuing/reservation disciplines that strictly limit inter-flow interference and provide predictable gap/burst behavior
3. Use extra buffers for known delay variations (e.g., forwarding delay)

Traditional Service



- Curve have long tails
- Average latency is good
- **Lowering the latency** means **losing packets** (or grossly overprovisioning)

TSN Service



- Packet loss is now due to equipment failure
- Average latency may be larger, but no tails

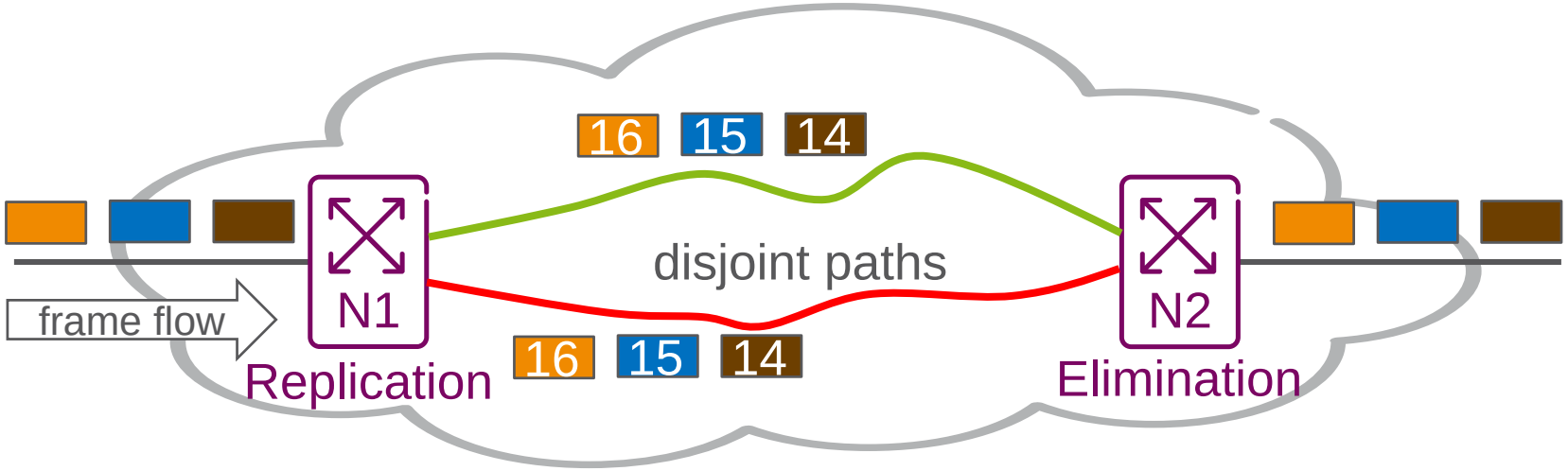
Bottom Line: **Why TSN**?

- Without TSN
  - Network engineering
  - Bandwidth, over-provisioning
  - Testing
- With TSN
  - Way easier to engineer
  - Works even in hard-to-test corner cases
  - Way **cheaper**

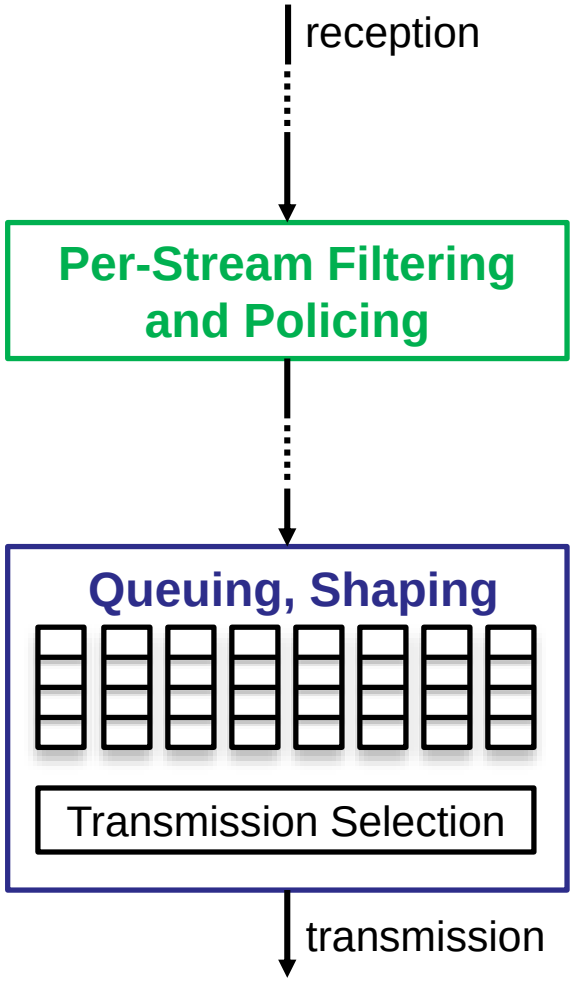
RELIABILITY

Frame Replication and Elimination

- Avoid frame loss due to equipment failure (802.1CB)
- Per-packet 1+1 (or 1+n) redundancy
  - NO failure detection / switchover
- Send packets on two (or more) disjoint paths, then combine and delete extras



Frame Forwarding Steps Discussed

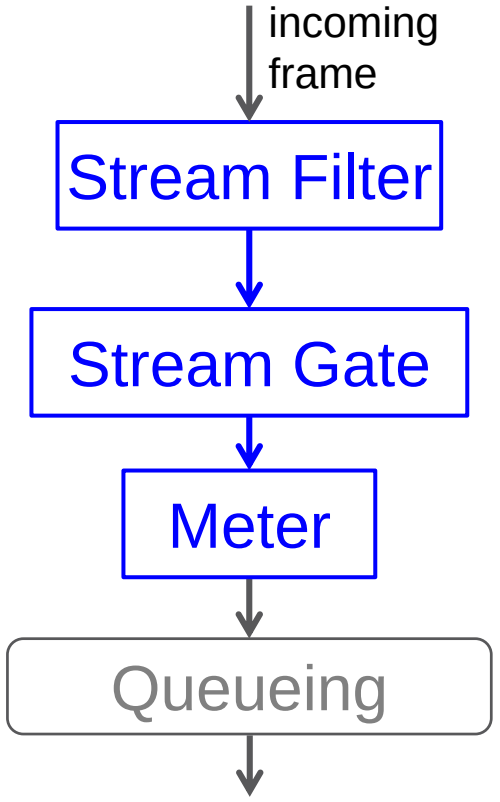


Policing

- Every frame can be marked “green” or “yellow” using the Drop Eligible bit of VLAN tags
- “red” are dropped
- “yellow” frames have a higher probability of being discarded than “green” frames
- Policing is done per input port, but only after it is determined that a frame can be delivered to some port. Frames that are dropped by the forwarding mechanism are not policed.
- Policing algorithm is from MEF Forum spec 10.3 (see also RFC 2963)

Per-Stream Filtering and Policing

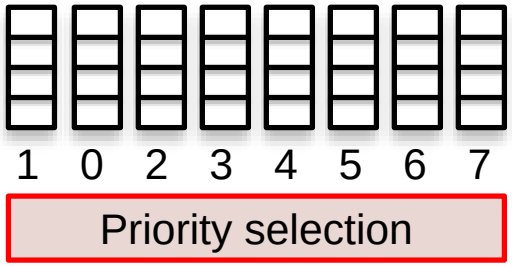
- Protection against bandwidth violation, malfunctioning, malicious attacks, etc. (802.1Qci)
- Decisions on per-stream, per-priority, etc.
- Stream Filter
  - Filters, Counters
- Stream Gate
  - Open or Closed
  - can be time-scheduled
- Meter
  - Bandwidth Profile of MEF 10.3
  - Marking



DETERMINISTIC LATENCY

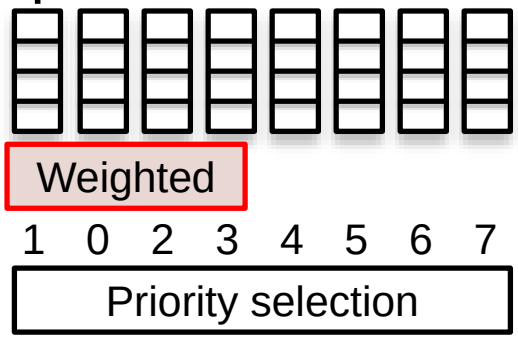
Priority and Weighted Queuing

- **Strict Priority** (802.1Q-1998)



Highest priority: 7

- **Weighted queues** (802.1Qaz)
  - Standard management hooks for weighted priority queues without over-specifying the details

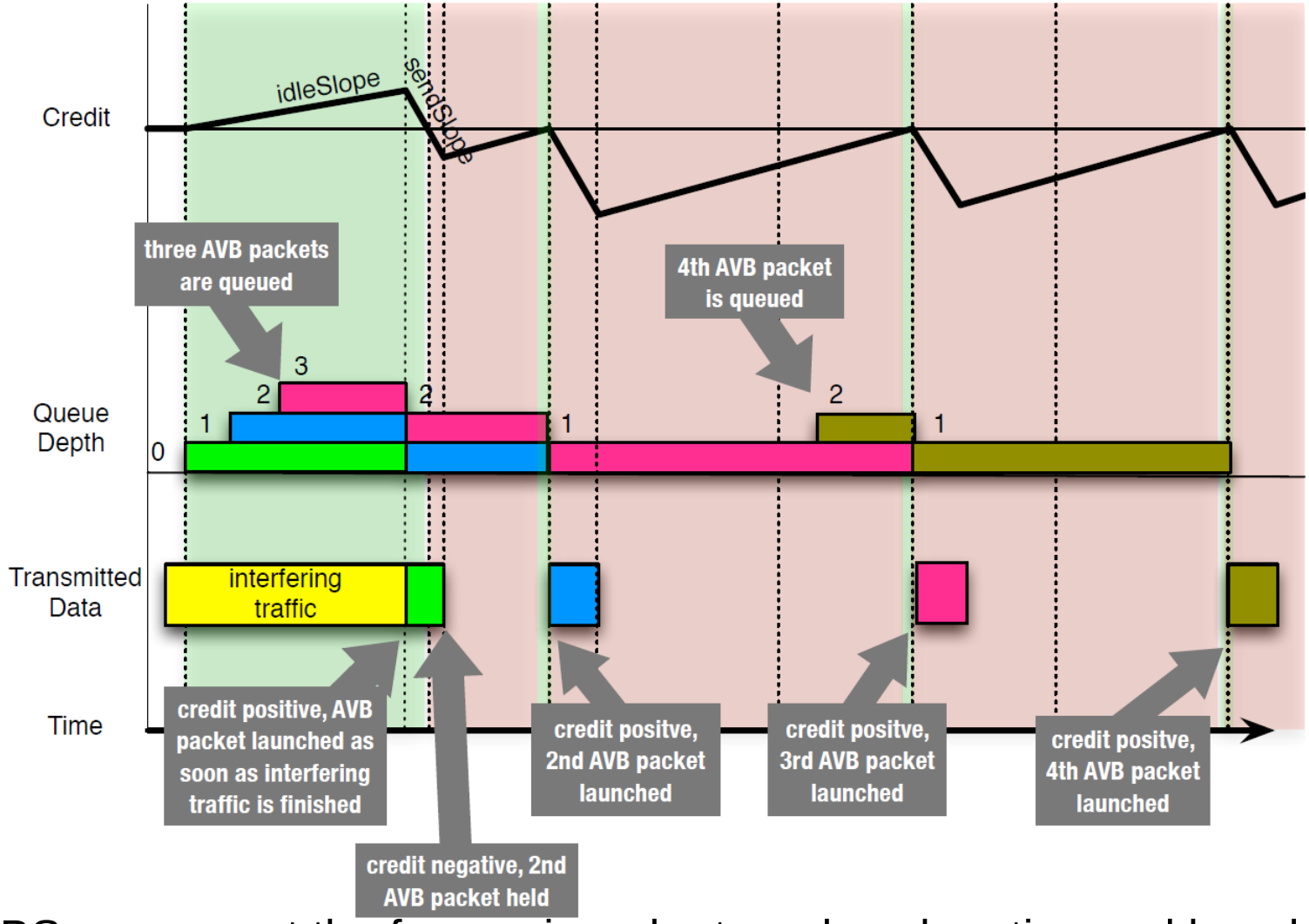


Credit Based Shaper

- Credit Based **Shaper** (CBS - 802.1Qat)
  - Shaped queues have higher priority than unshaped queues
  - Shaping still guarantees bandwidth to the highest unshaped priority (7)

- CBS is similar to the typical run rate/burst rate shaper, but with really useful mathematical properties
  - Only parameter = bandwidth
  - The impact on other queues of any number of adjacent shapers is the same as the impact of one shaper with the same total bandwidth.

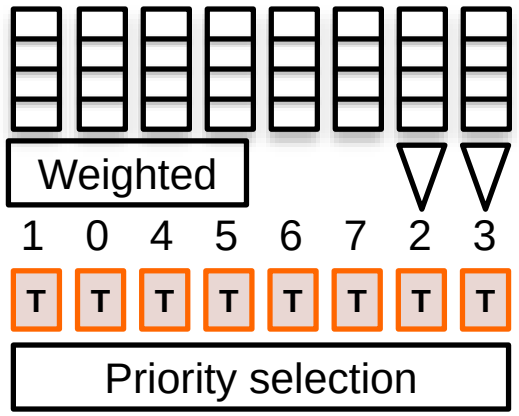
Credit Based Shaper – Example



- CBS spaces out the frames in order to reduce bursting and bunching

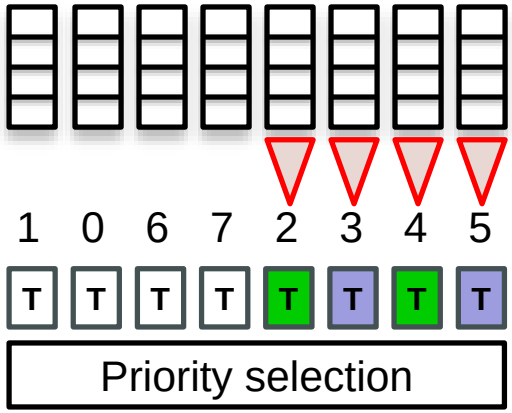
Scheduled Traffic

- Reduces latency variation for Constant Bit Rate (CBR) streams, which are periodic with known timing
- Time-based control/programming of the 8 bridge queues (802.1Qbv)
- Time-gated queues
- Gate: Open or Closed
- Periodically repeated time-schedule
- Time synchronization is needed



Cyclic Queuing and Forwarding

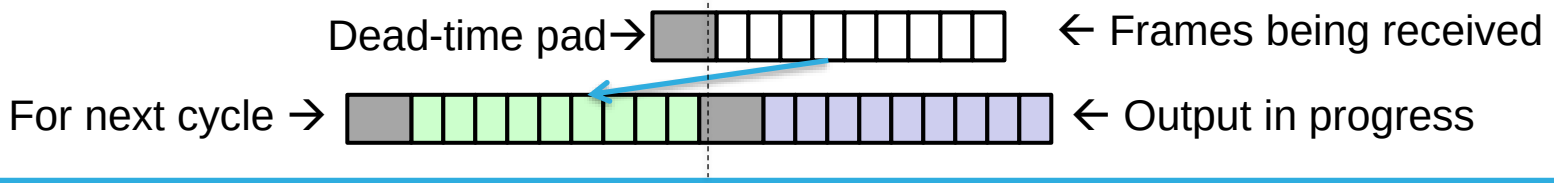
- **Double buffers** (802.1Qch) are served alternate using time-gated control
- Two pairs: 2–3 and 4–5 in this example



←Shapers ensure fair access for 0, 1, 6, 7 traffic

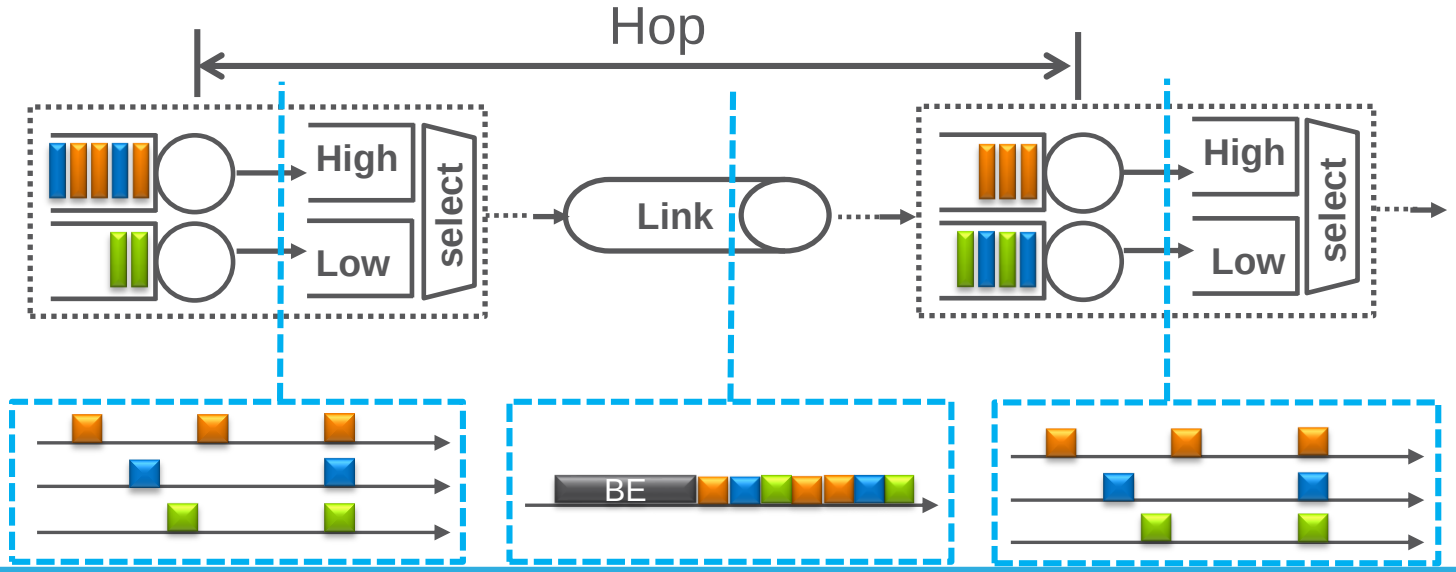
←Alternately open green and purple

- If the wire length and bridge transit time are negligible compared to the cycle time, double buffers are sufficient:



Asynchronous Traffic Shaping

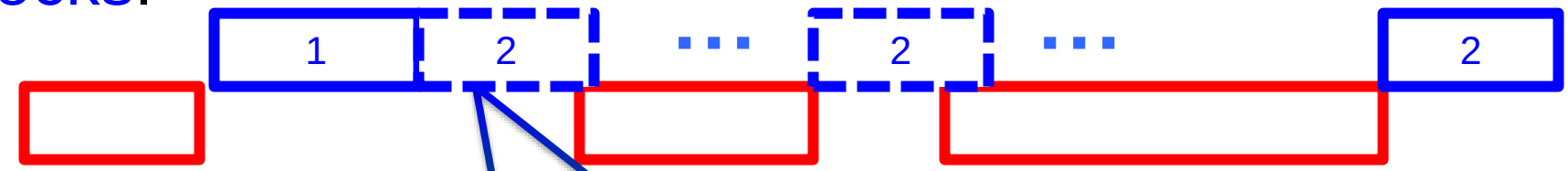
- Zero congestion loss without time synchronization
- Asynchronous Traffic Shaping (ATS - P802.1Qcr)
  - Smoothen traffic patterns by re-shaping per hop
  - Prioritize urgent traffic over relaxed traffic



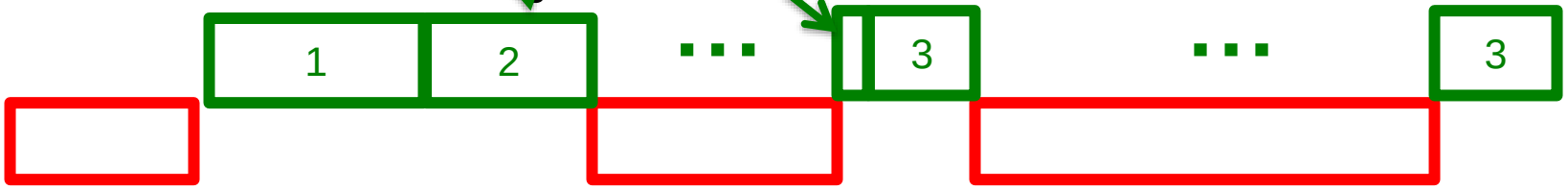
Frame Preemption

- Express frames suspend the transmission of preemptable frames (802.3br and 802.1Qbu)
- Scheduled rocks of critical packets in each cycle:

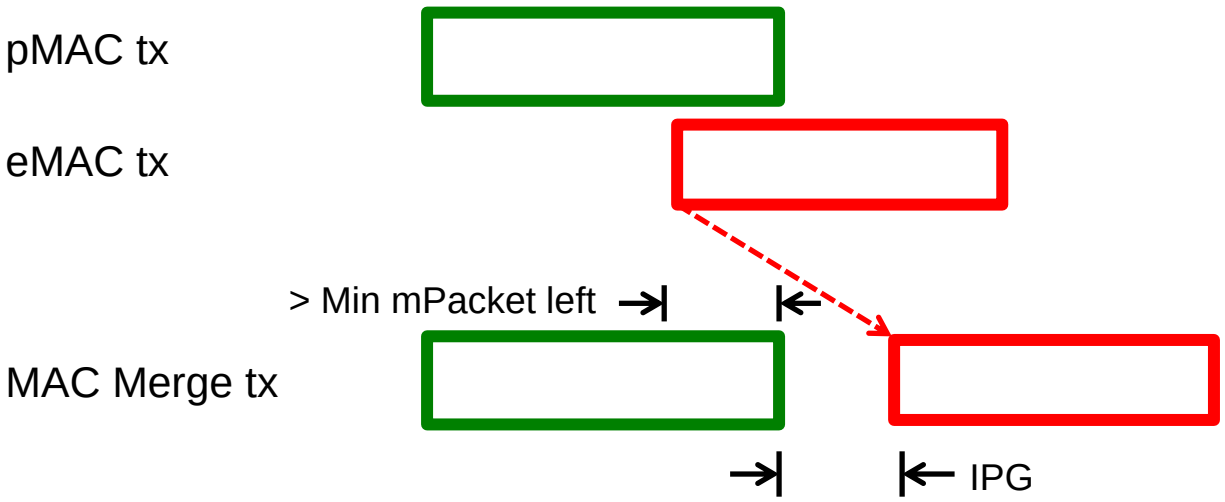
- Conflict excessively with non-guaranteed packet rocks:



- Problem solved by preemptive sand between the rocks: → reduced jitter for rocks & more bw for sand

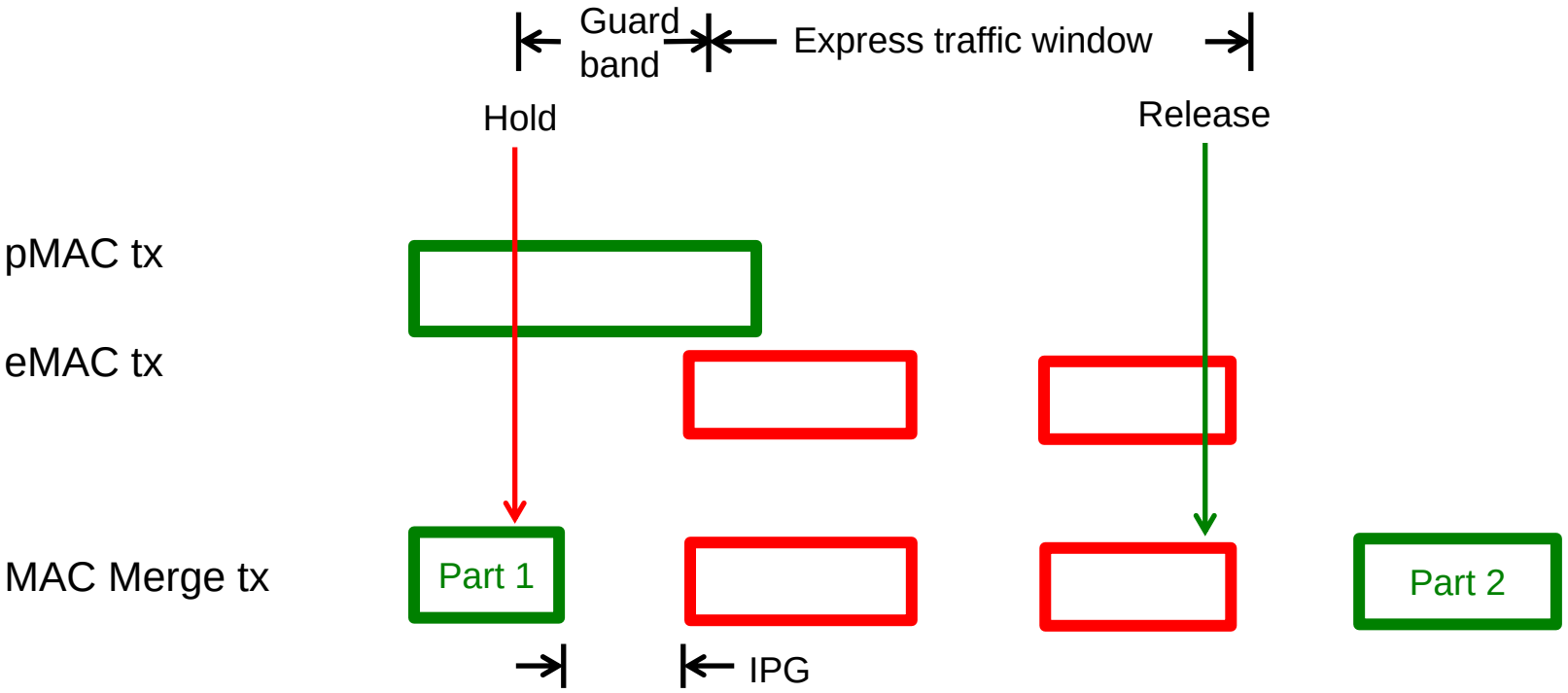


Without Hold and Release



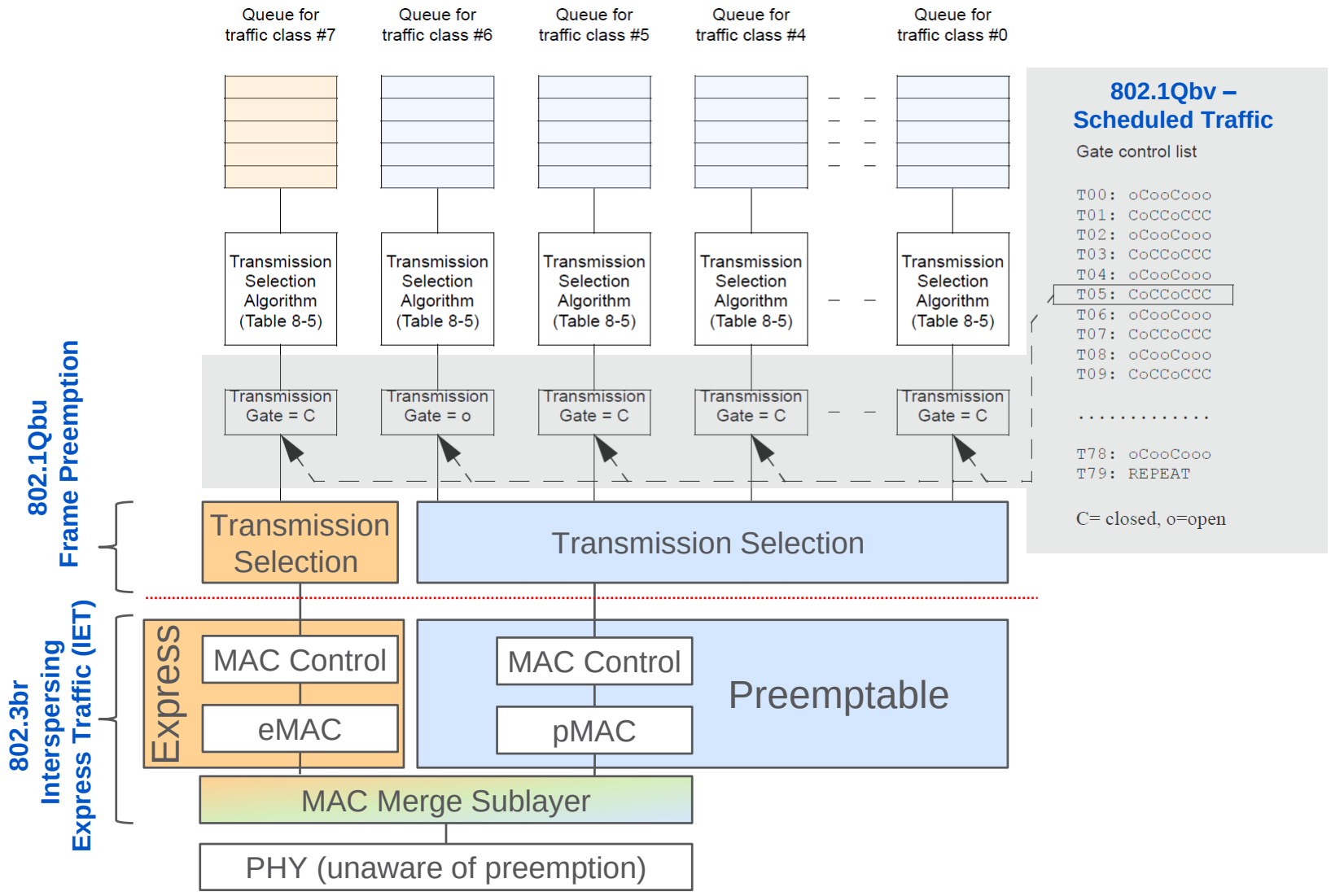
- Preemption isn't instantaneous.
- Packets with less than min packet size (64 octets) left to transmit or packets less than 123 octets can't be preempted.
- In many use cases, this delay is short enough but not in all cases.

With Hold and Release

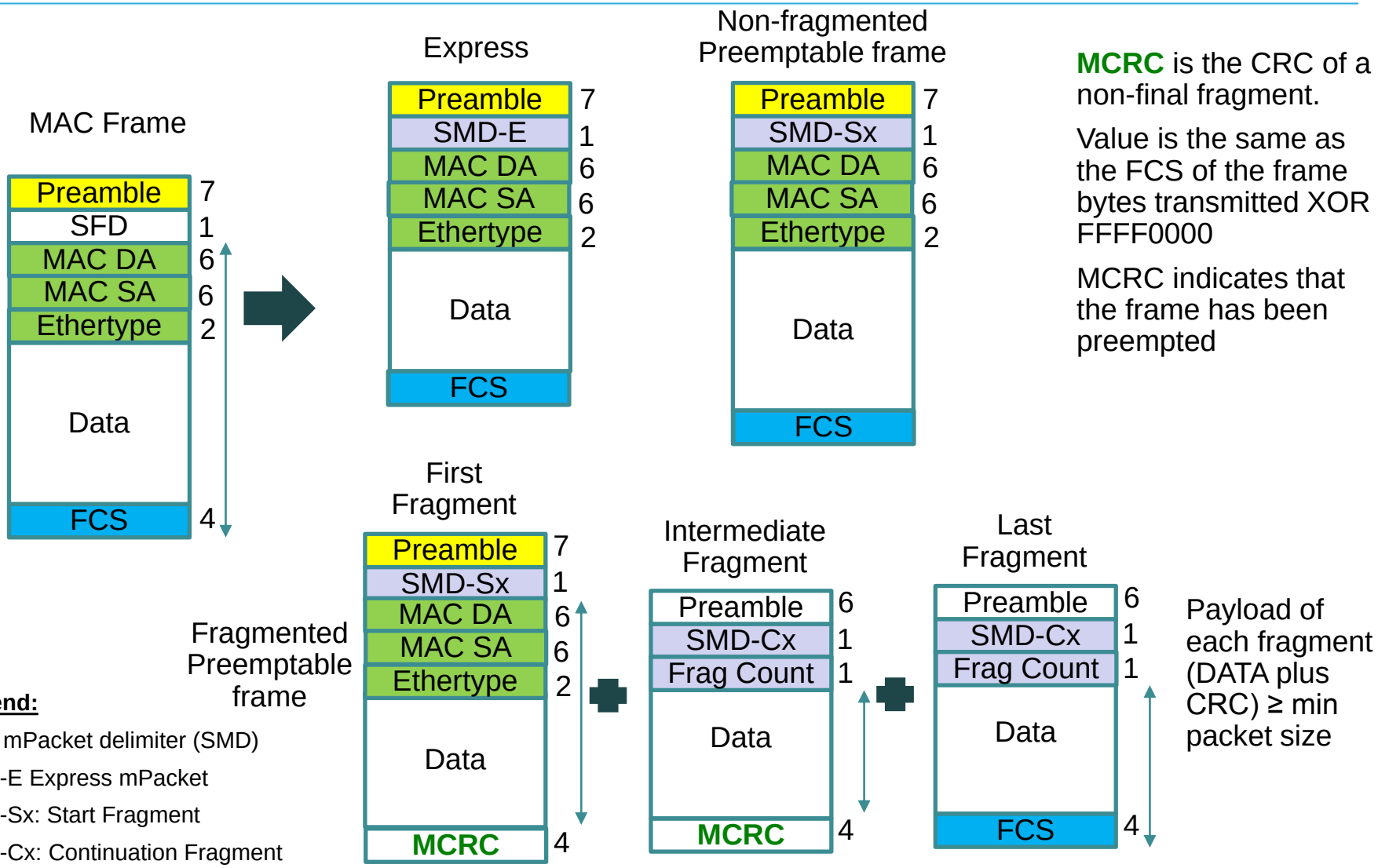


- Hold primitive can preempt packets before a the start of a scheduled **rock**

Preemption with Scheduling



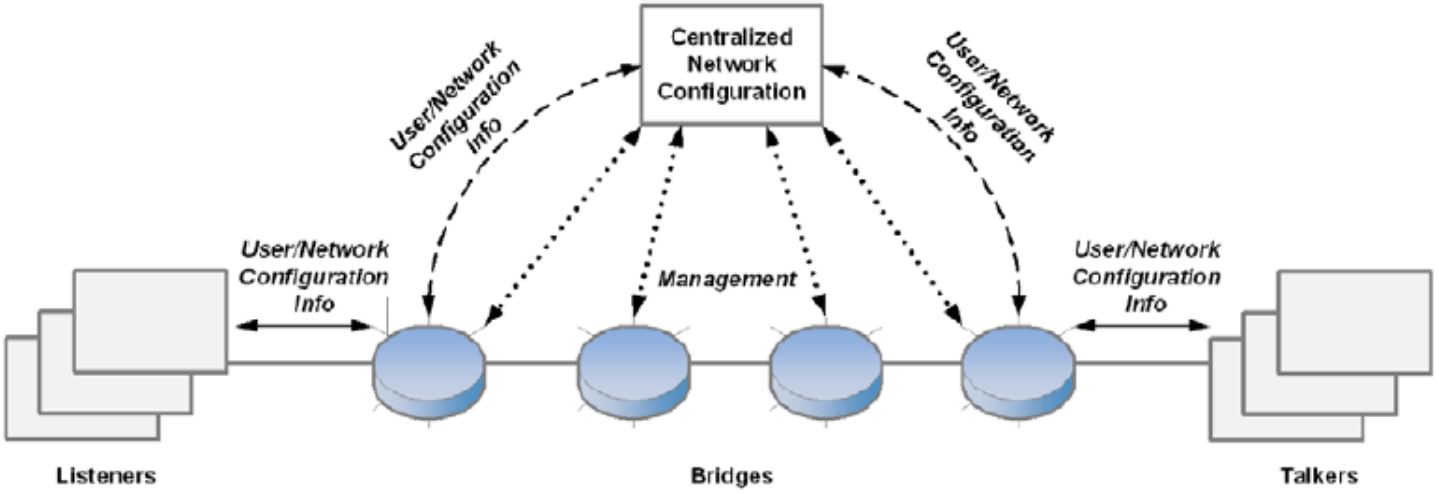
mPacket Format



DEDICATED RESOURCES

TSN Configuration

- TSN configuration (P802.1Qcc)
- Information model & YANG
- Configuration Models
  - Fully Distributed Model
  - Fully Centralized Model
  - Centralized Network / Distributed User Model



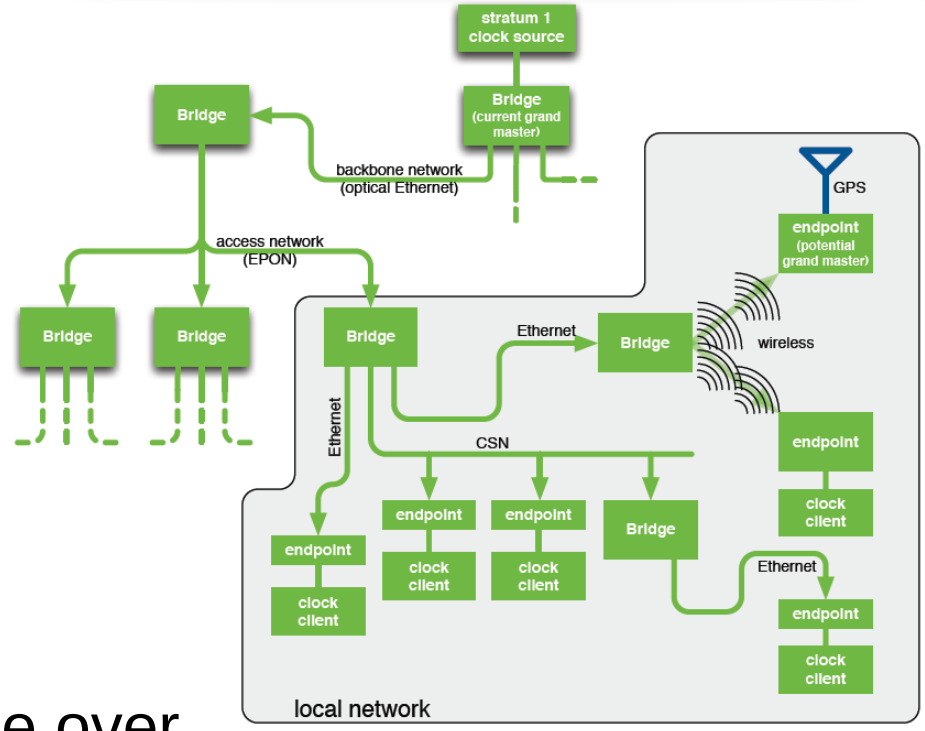
Reservation Protocol

- Stream Reservation Protocol (SRP - 802.1Qat)
  - Advertises streams
  - Registers the path of streams
  - Calculates the worst-case latency
  - Establishes an AVB domain
  - Reserves the bandwidth for streams
- SRP enhancements (P802.1Qcc)
- Link-local Registration Protocol (LRP - P802.1CS)
  - Replicate a registration including changes
  - Optimized for databases on the order of 1 Mbyte
  - Not tied to bridges

NO TIME TO TALK ABOUT

Timing & Synchronization

- A profile of IEEE 1588v2 for Layer 2 Ethernet (P802.1AS-Rev)
- Redundancy
  - Redundant paths
  - Redundant GMs
- Improved scalability
- Improved support for long chains, rings
- More responsive
- Faster Grand Master change over
- Reduce Best Master Clock Algorithm (BMCA) convergence time
- Multiple domains with synchronization information

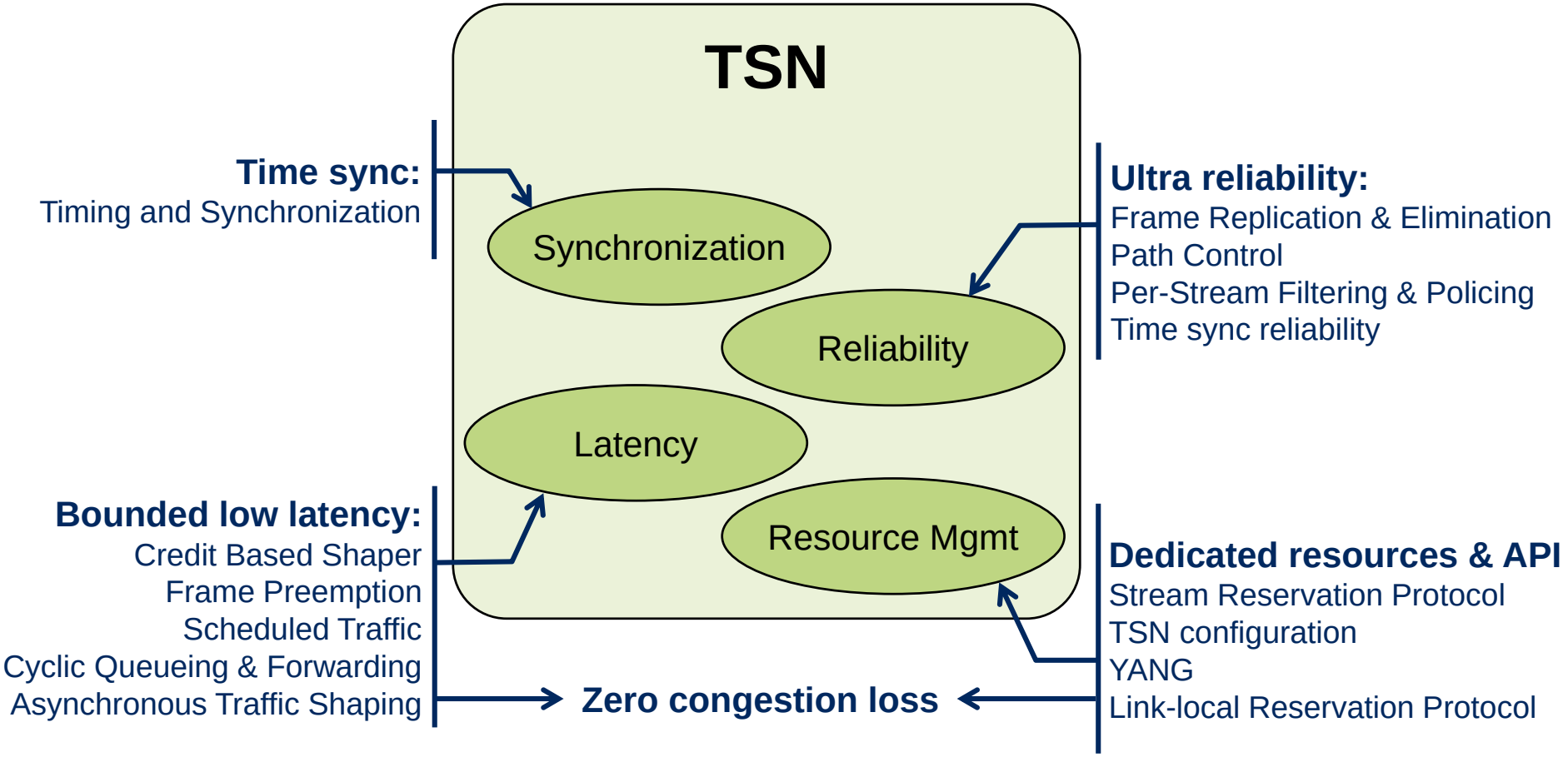


Security

- Port-based Network Access Control (802.1X)
  - Defines encapsulation of Extensible Authentication Protocol (EAP) over IEEE 802
  - Widely deployed on both wired and Wi-Fi networks
- MAC Security (MACsec) (802.1AE)
  - MACsec secures a link not a conversation
  - MACsec counters 802.1X man-in-the-middle attacks
- Secure Device Identity (802.1AR)
  - Supports trail of trust from manufacturer to user
  - Defines how a Secure Device Identifier may be cryptographically bound to a device to support device identity authentication

SUMMARY

Summary



Guaranteed data transport with bounded low latency, low delay variation, and extremely low loss

Q & A

Survey:
https://www.surveymonkey.com/r/99ieee

Thank You!

FURTHER READING

Further Reading

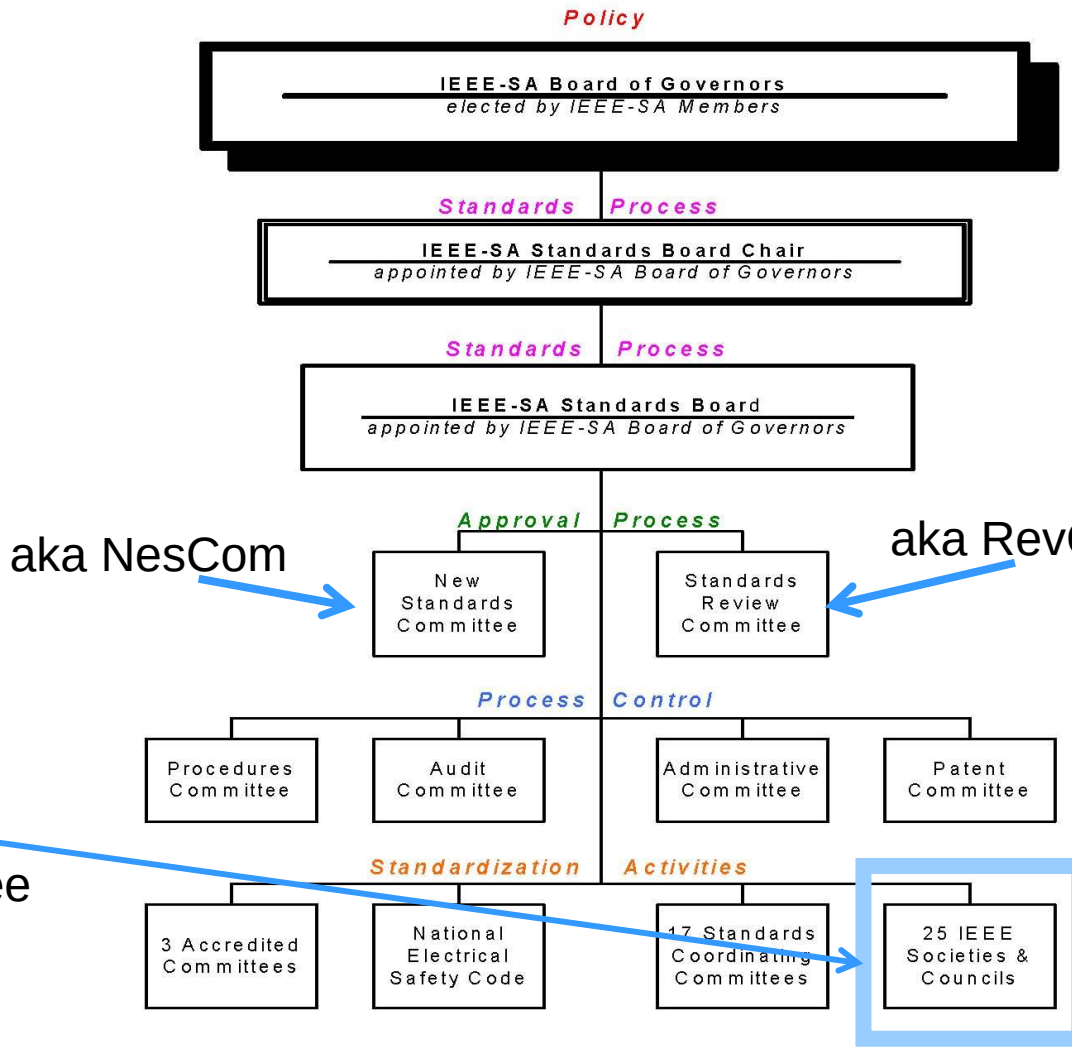
- http://www.ieee802.org/1, http://www.ieee802.org/1/pages/tsn.html
- IEEE 802.1 TSN for Automotive Networks – flyer http://standards.ieee.org/downloads/TSN_for_Automotive_Networks.pdf
- IEEE 802.1 TSN for Industrial Networks – flyer http://standards.ieee.org/downloads/TSN_for_Industrial_Networks.pdf
- Introduction to IEEE 802.1 TSN http://www.ieee802.org/1/files/public/docs2017/tsn-farkas-intro-0517-v01.pdf
- "A Time-Sensitive Networking Primer: Putting It All Together" https://drive.google.com/file/d/0B6Xurc4m_PVsZ1lzWWoxS0pTNVE/view?usp=sharing
- "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://www.ietf.org/meeting/86/tutorials/86-IEEE-8021-Thaler.pdf

Further Reading

- IEEE Std 802.1AE-2006 MAC Security
- IEEE Std 802.1AEbn-2011 Amendment: GCM-AES-256 Cipher Suite
- IEEE Std 802.1AEbw-2013 Amendment: Extended Packet Numbering
- P802.1AR-Rev/D2.2 Secure Device Identity
- IEEE Std 802.1X-2010 Port-Based Network Access Control
- IEEE Std 802.1Xbx-2014 Amendment: MAC Security Key Agreement Protocol (MKA) Extensions
- P802.1Xck Amendment: YANG Data Model
- RFC 7030 Enrollment over Secure Transport

BACKUP

IEEE Standards Organization



IEEE 802 is here:
a standards committee
formed by the
Computer Society

All Those Dots …..

- 802.1 Bridging and Architecture
  – generally the top of the link layer
- 802.3 Ethernet
- 802.11 Wireless LAN (WLAN)
- 802.15 Wireless Specialty Networks (WSN)
- 802.16 Broadband Wireless Access (BWA)
- 802.18 Radio Regulatory TAG
- 802.19 Coexistence
- 802.21 Media Independent Handover
- 802.22 Wireless Regional Area Networks (WRAN)
- 802.24 Vertical Applications TAG

TAG = Technical Advisory Group

IEEE 802.1 Working Group

- 802 LAN/MAN architecture, internetworking among 802 LANs, MANs and other wide area networks, 802 Security, 802 overall network management, and protocol layers above the MAC & LLC layers.
- Chair: Glenn Parsons
- Vice-chair: John Messenger
- Addressing and Data Center Bridging (DCB) TG
  - Chair: Patricia Thaler
- Maintenance TG
  - Chair: John Messenger
- OmniRAN TG (Model of IEEE 802 Access Networks)
  - Chair: Maximilian Riegel
- Security TG
  - Chair: Michael Seaman
- Time-Sensitive Networking (TSN) TG
  - Chair: János Farkas

IEEE 802.1 Standards

- The ones with capital letters, e.g. 802.1Q or 802.1AX are independent standards
- Amendments to these standards are identified by lower case letters e.g., 802.1Qbv or 802.1AEcg
- Periodically the amendments get merged into a revision of the main standard, e.g., 802.1Qav is now part of 802.1Q-2014
- 802.1Q can be considered as many individual standards (RFCs) integrated into a single document
  - Clauses 6 through 9 give a general overview of the 802.1Q bridge architecture
  - To get oriented on an additional area, it's best to read the Clause titled the "Principles of <area>"
  - Once oriented, references in the subclause of Clause 5 Conformance for the relevant device can be helpful

Basic Principles

- MAC addresses are “identifier” addresses, not “location” addresses
  - *This is a major Layer 2 value, not a defect!*
- Bridge forwarding is based on
  - Destination MAC
  - VLAN ID (VID)
- Frame filtering for only forwarding to proper outbound ports(s)
  - Frame is forwarded to every port (except for reception port) within the frame's VLAN if it is not known where to send it
  - Filter (unnecessary) ports if it is known where to send the frame (e.g. frame is only forwarded towards the destination)
- Quality of Service (QoS) is implemented after the forwarding decision based on
  - Priority
  - Drop Eligibility
  - Time

AVB Standards

- IEEE Std. 802.1AS-2011 – generalized Precision Time Protocol (gPTP)
  - A Layer 2 profile of the IEEE 1588 Precision Time Protocol (PTP)
- IEEE Std. 802.1Qav – Forwarding and Queuing of Time-Sensitive Streams (FQTSS):
  - Specifies Credit-Based Shaper (CBS)
- IEEE Std. 802.1Qat – Stream Reservation Protocol (SRP)
  - Registration and reservation of time-sensitive streams
- IEEE Std. 802.1BA – AVB Systems
  - Provides an overall AVB architecture and AVB profiles
- CBS + SRP to provide delays under 250 µs per bridge

Forwarding Process in 802.1Q