Choosing the Right TSN Tools to meet a Bounded Latency

Don Pannell

Fellow
Automotive Ethernet Networking, NXP

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Preamble

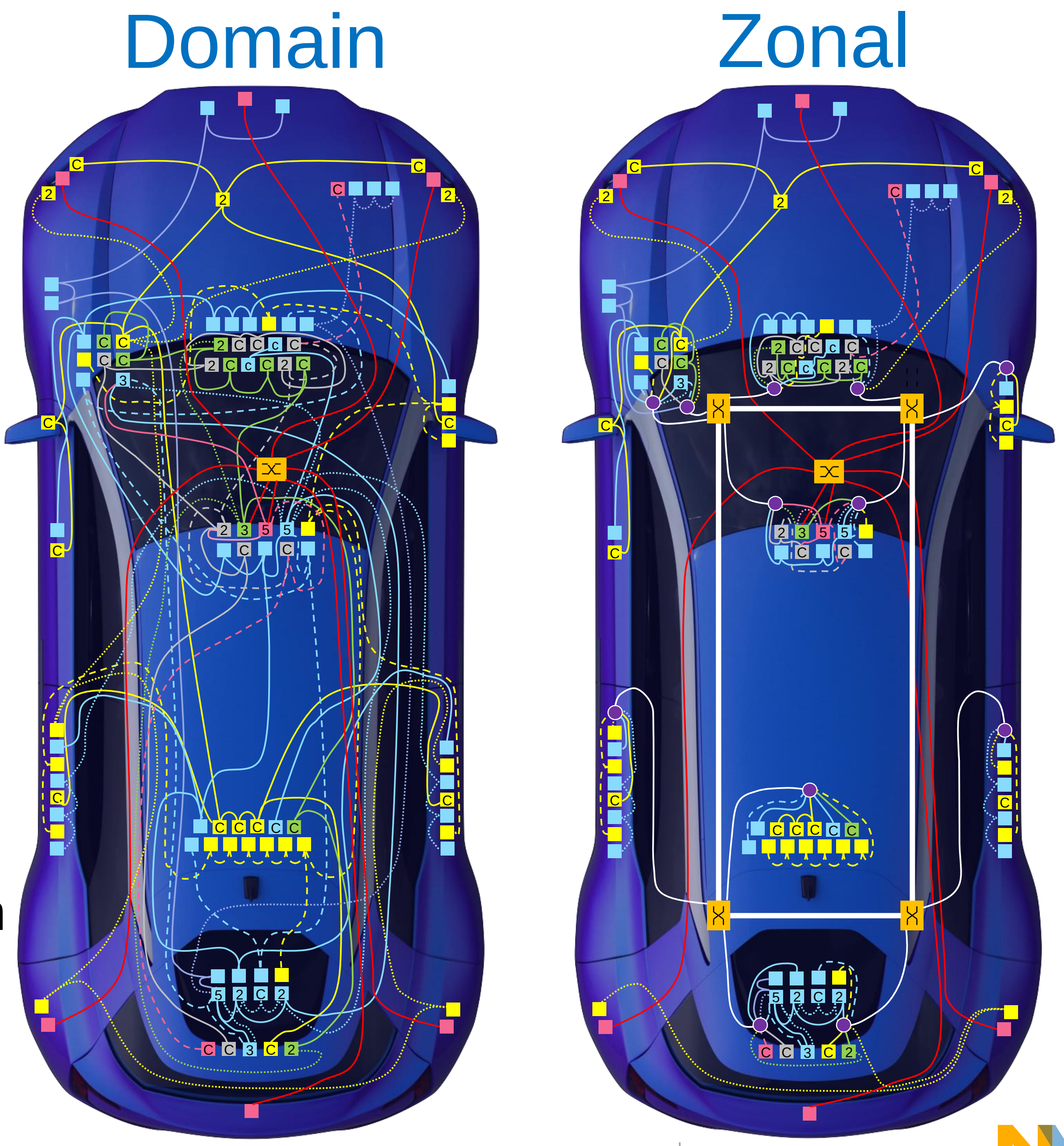
- This presentations was originally presented at the Sep 2019 IEEE Ethernet & IP Tech Day conference in Detroit and subsequently at the Feb 2020 Automotive Ethernet Congress in Munich

- An article is available that covers this presentation at:
- https://www.allaboutcircuits.com/industry-articles/choosing-the-right-tsn-tools-to-meet-a-bounded-latency/

- The goal of this presentation was to:
  - Simplify the latency equations for the selected TSN shapers so that some quick evaluation of what shaper may be appropriate for a given bounded latency can be made
  - Propose a queue model showing how the various shapers may be used together for automotive

The Need

- Ethernet's high speeds saves wires in Zonal networks
- And Zonal networks bring new requirements that (TSN) solves
  - Multiple Domains using the same wire
  - Yet each Domain needs to know its data will get delivered in the needed maximum time – as it no longer has its own dedicated wire!
  - How to guarantee & plan the maximum bounded latency for each flow is the focus of this presentation



Overview

- This presentation focuses on the TSN standards that affect bounded latency of flows through the Automotive Ethernet network
- It briefly lists the unique problems each of these Time Sensitive Networking (TSN) standards solves & the relative ‘costs’ of using each tool
- Based on these numbers, a per-hop metric is proposed, to help determine which TSN tool should be used and when
- This tool usage order, makes the job of “Engineering” the network easier via the step-by-step process described

List of Available TSN Tools for Controlling Latency

Standard's Name:	Also Known As:
Strict Priority	802.1p-1998 / QoS
Forwarding & Queueing for Time-Sensitive Streams	802.1Qav-2009 / Credit Based Shaper or FQTSS
Enhancements for Scheduled Traffic	802.1Qbv-2015 / Time Aware Shaper
Frame Preemption	802.1Qbu-2016 & 802.3br-2016

Note: IEEE 802.1 TSN is constantly doing new work so new tools will become available in products.

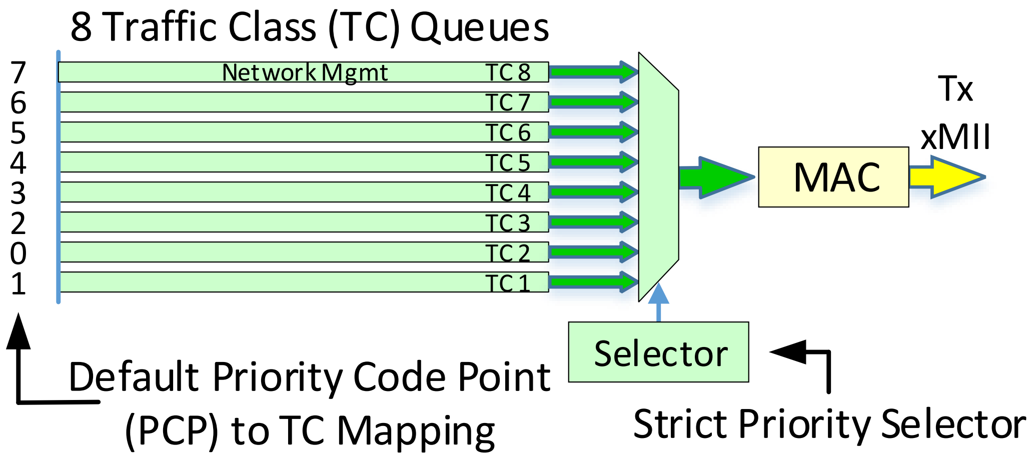
Known ones are: Cyclic Queueing & Forwarding, 802.1Qch; & Asynchronous Traffic Shaping, 802.1Qcr

The Shaper Standards:

What Problems the Standards Solve & How They were Envisioned to be Used

Strict Priority Shaper (Strict) – 802.1p-1998

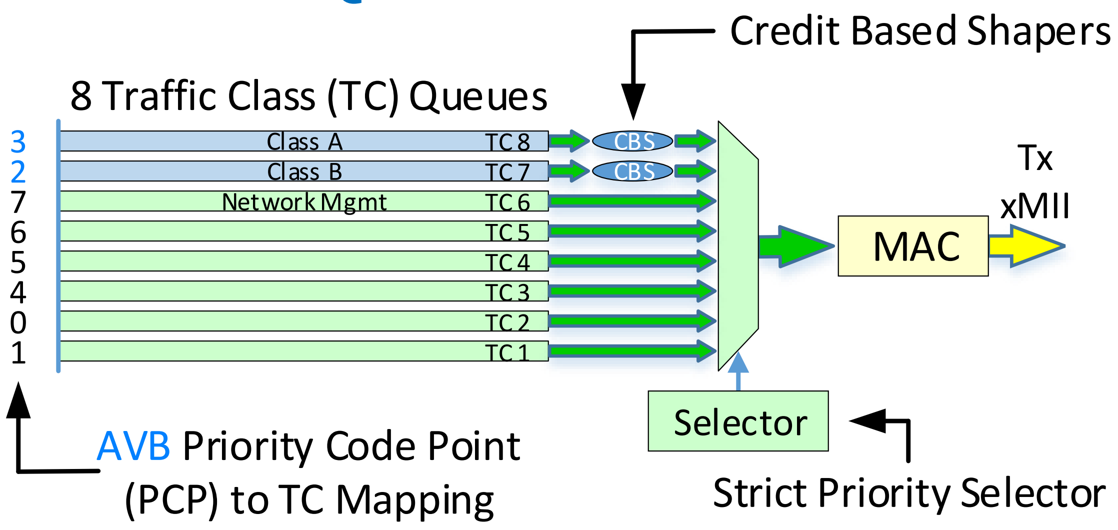
- Priority solves the problem that some frames are more important than others
- It was needed so Network Management could work



- Management frames had to get through in order to be able to fix Network problems – thus their placement in the top Traffic Class
- The Strict hardware selector is defined as: "Frames are selected from the corresponding queue for transmission only if all queues corresponding to numerically higher values of traffic class … are empty at the time of selection."

Credit Based Shaper (CBS) – 802.1Qav-2009

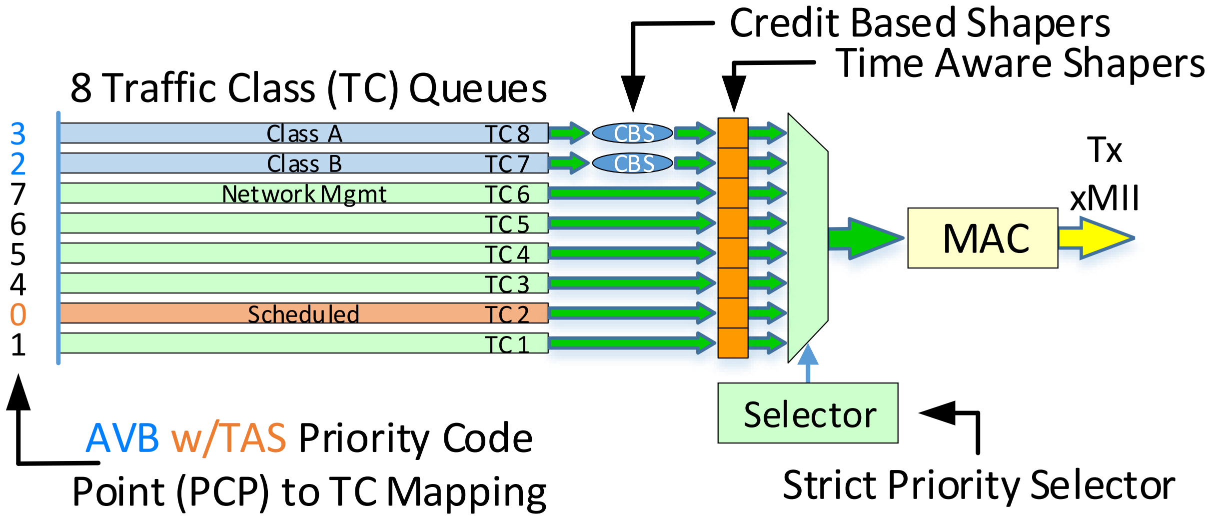
- CBS solves the problem that long bursts of data are really bad for the Bridges
- It was needed so Reserved frames are not dropped



- It caps the bandwidth a queue can transmit with hardware
- It de-bursts flows in hardware so that optimized software stacks that try to burst can be used (for streams that are not self-shaping)
  - I.e., audio from a USB drive vs. audio from a microphone or radio
  - It allows very small bursts of data to 'catch-up' due to momentary interference so the Reserved data rate can be maintained
  - In AVB, PCP 2,3 are re-mapped above Mgmt since they can't use 100% of the wire

Time Aware Shaper (TAS) – 802.1Qbv-2015

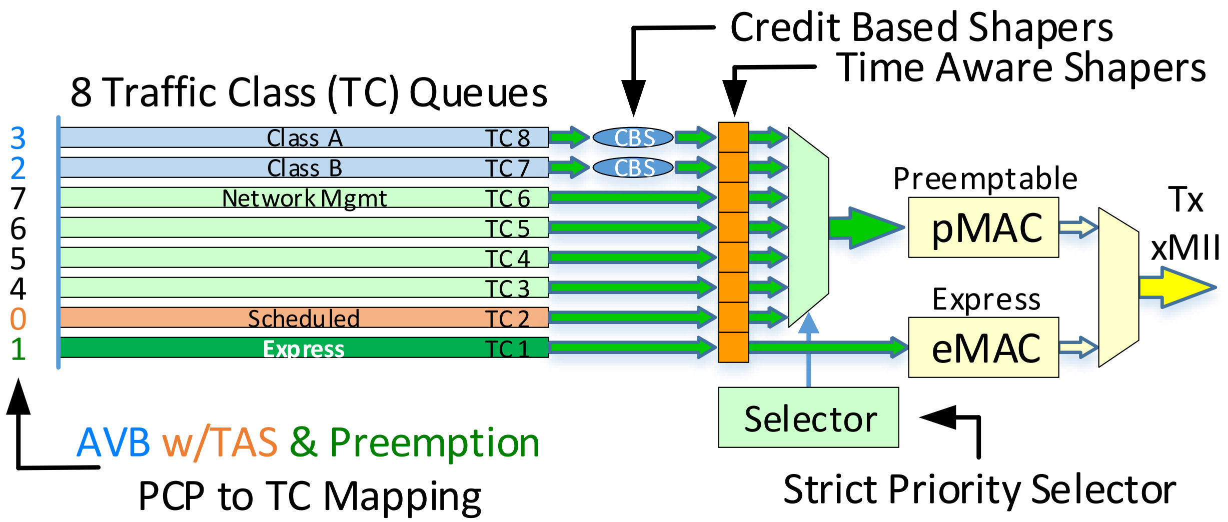
- TAS delivers the theoretically lowest possible latency for scheduled periodic data
- It uses significant bandwidth, so is best used as a last resort



- Transmission Gates are added for ALL queues just before the Strict Priority Selector
  - Following a defined periodic schedule, the gates on the queues are opened or closed for a period of time – allowing critical traffic to pass without interference
  - ALL queues are time-gated, but really only 1 or 2 queues are actually “Scheduled” and the “non-Scheduled” queues are left open during the remainder of the time
  - Any TC can be used for “critical” scheduled traffic (TC 2 in the figure)

Preemption – 802.1Qbu-2016 & 802.3br-2016

- ➢Preemption delivers very low latency for a limited set of non-scheduled data
- ➢Preemption gains the most on slow data links (≤ 100 Mb/s)



- ➢Two 802.3 MACs are used, a new one for "preemptable" traffic (pMAC) and the old one for "express" preempting traffic (eMAC)
  - ➢Only 1 level of preemption is supported & frames < 127 bytes can't be preempted
  - ➢802.1 allows connection of each TC queues to either MAC – if more than one queue connects to a MAC, the Strict selector algorithm is assumed
  - ➢In the figure, TC 1 is effectively above all the other TC's since it can preempt them!

The Shaper Standards: Their Metrics

Latency TSN Tool Comparison

TSN Tool	Silicon Complexity	Engineering Complexity[1]	Wire Efficiency[2]	Comments
Strict Priority	Low	Easy	100%	Needed component, but it is not deterministic by itself
Credit Based Shaper	Medium	Easy	100%	All CBS queues are deterministic + next highest TC (for Mgmt)
Time Aware Shaper	Medium	Hard (>1 TC) Medium (1 TC)	- Guard band - Idle opens	All TAS queues are deterministic
Frame Preemption[3]	High	Medium but only 1 level deep	- Fragment overhead	Fragmentation can affect determinism on the other flows

1: Engineering Complexity is the expected user difficulty or effort, needed to get proper results

2: Wire Efficiency is how much data can go down the wire – this includes critical data and background data

3: Note: Preemption is the only standard that requires support on both sides of the wire

Per Hop Latency – Credit Based Shaper

- Class A ≈ $_t$Interval + $_t$MaxFrameSize
  - $_t$Interval = observation interval of the Class (125 uSec for AVB – but can be changed)
  - $_t$MaxFrameSize = the maximum size of an interfering frame + gaps, etc.
  - This is a good rule-of-thumb equation that results in slightly higher numbers than the equation in 802.1BA-2011 subclause 6.5
- Class B ≈ $_t$Interval + $_t$MaxFrameSize + $_t$TimeForAllHigherFrames
  - $_t$TimeForAllHigherFrames = the time to transmit all Class A frames (+ gaps, etc.) for the duration of Class B's $_t$Interval (which is typically multiple Class A tIntervals)
- Class C ≈ $_t$Interval + $_t$MaxFrameSize + $_t$TimeForAllHigherFrames
  - Where tTimeForAllHigherFrames includes Class A & Class B frames
- Etc.

Per Hop Latency – Credit Based Shaper – part 2

- Class A ≈ $_{t}$Interval + $_{t}$MaxFrameSize
  - For a 64 byte frame in a 125uSec observation interval the worst case # is:
  - On a 100BASE link ≈ 125 uSec + 124 uSec = 249 uSec per hop
  - On a 1000BASE link ≈ 125 uSec + 13 uSec = 138 uSec per hop
- The observation interval is a significant portion of these latencies
  - Lower worst case latency numbers are possible on 1000BASE links by using shorter observation intervals, but it can't go below the time of $_{t}$MaxFrameSize
  - But lowering this number reduces latency at the cost of Reservation capacity
    - 1000 vs 100 is either 10x lower latency or 10x the capacity or somewhere in between

Note: The simplified equation on the previous page is useful for calculating the worst case latency range for a fully loaded (i.e., 75% bandwidth allocation) on a Class A link. A scheduling tool needs to use the equation that is in IEEE 802.1BA. Also see: http://www.ieee802.org/1/files/public/docs2011/ba-boiger-per-hop-class-a-wc-latency-0311.pdf

Per Hop Latency – Time Aware Shaper

- Store & Forward with Gate Open ≈ $_t$Device + $_t$FrameSize
  - $_t$Device = the delay through a Store & Forward bridge
    - Good Rule-of-Thumb is 2 x 512 bit times + Cable delay
      - or 10.5 uSec for 100BASE & 1.5 uSec for 1GBASE
  - $_t$FrameSize = the size of the frame passing through the bridge
      - For more information see http://www.ieee802.org/1/files/public/docs2011/new-pannell-latency-options-0311-v1.pdf
- For a 64 byte frame the worst case # is:
  - On a 100BASE link ≈ 10.5 uSec + 5.2 uSec = 15.7 uSec per hop
  - On a 1000BASE link ≈ 1.5 uSec + 0.5 uSec = 2.0 uSec per hop

Per Hop Latency – Frame Preemption

- Store & Forward w/ Preemption ≈ $_t$Device + $_t$FrameSize + $_t$Framelet
  - $_t$Device = the delay through a Store & Forward bridge
    - Good Rule-of-Thumb is 2 x 512 bit times + Cable delay
      - or 10.5 uSec for 100BASE & 1.5 uSec for 1GBASE
  - $_t$FrameSize = the size of the frame passing through the bridge
  - $_t$Framelet = 127 bytes + overhead, max size interfering frame that can't be preempted
      - For more information see http://www.ieee802.org/1/files/public/docs2011/new-avb-pannell-latency-options-1111-v2.pdf
- For a 64 byte frame the worst case # is:
  - On a 100BASE link ≈ 10.5 uSec + 5.2 uSec + 11.8 uSec = 27.5 uSec per hop
  - On a 1000BASE link ≈ 1.5 uSec + 0.5 uSec + 1.2 uSec = 3.2 uSec per hop

Note: Preemption requires support on both sides of the wire

Latency TSN Tool Comparison in Lowest Latency Order

TSN Tool	Engineering Complexity	Wire Efficiency	Worst Case Latencies – 1st Order Approximation	Ranking
Time Aware Shaper	Hard (>1 TC) Medium (1 TC)	- Guard band - Idle Opens	15.7 uSec FE Hop 2.0 uSec GE Hop	2
Frame Preemption	Medium but only 1 level deep	- Fragment overhead	27.4 uSec FE Hop 3.2 uSec GE Hop	3
Credit Based Shaper	Easy	100%	249 uSec FE Hop 138 uSec GE Hop	1
Strict Priority	Easy	100%	Can't determine	N/A

Note: FE = 100BASE, GE = 1000BASE

Reasons for the Rankings:

1 = Multiple queues can be used with different observation intervals/latencies

2 & 3 = Assuming only 1 TC is used for very limited, very critical traffic only

2 is more available than 3 in products, supports lower latencies & has a more deterministic effect on the impacted Reserved flows

The Shaper Standards: Which Tool to Use First

Proposed Tool Usage Order

- Process the critical flows in smallest to highest allowed latency order
- First ensure the total bandwidth through any link is not more than 75% loaded with these flows
  - This # could go a bit higher, but 60% to 75% is a good place to start
- Start with the Credit Based Shaper
  - Select an Observation Interval that is as large as possible that delivers the required latency over the path(s) the flow uses
  - If the default 125 uSec Observation Interval is too long, reduce it, but don’t go < 125 uSec on 100BASE links
  - If that doesn’t work, use Time Aware Shaping &/or Preemption as last resorts
    - As these are limited resource that are less wire efficient
    - Subtract any wire efficiency loss as used bandwidth toward the 75% critical flow limit

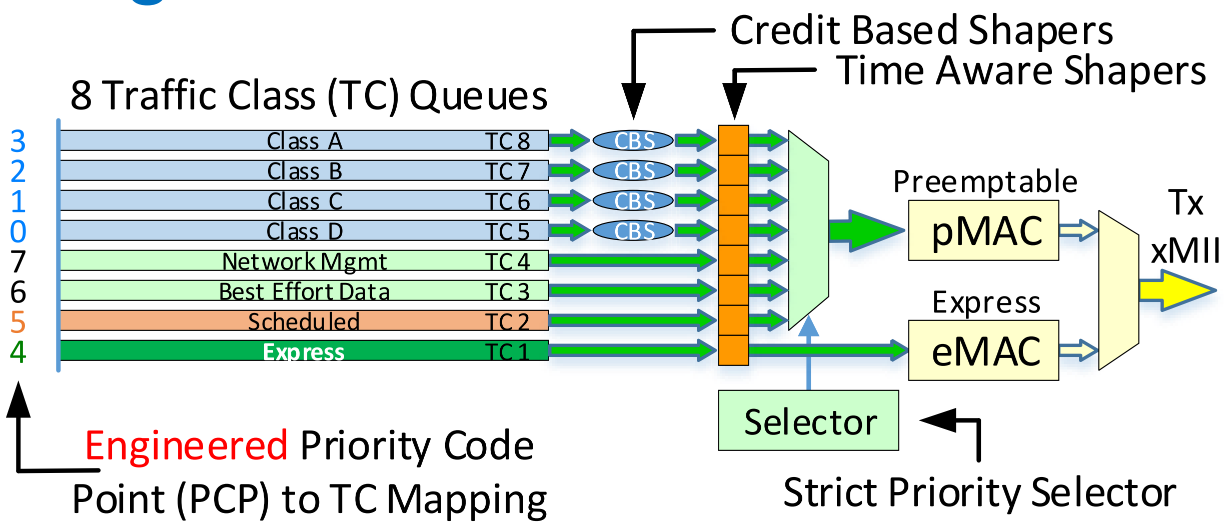
Proposed Tool Usage Order – part 2

- Multiple Credit Based Shaper's w/increasing Observation Intervals can be used – More than two Classes can be used if needed!
  - Start by loading each Class no more than 20% of the link's bandwidth
  - Keep in mind that the sum total of ALL Reserved flows, & their frame (IFG, etc.) & scheduler overhead (Qbv & Qbu), must not exceed 75% of any one link's bandwidth
    - If this happens, try an alternate path for the flow
    - 60% may be a better starting number so that new flows can fit in easier
      - CAN network loading is typically started at 50% so new messages can be added
        - To fix bugs & oversites
        - And to add new features
- Network Mgmt must be the highest non-CBS Traffic Class
- The remaining "non-Reserved" flows will use the remainder of the unused bandwidth in a Best Effort fashion

Summary

Summary & Proposed Queueing Model

- These standards are designed to work together
- Multiple different data delivery requirements/latencies can be supported on the same wire



- The Credit Based Shaper is not limited to just Audio & Video data & it is not limited to the AVB Profile's plug-&-play parameters
- There is a current limit of 8 Priority Code Points (PCP) that are effectively used to indicate the "type of service" a flow needs
- Automotive networks are Engineered, but let the hardware enforce the needed guarantees to make the job much simpler

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Disclaimers

- This is a really hard concept that has been simplified so that an easy starting point on which shaper to use for a target flow can be made
- The listed latency numbers are in the correct range but they are still estimates. For example:
  - A generic bridge delay is used vs. the actual delay in the specific bridge being used
  - All latency numbers use 64 byte data frames. In most cases, larger data frames will impact the latency numbers.
  - 127 byte non-preemptable frames is clear to understand & is a good 1st order approximation
  - Cable delay is mostly ignored – which is approximately 80ns for 15 meters
  - Look at the referenced presentations & others on the same subject in the same areas
- As a rule-of-thumb for link speed conversion in a bridge:
  - For $_t$MaxFrameSize & $_t$Framelet use the egress link speed, for $_t$FrameSize use the ingress link speed and for $_t$Device use the faster link speed of the two

IEEE 802.1 Automotive AVB and TSN Standards Handout

	Transport	Synchroni-zation	Stream Reservation	Quality of Service	Redundancy	Security
AVB 802.1BA-2011 The AVB Profile	1722-2011 Media Transport Protocol	802.1AS-2011 gPTP	802.1Qat-2010 SRP (now Q clause 35)	802.1Qav-2009 Credit Based Shaper (now Q clause 34)	-	802.1X-2010 802.1Xbx-2014 802.1Xck-2018 Network Access
TSN	1722-2016 Adds CAN, FlexRay, LIN, + more Audio/Video Transports	802.1AS-2020 Redundant gPTP	802.1Qcc-2018 Enhanced SRP 802.1Qca-2015 Path Control & Reservation	802.1Qbv-2015 Time Aware Shaper 802.1Qbu-2016 & 802.3br-2016 Preemption 802.1Qch-2017 Cyclic Queue Forwarding 802.1Qcr Asynchronous Shaping	802.1CB-2017 Frame Replication & Elimination 802.1AS-2020 Redundant gPTP	802.1Qci-2017 Policing 802.1AEcg-2017 (end-to-end) MACSec

Standards without an appended year are not completed yet.

Updated 1-2020

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-2019 10BASE-T1S 15m Point to Point 25m Multi-Drop 10BASE-T1L 1000m Point to Point	802.3bw-2015 100BASE-T1 15m Point to Point	802.3bp-2016 1000BASE-T1 15m Point to Point	802.3ch 2500BASE-T1 15m Point to Point	802.3ch 10GBASE-T1 15m Point to Point	?

Media Interface (PHY) Standards without an appended year are not completed yet. Updated 1-2020