Challenges & Solutions of Mixed Data Rate Ethernet Networks

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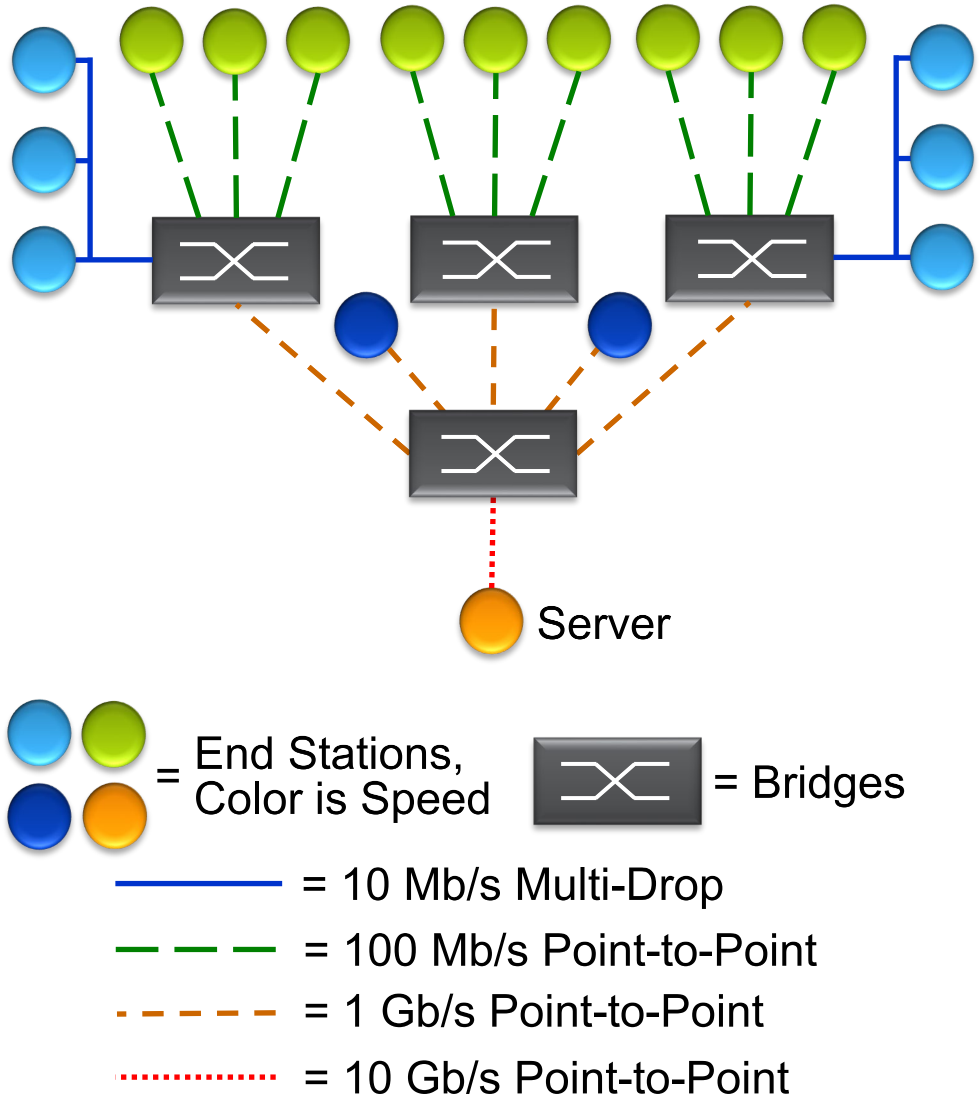
OVERVIEW

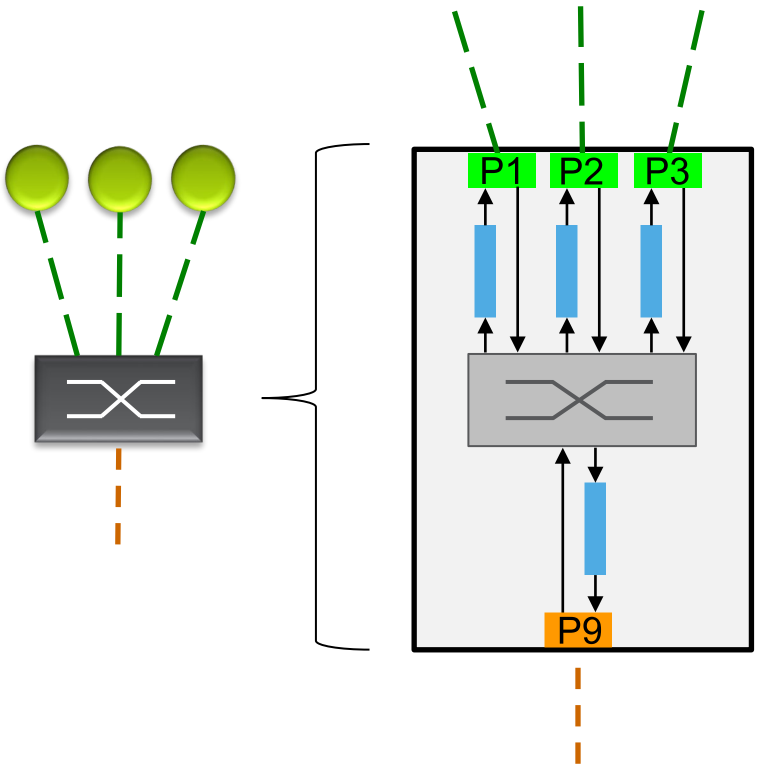
- The Challenges
- Historical Solutions
- Today’s Solutions
- Summary

Overview – The Challenges of Mixed Data Rate Networks



- IEEE 802.3 has standardized Automotive PHYs in link speeds from 10 Mb/s to 10 Gb/s
- This variety gives a network designer the ability to use the most cost-effective / power-efficient solution at each point in the network
- A classic client-server architecture model is shown
  - Bridges are used to connect multiple slower links to a single faster link as flows move down toward the server
  - This allows all nodes to talk to the server at the same time without concern for the bridges dropping frames
  - The server can also talk to all the end stations assuming it can keep up with its processing – but faster link to slower link flows create congestion points where bridges can drop packets
  - This model will be used to show the methods available to mitigate dropped packets due to congestion

The Problem – Congestion Points



= Tx Queues/Buffer

= MACs = Switch Fabric

= 100 Mb/s Point-to-Point

= 1 Gb/s Point-to-Point

- Congestion points occur wherever the rate of data entering a port's Tx Queue's buffer exceeds the port's transmit rate
- This rate change is easy to see if P9 (1 Gb/s) is sending data to P1 or P2 or P3 (all 100 Mb/s) – a 10 to 1 ratio
- But P1 could also be a congestion point if both P2 & P3 are sending data to it at the same time – a 2 to 1 ratio
  - This is true for any port where 2 or more ports of the same speed are sending data to a port at the same time
- Tx Queue buffers are like shock absorbers designed to absorb the impact of momentary congestion
  - But if the congestion is too long, the buffers will fill, and packets will be dropped! They are like water funnels that can overflow.
- Note: 10BASE-T1S ports are congestion points even if the data entering a 10BASE-T1S port's buffer is 10 Mb/s
  - This is because the 10 Mb/s media is shared between all nodes

Historical Solutions

The non- Time Sensitive Networking solutions

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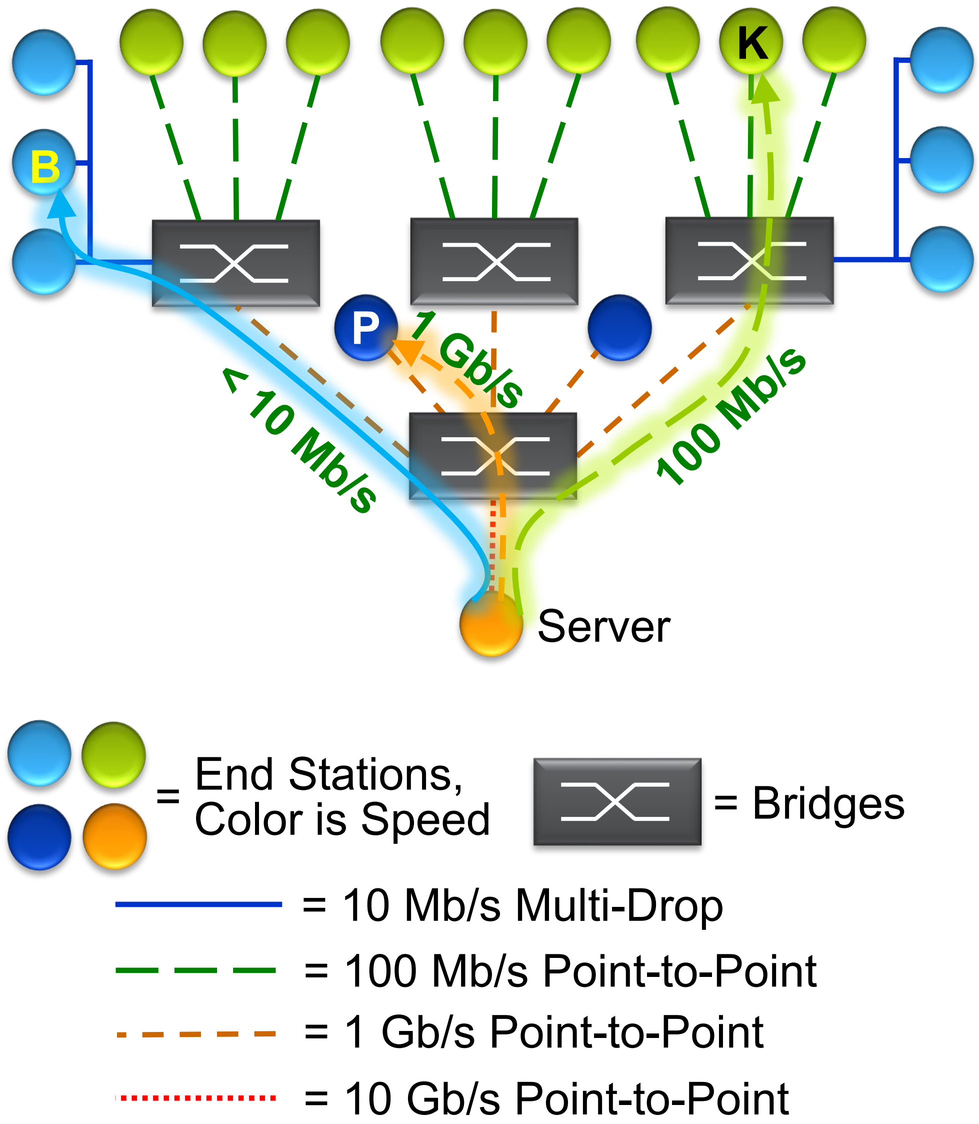
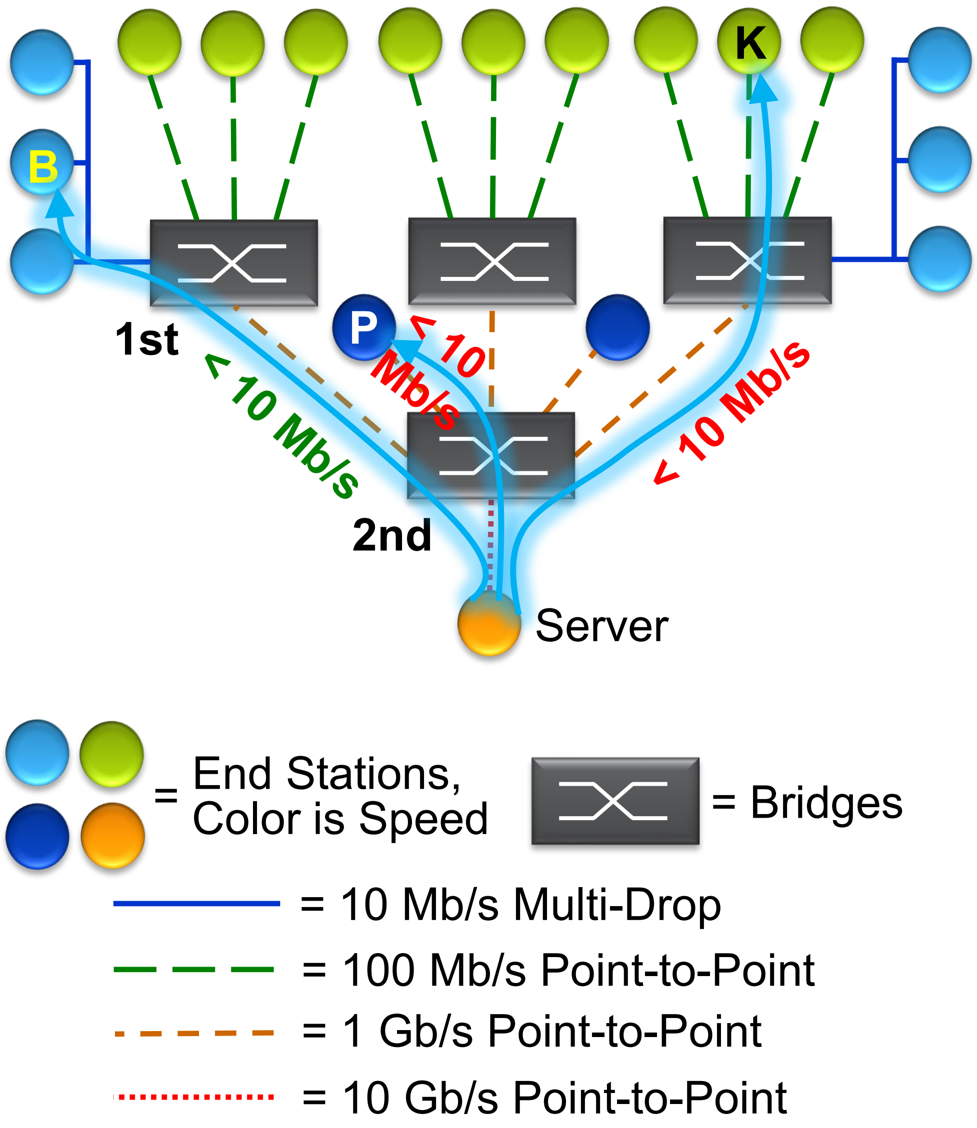
TCP/IP's Built-in per-flow Slow Start Rate Mechanism



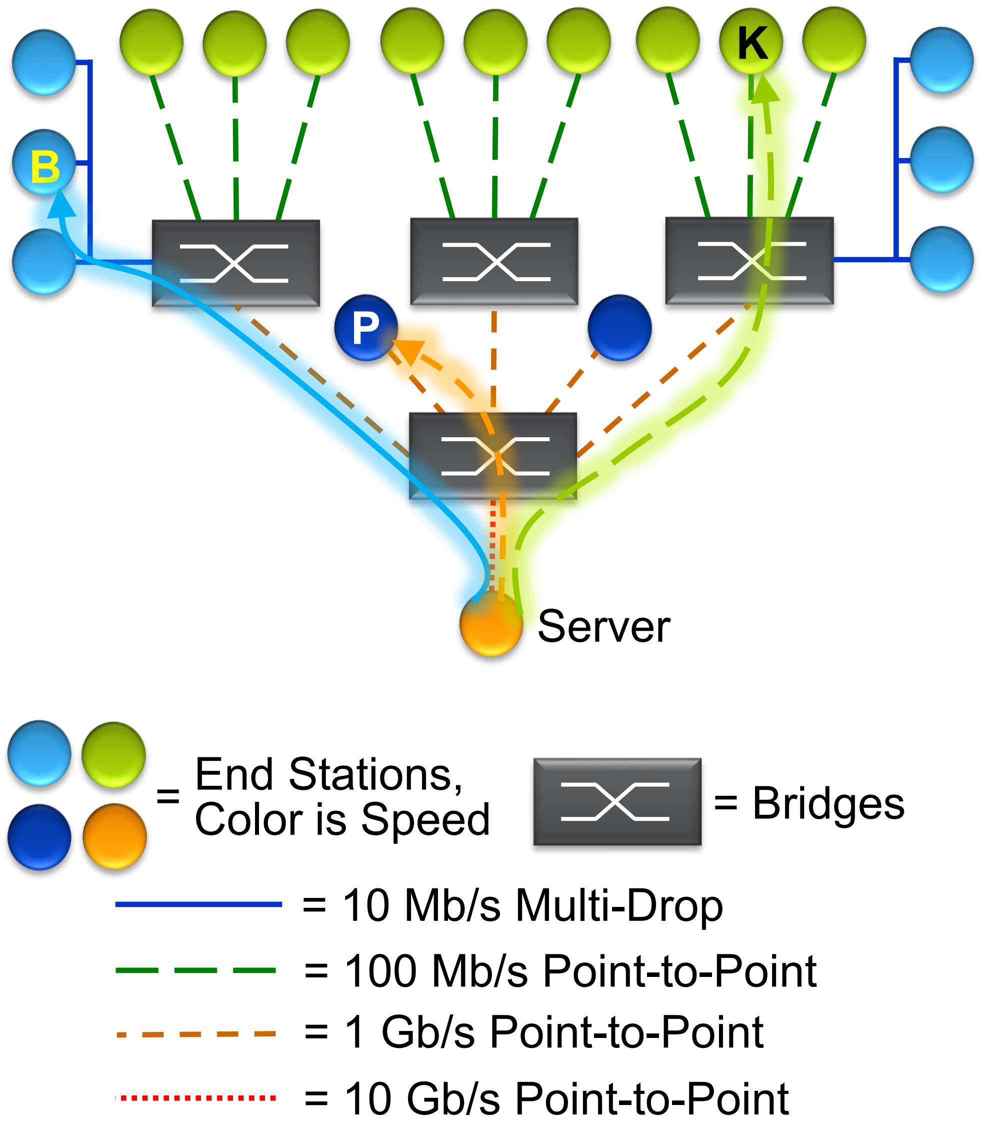
- When the Server sends a flow to nodes B, K & P each flow needs to be at a different Tx rate due to link speeds used and due to other network traffic flows
- TCP/IP sends a small burst of packets to each node
  - If the node acknowledges a good reception (ACK), TCP/IP increases the burst size for that flow until the node replies that it didn't get all the data (NAK - negative acknowledge)
  - TCP/IP periodically re-tests the limits to see if the congestion went away; resulting in additional packet loss
- Benefits:
  - The Server can send data to many nodes back-to-back utilizing its link's bandwidth as well as dynamically adjusting to the network's link utilization changes
- Problems:
  - It is slow to stabilize the rate, it is non-deterministic, and it requires packets to be dropped to adjust!
    - This works for TCP/IP as it supports re-transmission of lost data

IEEE 802.3x MAC Flow Control



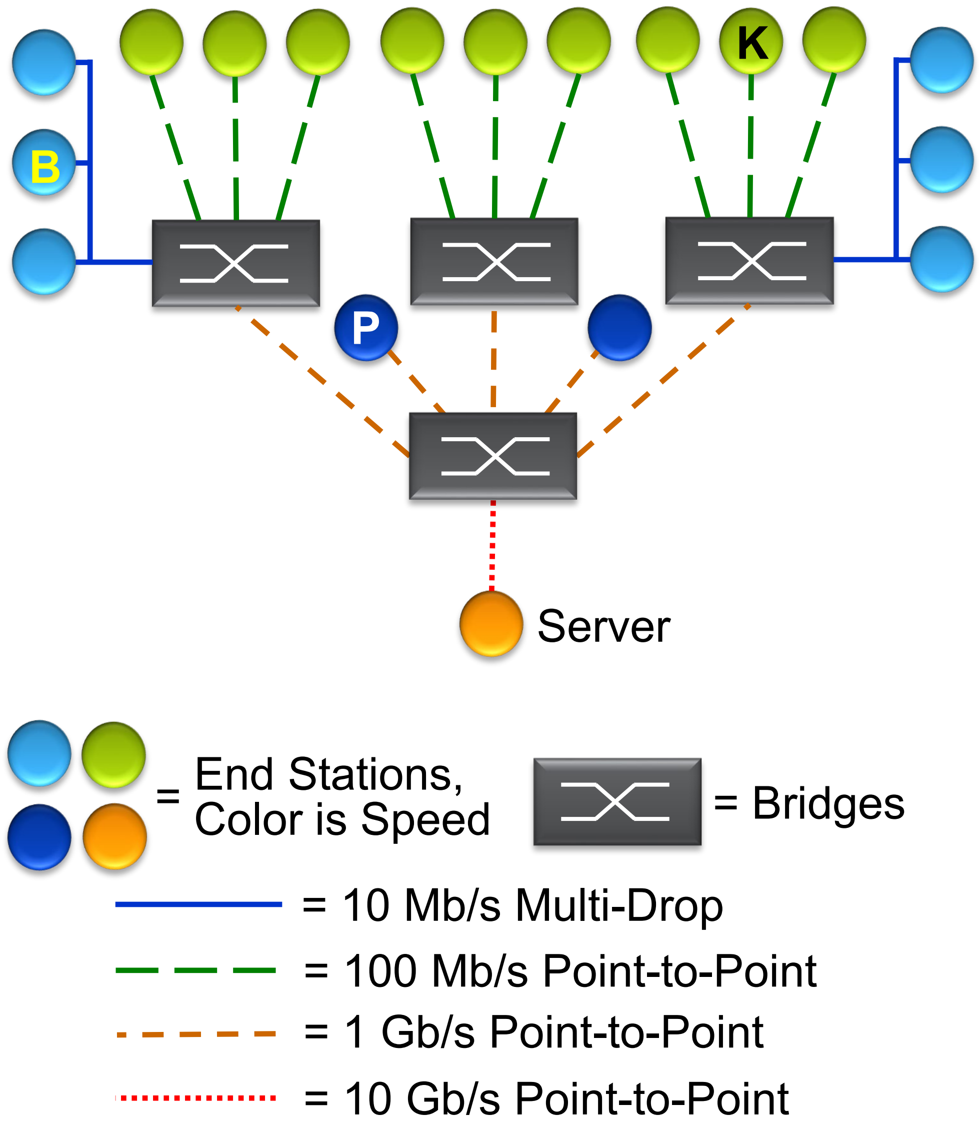
- MAC Flow Control uses Pause frames
  - The receiving node use these frames to tell the sending node to stop transmitting due to its buffers filling up, and when the buffers recover, to re-start transmitting again
  - It is limited to Full-Duplex links only **10BASE-T1S**
- Benefits:
  - No packets are dropped if the buffers are large enough to support the round-trip time of sending the Pause (after the Tx line frees up) to the time the flow stops
- Problems:
  - Since a Paused port stops sending all frames, the network can slow down to the speed of the slowest link
    - For example: If the 1st Bridge connected to node B sees its buffer filling it will Pause the 2nd Bridge; which causes the 2nd Bridge's buffer to fill which causes the Server to be Paused – slowing the Server's 10 Gb/s link to < 10 Mb/s – for all flows! This happens in the real-world when Bridges are configured to never drop any frames

IEEE 802.1Qbb MAC Priority-based Flow Control



- Priority-base Flow Control was developed for Data Center Bridging when it was evident its Congestion Notification Protocol (802.1Qau) could not prevent packet drops under quick changes in network congestion
  - It is limited to Full-Duplex links only **10BASE-T1S**
  - It was designed to work with Congestion Notification
- Benefits:
  - It is an enhancement to Pause frames where only designated Traffic Class Queues are paused allowing others Traffic Classes to transmit
- Problems:
  - All flows in a given Traffic Class Queue are Paused
    - Which generally contain multiple flows!
  - Hard to configure - there are at most 8 Traffic Classes

Summary of non-TSN Mechanisms



- TCP/IP Slow Start
  - Great for the Internet – doesn't work with UDP, etc.
- IEEE 802.3x MAC Pause
  - May be OK "inside a box" (for single flow applications) – But "outside the box" it breaks TCP/IP's Slow Start mechanism & can choke link bandwidth
- IEEE 802.1Qbb Priority-based Flow Control
  - Designed for Data Center Bridging where short delays on the data are better than TCP/IPs re-transmission
- TCP/IP gets each flow to its intended destination at its optimal rate – but can this be done for non-TCP/IP flow types without dropping any packets?

Today’s Solutions

The Time Sensitive Networking solutions

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TCP/IP is a very Interesting Historical Model

- TCP/IP scales as each End Station is responsible to adjust the needed buffering and transmission rate of each of its <u>independent</u> flows
  - It works in the largest of networks today (Corporations & the Internet) – but for TCP/IP flows only
  - Each End Station is responsible for the number of flows it generates as a self-contained system
    - Giving designers a simpler problem to solve, & to verify, as its all local to the End Station Talker only!
  - And it works with simple Bridges for 10 flows or 10,000 flows through the device
    - Bridges don't need to be per-flow aware (except for policing at the End Station to Bridge connection)
- TCP/IP gets each flow to its intended destination at its (almost) best possible rate

- But TCP/IP has drawbacks for deterministic real-time applications
  - A TSN solution needs to work without dropping any packets as part of the flow rate mechanism
  - And it needs to work with UDP in addition to OSI Layer 2 flows, etc.

- Can we keep the good parts of TCP/IP and improve on its problem areas?

IEEE 802.1Qav – TSN's Credit Based Shaper (CBS)

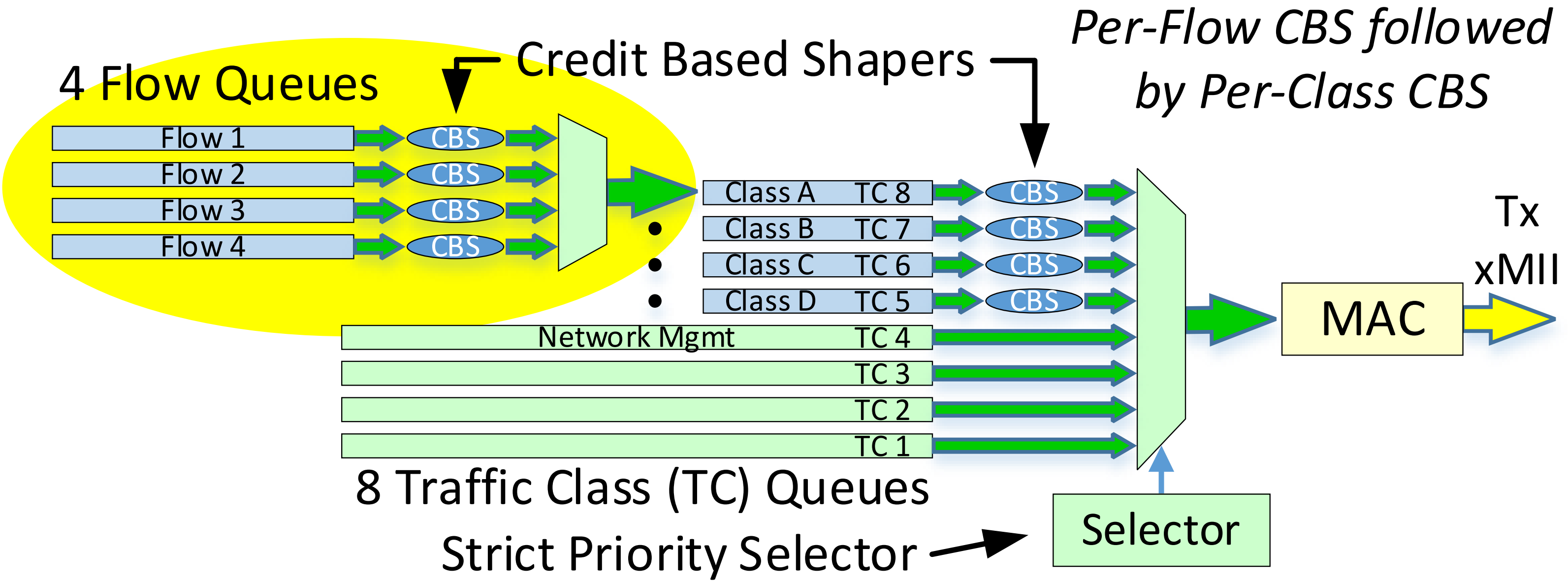
- The problem of "sending many streams of data through a network such that no packets are dropped" was solved by the 1st TSN Profile, the plug-&-play AVB use case
  - This solution needed:
    - To support non-TCP/IP flows (e.g., UDP & OSI Layer 2) where re-transmission is too slow
  - And it was accomplished:
    - By reducing the stress (on the buffers) at all network congestion points for a given class of flows

- CBS ensures no packets are dropped due to congestion by adding a specific requirement for end station Talkers:
  - Clause 5.20 b) of IEEE 802.1Q-2018: "Support the operation of the credit-based shaper algorithm (8.6.8.2) as the transmission selection algorithm used for frames transmitted for each stream associated with the SR class."
  - This additional requirement for Talkers over Bridges, performs per-flow shaping (to limit each flow's transmission rate independently like TCP/IP does) followed by a per-class shaper (to de-burst each class's data – a common requirement for both Bridges & Talkers)

Note: CBS does not require network-wide time awareness, meaning it works without gPTP (IEEE 802.1AS)

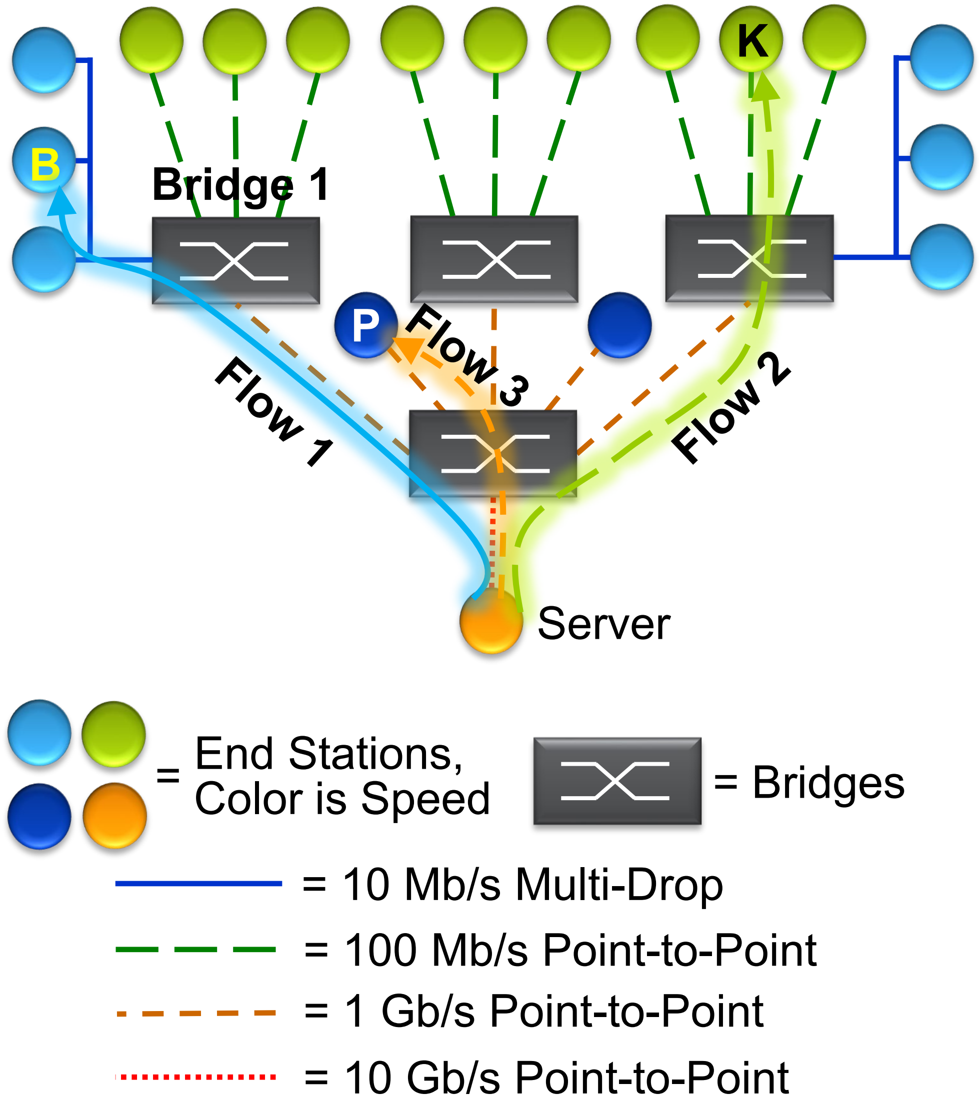
IEEE 802.1Qav – A Talker's Credit Based Shaper (CBS)

- The figure below shows an example of the CBS requirements in a Talker
  - All Classes (A, B, C & D) have the same structure – i.e., per flow rate-limiting by CBS, merging into a Traffic Class queue where the aggregate is de-burst by the Traffic Class's CBS
  - Only Class A's 4 Flow Queues are shown, but each Class can have any number as needed
- Since Automotive is outside the AVB Profile (IEEE 802.1BA) Automotive can define more than AVB's 2 Classes (A & B) & it can define their Observation Intervals to be different



- This is a model only – there are many ways to implement this
  - Buffers for Flow 1 to 4 are needed, but Class A's buffer can be virtual
  - When frames appears on the wire is what is important!
  - Software implementations can be used for mid to low-rate flows

Why is per-flow Rate Shaping Required in a Talker and not a Bridge?



- Consider the Server being a Talker sending:
  - Class A **Flow 1** to End Station B at **2 Mb/s**
  - Class A **Flow 2** to End Station K at **20 Mb/s**
  - Class A **Flow 3** to End Station P at **200 Mb/s**
  - A total of **222 Mb/s** for **Class A**
  - The Server's Class A CBS setting = 222 Mb/s
- Also consider <u>without</u> per-flow CBS, if the Server:
  - Builds a large burst of frames for End Station B
  - And places these frames into Class A's queue ahead of frames intended for Flow 2 and/or Flow 3
    - Likely, as CPU's work on one task at a time for a period
  - Bridge 1 will receive Flow 1's burst at 222 Mb/s and will transmit that burst at < 10 Mb/s to End Station B
  - Depending on the burst size, frames will be dropped!

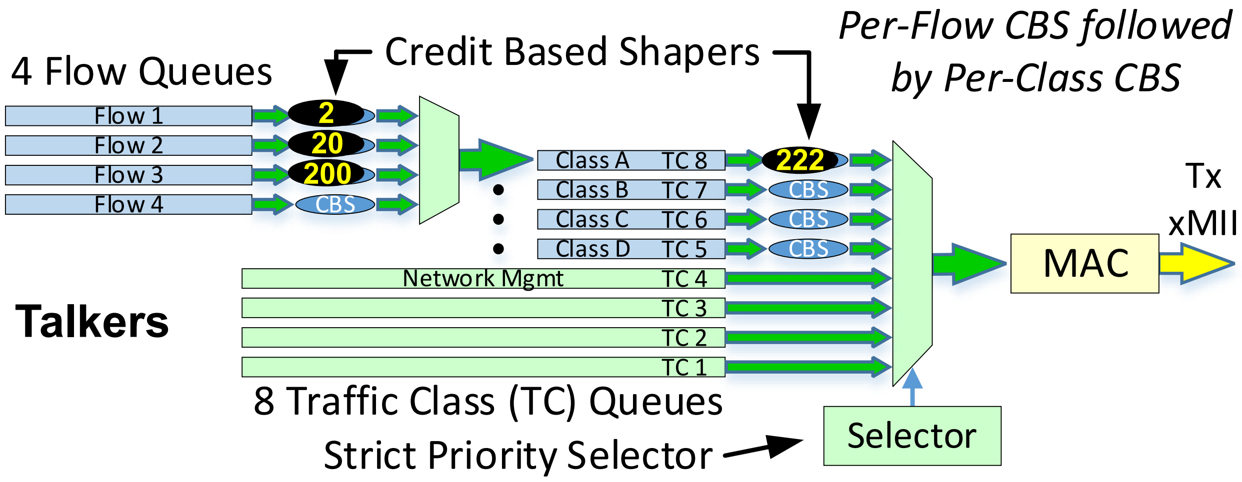
Comparing Per-Flow CBS vs. Per-Class CBS in a Talker

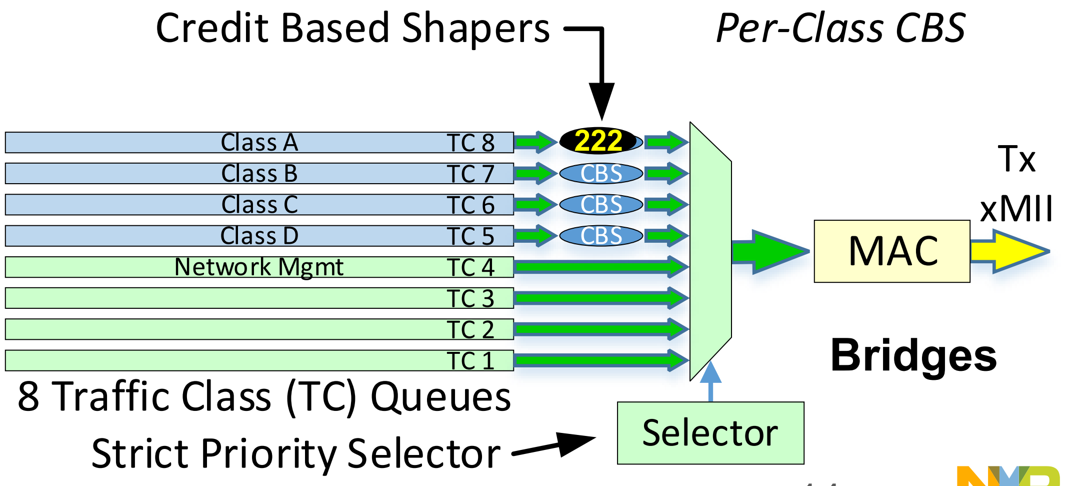
- In a single process time slot, the CPU links in a burst of 2 Mb/s packets for End Station B

Talker model	Bridge model
• Talker model the frames go in Flow 1's queue • Flow 1's CBS releases them at 2 Mb/s	• Bridge model the frames go in Class A's queue • Class A releases them at 222 Mb/s!

- In a subsequent process time slot, the CPU links in a burst of 200 Mb/s packets for End Station P

Talker model	Bridge model
• Talker model the frames go in Flow 3's queue • Flow 3's CBS releases them at 200 Mb/s	• Bridge model the frames go in Class A's queue • Class A releases them at 222 Mb/s!
• Flow 1 Tx = 2 Mb/s, Flow 3 Tx = 200 Mb/s	• Flow 1 Tx = 222 Mb/s, Flow 3 Tx = 222 Mb/s





Common Questions about Talker CBS

- Why not add more buffering to Bridges (Bridge 1 specifically in the example)?
  - This doesn't scale: The memory size that works for one application probably won't for another
    - The buffer size may work for 2 to 1 congestion, but then fails with 3 to 1 or higher congestion
  - Not possible: Memory can't be added to self-contained single chip Bridges
- What is the purpose of the Class CBS in a Talker?
  - If Flow 1, 2 & 3 are all 30 Mb/s, Class A is 90 Mb/s. Class A's CBS helps spread out the 3-frame burst if a frame from each Flow showed up in Class A for transmission at, or near, the same time
- How does this solve congestion?
  - If the Talker transmit each flow at its intended rate, congestion point are de-stressed
    - The only remaining contentions are a single lower priority interfering frame, and frames at the same priority. But Bridge buffers can handle these small-size contentions
- Can IEEE 802.1Qcr, Asynchronous Traffic Shaping (ATS), solve this?
  - ATS in Bridges is great. But ATS rate limits flows so large bursts from a Talker will still blow out a Bridge's buffers & frames are dropped. Talkers still need to Tx each flow at its expected rate!

Summary & Conclusions

Summary & Conclusion

- Talker per-flow rate transmission control solves the problem
  - And the Credit Based Shaper (CBS) is the only TSN Tool defined for Talker per-flow rate control
- CBS was standardized in 2009 so it is mature & available in many products
  - CBS does not require network-wide time awareness, meaning it works <u>without</u> gPTP (802.1AS)
- Per-flow CBS does not always require hardware as it is a frames/second problem
- Some flows are self-shaping, and these flows don't need the a per-flow CBS queue
  - For example, audio flows from a microphone collects *n* samples and then transmits a frame, collects *n* more samples and then transmits the next frame, … at a constant frames/sec rate
- Do bridges need CBS in small networks?
  - CBS allows small bursts of packets to "catch up" due to momentary contention
  - The per-class CBS function in Bridges, de-burst these small bursts so they don't get larger
  - In my opinion, due to the small size of Automotive networks, per-flow Talker CBS is all that is required if Bridge hops are few, as <u>the Talker is the critical place to get the flow rate correct</u>!
- Solution: <u>Per-flow CBS in Talkers</u> + CBS in Bridges (for larger networks)

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