On ATS

Johannes Specht (Self)

Introduction

Simple questions

- What is the best TSN shaper?
- Is ATS or TAS better for me?
- …

Giving Answers is tough

- What is your topology, in detail?
- What is your traffic, in detail?
  Path, pattern, quantitative and qualitative requirements of every stream!
- How dynamic is traffic and topology during runtime?
- How much planning and/or computation is ok?
- Do end station applications like the network timing?
- What is your Bridge failure model?
  They never fail, fail-silent only, or in a malicious manner?
- …

This Session

- Encourage discussion
  - Discussion ATS and other “TSN Shapers”
  - Discussion of aerospace use-cases

→ **Please just ask questions, interrupt me/add yourself to the queue, etc.**

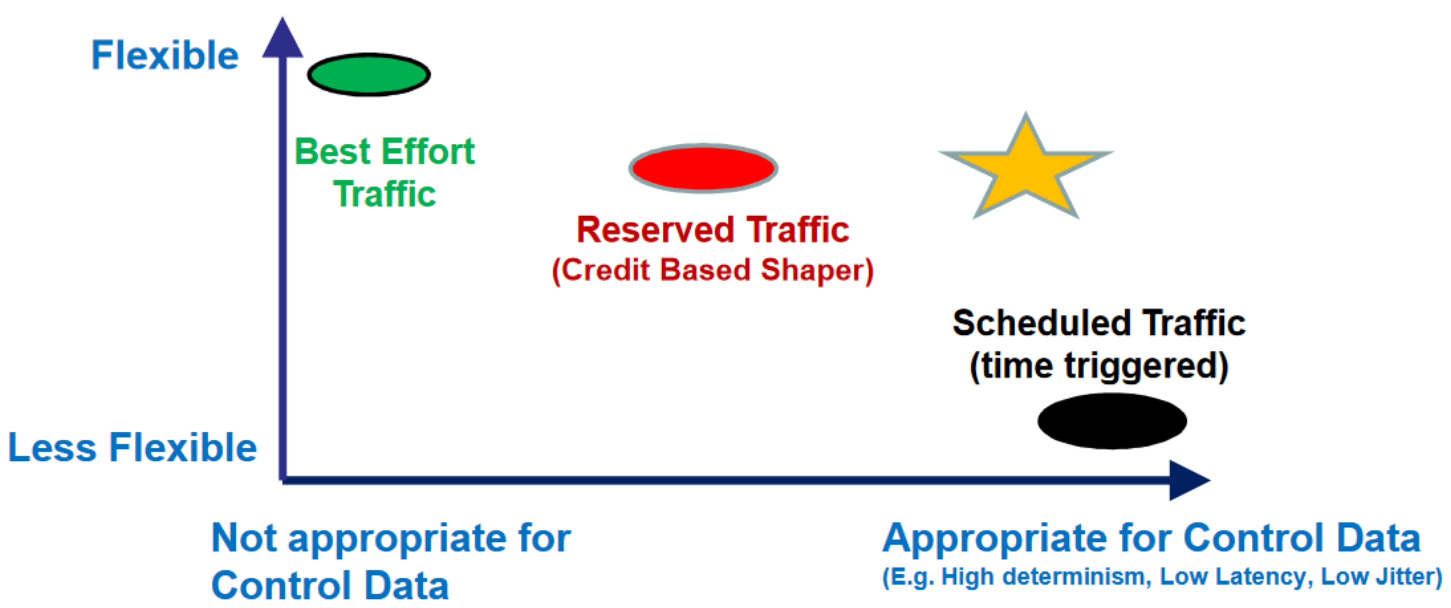
This Slide Set

- Put ATS in context
- Properties of ATS/first thoughts on aerospace traffic
- ATS Math
- Explicit Pointers/References
  (in addition, look for “specht”, “ubs”, or “ats” in https://www.ieee802.org/1/files/public/docs2013 through https://www.ieee802.org/1/files/public/docs2021)

ATS Context

Background & Motivation: UBS → ATS

Flexible Control Traffic Class



- IEEE 802.1 TSN is currently working on proposals for additional traffic types with the desired properties: Flexible AND Appropriate for Control Data ★
- AAA_2C input on requirements / desired properties.

GM

Markus Jochim, General Motors Research
Johannes Specht, University of Duisburg-Essen

IEEE 802.1 Plenary Session
July 14 - 19, 2013 – Geneva, Switzerland

8

Source: https://www.ieee802.org/1/files/public/docs2013/new-tsn-jochim-aaa2c-requirements-for-control-traffic-0713-v01.pdf

The Standardized “TSN Shapers” @ Zero Congestion Loss

→ No “one size fits all”

- ***Different shapers are optimized for different areas in a multi-dimensional problem space***
- ***Performance Requirements, Reliability Requirements, Network Layout, etc.***

Shaper Std. and usage	**Bandwidth Efficiency** Converged Traffic	**Latency Bounds**	**Jitter Bounds**	**Global Clock Sync. Dependency**	**Configuration Complexity**	**Protection & Isolation** Per-stream filtering and policing (802.1Qci-2017)
Credit-based Shaper (CBS) IEEE Std 802.1BA-2011/AVB w. MSRP	High	High	Loose	No	Low, Dynamic	Loose
Time-Aware Shaper (TAS) IEEE Std 802.1Qbv-2016 /TDM & Zero Interference/Sync. Apps	Low	Ultra Low	Ultra Tight	Yes	High, Static	Tight
Cyclic Queuing and Forwarding (CQF) IEEE Std 802.1Qch-2016	Low	Medium	Tight	Yes	Low, Dynamic	Loose
Asynchronous Traffic Shaping (ATS) IEEE Std 802.1Qcr-2020	High	Medium	Loose	No	Low, Dynamic	Tight
Strict Priority (SP) IEEE Std 802.1Q, static usage	Medium	Medium	Loose	No	High, Static	Loose
Strict Priority (SP) IEEE Std 802.1Q, with a priori bounds	Medium	Medium	Loose	No	Medium, Dynamic	Loose

Results of abstraction, individual experiences, systems/use-cases in mind, etc.:
Ask *M* people to insert values, get *M* different tables! Ask *N* people for the important columns, get *N* sets of columns!
Interpretations, conclusions, translations to numbers (e.g., “Medium” v. “Medium”) are impossible without knowing all background details from the author!

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Found in many, maybe all “TSN Switches”

If TAS is supported, and PSFP is *properly* implemented, CQF is supported.

Focus of this slide set

Always present

<u>**Results of abstraction, individual experiences, systems/use-cases in mind, etc.:**</u>
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Upfront, first thoughts: ATS for Aerospace Traffic?

Traffic Types Documentation

- Both supported
- Irrelevant/per stream abstraction
- NO => No significant delay penalty
- End station perception
- Supported
- Supported
- **Numbers needed!**
- Designed for 0 loss in absence of errors on path
- Supported

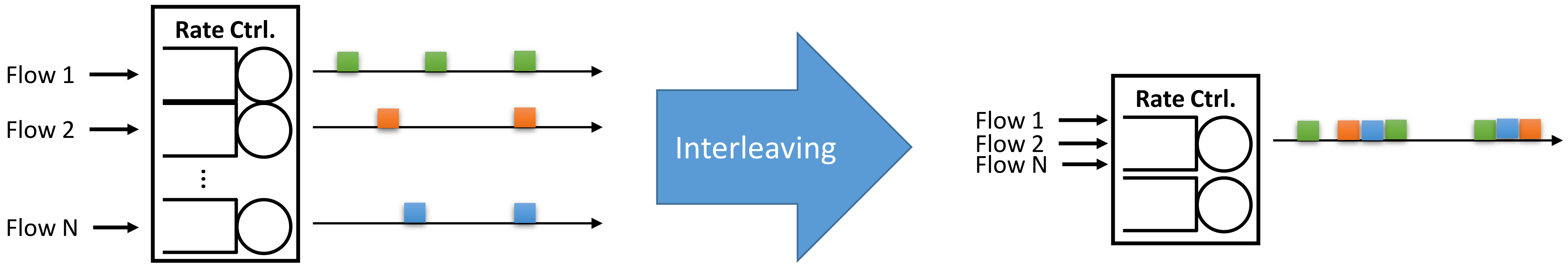
Characteristic	Description
Periodicity	Traffic types comprise data streams that can either be **Periodic:** transmitted in a cyclic/periodic (e.g. signal transmission) or **Aperiodic:** transmitted in a acyclic/sporadic (e.g. event-driven) manner
Typical Period	Period denotes the planned data transmission interval (often also called "cycle") at the application layer. **#:** Specify period for cyclic traffic **N/A:** for aperiod/acyclic traffic
Application Synchronized to Network	Is the application producing traffic type synchronized to the network time at the application layer? **YES or NO**
Data Delivery Guarantee Mode	Packet(s) are delivered to all receivers: **Deadline:** before a specified time, relative to cycle time. (applies to periodic data) **Latency:** within a predictable timespan from the start of the transmission **Bandwidth:** if bandwidth utilization is within in the resources reserved by the sender **None:** no special delivery requirements
Delivery Guarantee Value	**#:** Typical quantification of the data delivery guarantee for 80% of the use cases If "deadline" mode is used, specify if the data will be delivered in the same period or not
Application Tolerant to Jitter	application's tolerance of a certain amount of latency variati **yes:** application can tolerate jitter as specified (always yes f **no:** highly sensitive application requires negligible jitter
Tolerable Jitter Value	**#:** Value of acceptable jitter for periodic applications **NEG:** Jitter must be negligible **N/A:** if data delivery guarantee mode is "bandwidth" or "nor
Applications Tolerant to packet loss	Application's tolerance to a certain amount of consecutive packet loss **Yes:** app can tolerate loss due to recovery mechanism in upper layer protocols or basic redundancy **No:** app cannot tolerate a single packet loss
Tolerable packet loss Value	**#:** Num of consecutive packet loss tolerable to app. **0:** if application is not tolerant to packet loss
Application payload size variability	**fixed:** application payload size remain fixed **variable:** app payload varies from one packet to packet
Payload Value (Bytes)	**#:** size/range of application data (payload) to be transmitted in the Ethernet frames.
Data Criticality	Criticality of this data for operation of the critical parts of the system **high:** highly critical for the operation. (DAL A, B) **medium:** relevant but not continuously needed for the operation (Dal C, D) **low:** not relevant for operation (DAL E)

"AVB-Style", playout buffers, or DPS*
(https://www.ieee802.org/1/files/public/docs2020/new-specht-dampers-fti-0620-v02.pdf)

Source: https://www.ieee802.org/1/files/public/docs2021/dp-Jabbar-Aerospace-TrafficTypes-Summary-0521-v02.pdf

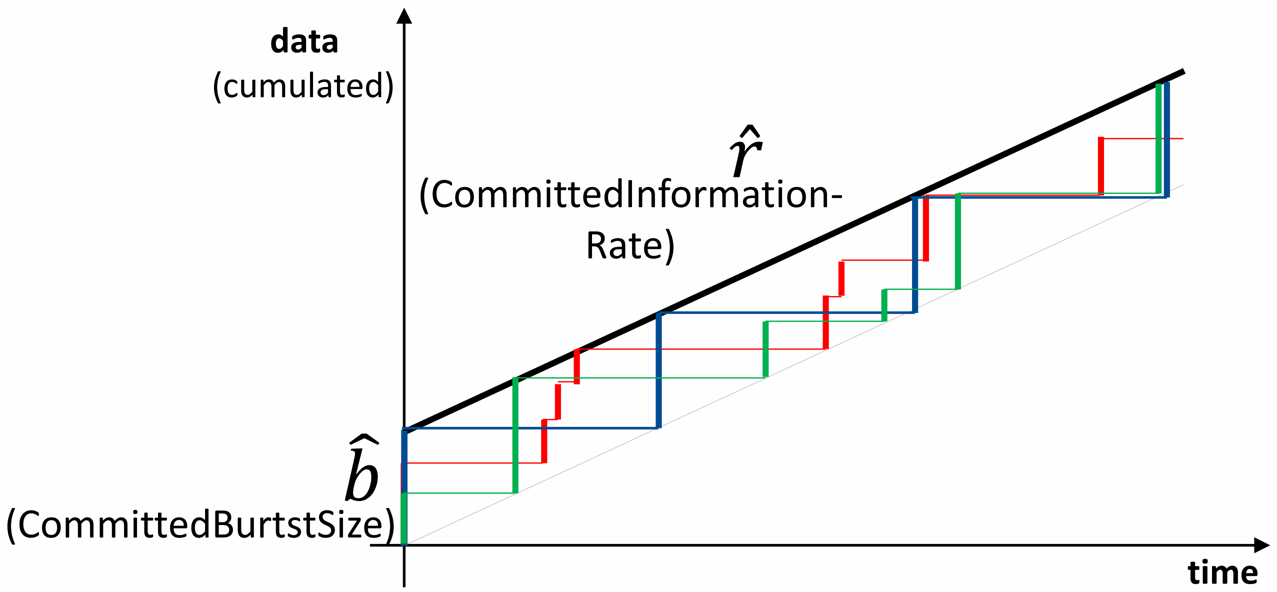
ATS Traffic Types/Streams

Token Bucket Traffic Model



Token Bucket Shaping in a Nutshell

- Buckets fills with tokens at *Flow Rate*
- Tokens consumed by *Packet Length*
- Delay, if not enough tokens



Traffic Types

Min. Designflow

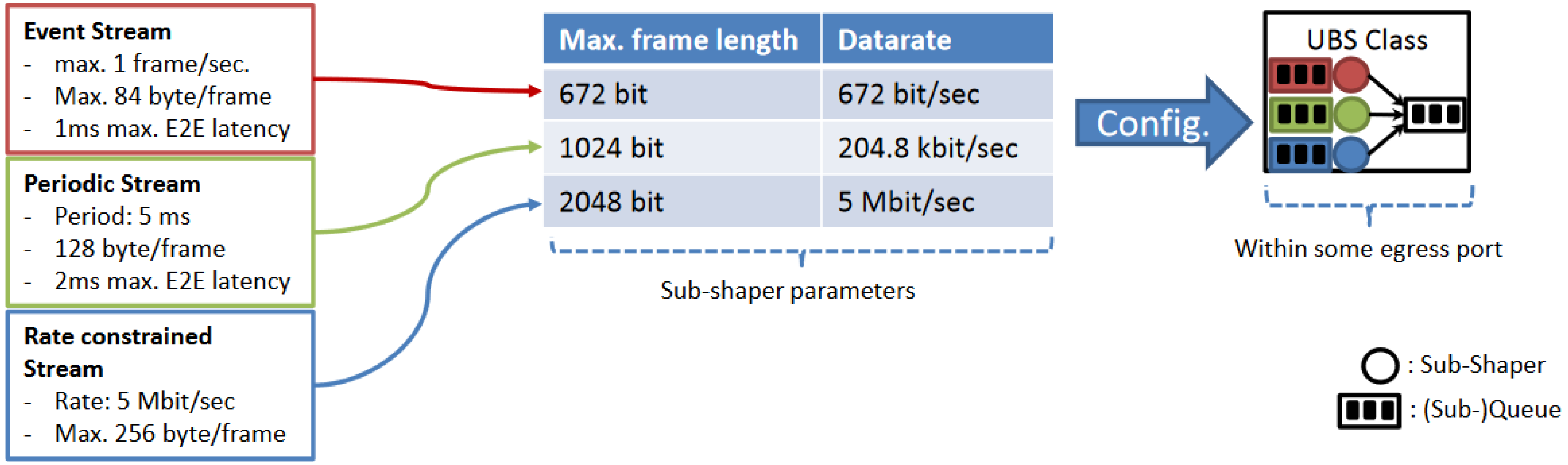
1. Per stream mapping to token bucket parameters (CommittedBurstSize & CommittedInformationRate)
2. Delay analysis and network configuration

Aspect to *not* think too much about

- Synchronizing end station timing and network timing (which simply does not exist for ATS)
- Harmonizing periods within a converged network/ mixtures on the same wires

Sidenote: Compared to UBS@2014, ATS “Interleaving” simplifies queuing

Automotive Control Streams



Automotive Control Streams in UBS

- Automotive networks need to transport control stream (cmp. [FCTC]):
  - Periodic Control Streams
  - Event-based Control Streams
- **Both are supported** by UBS and **treated as rate constrained streams**, i.e. there is no differentiation between stream types.
- Streams transferred via UBS get **automotive grade E2E latency guarantees** (cmp [FCTC]) - even without latency-requirement-to-priority mapping (i.e. use UBS *unscheduled*) and at 100MBit/s link speed (cmp. [UWC])

Source: https://www.ieee802.org/1/files/public/docs2014/new-tsn-specht-ubs-automotive-1114-v01.pdf

ATS Latency & Configuration

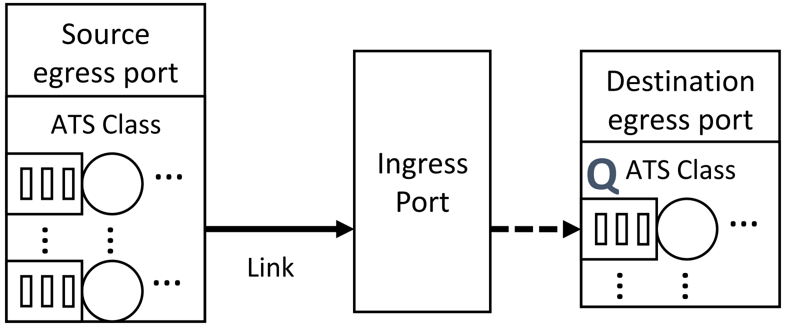
Per Hop Latency Math (Simplified)

$$W_f^{max} \le \max_{\forall f' \text{ in } Q(f)} \left(\frac{\sum_{i\in H} l_i^{max} + \sum_{i\in S} l_i^{max} + \max_{i\in L}(l_i^{max})}{R - \sum_{i\in H} R_i} + \frac{l_{f'}^{max}}{R} \right)$$

Max. over all streams sharing The queue with f in the destination port

Interference by all competing streams In the source egress port (not only The ones in the same queue like f).

S&F



Properties

- Closed expression per hop
- Sum along the path from talker to listener

Simplification (won't change the properties above)

- <u>On this slide</u>
  CommittedBurstSize = Max. packet length
- <u>Key paper</u>
  J. Specht and S. Samii, *Urgency-Based Scheduler for Time-Sensitive Switched Ethernet Networks*, ECRTS 2016
- <u>Full</u>
  Annex V of IEEE Std 802.1Qcr-2020

Term	Description
W_f^{max}	Max. per hop delay of a stream f
$\sum_{i\in H} l_i^{max}$	Sum of max. packet lengths of streams with a higher sub-priority than f
$\sum_{i\in S} l_i^{max}$	Sum of max. packet lengths of streams with sub-priority equal to the sub-priority of f
$\max_{i\in L}(l_i^{max})$	Maximum packet length of all streams with a lower sub-pririty than f, including lower priority traffic classes.
l_f^{max}	Maximum packet length of streams f.
R	Link speed.
$\sum_{i\in H} R_i$	Sum. of datarates of streams (i.e., CommittedBurstSize) with a higher sub-priority than f.

Latency Bounds: Order of Magnitude

Satisfies the boundaries found in 802.1BA (AVB)

Sub Shapers – what has been shown

(see also http://www.ieee802.org/1/files/public/docs2013/new-tsn-specht-ubs-perfchar-1113-v1.pdf)

- Bursts can't accumulate/propagate
- Latency can be calculated for each Hop independently
- Even without sub priorities, the end-to-end latency is low:

5612.2 µs (1 CBSA Shaper) **vs.** **1432.32 µs** (UBS Sub Shapers)

Underlying assumptions on Streams

- **Max. Rate** & **max. Frame Length**
- no further assumptions, e.g.
  - Talker transmission behavior
  - prev. Hops/topology

Further Cases

- Readers are encouraged to analyze UBS independently and present:
  - Counterexamples, other cases
  - Analyze whether the shown math. is totally wrong – or totally right
  - etc.

Latency for 1 CBSA Shaper taken from http://www.ieee802.org/1/files/public/docs2010/ba-boiger-bridge-latency-calculations.pdf

12/2/2013 Johannes Specht - University of Duisburg-Essen 8

Source: https://www.ieee802.org/1/files/public/docs2013/new-tsn-specht-ubs-avb1case-1213-v01.pdf

Configuration

There is a Range: How much computation/how optimized?

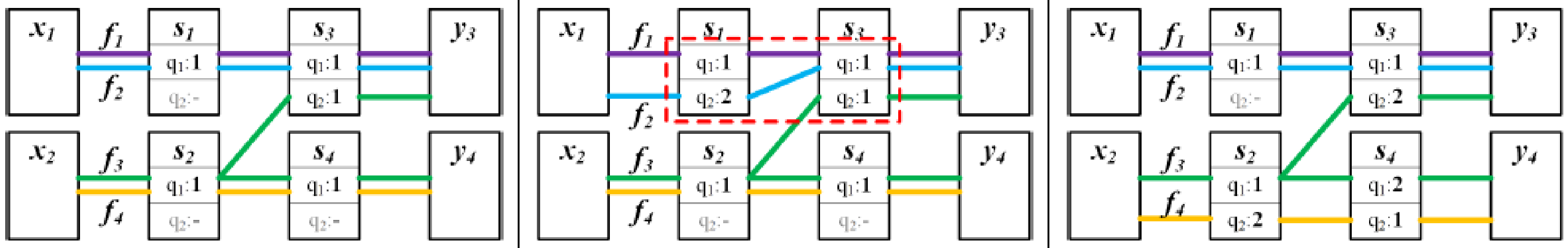
Simple (prev. Slides)

- Trivial latency calculation and setup
- All streams in one or more *global* traffic classes (aka priority level)
- “man-made” stream-to-class association
- Simple enough for distributed dynamic reservation without significant overprovisioning (e.g., P802.1Qdd)

…

Complex

- Fine-tuning by assigning individual per stream per hop priority levels
- Optimize for matching tough/wide-spread per stream E2E latency requirements

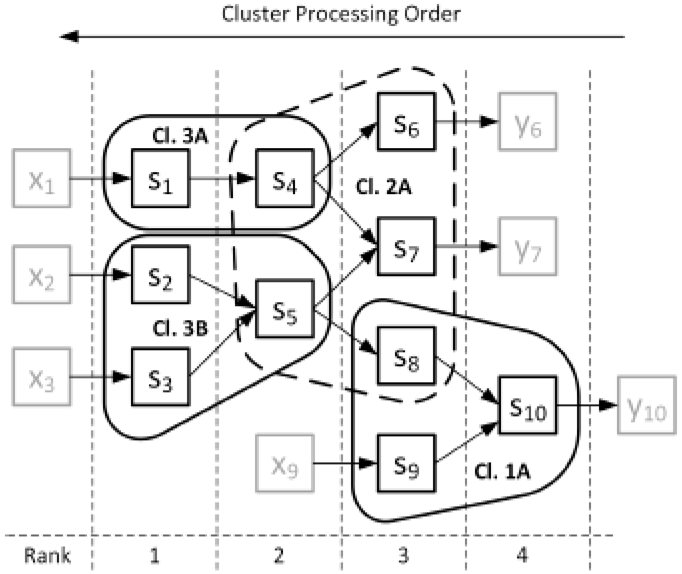


(a) Single priority level configuration c_1 (valid) violating deadline constraint CC2.

(b) Invalid configuration c_2 (violates $QC2$)

(c) Solution c_3 (and likewise a minimal configuration)

Flow	Sink	$\bar{d}(f,y)$	$\hat{d}(c_i,f,y)$		
			$c_i = c_1$	$c_i = c_2$	$c_i = c_3$
f_1	y_3	6.5 µs	**7 µs**	6 µs	6.0 µs
f_2	y_3	8.0 µs	7 µs	7.7 µs	6.0 µs
f_3	y_3	9.5 µs	7 µs	7 µs	9.0 µs
	y_4	6.5 µs	6 µs	6 µs	5.7 µs
f_4	y_4	6.5 µs	6 µs	6 µs	5.7 µs



Source of all figures and tables on this slide: J. Specht and S. Samii, *Synthesis of Queue and Priority Assignment for Asynchronous Traffic Shaping in Switched Ethernet*, RTSS 2017

ATS Robustness

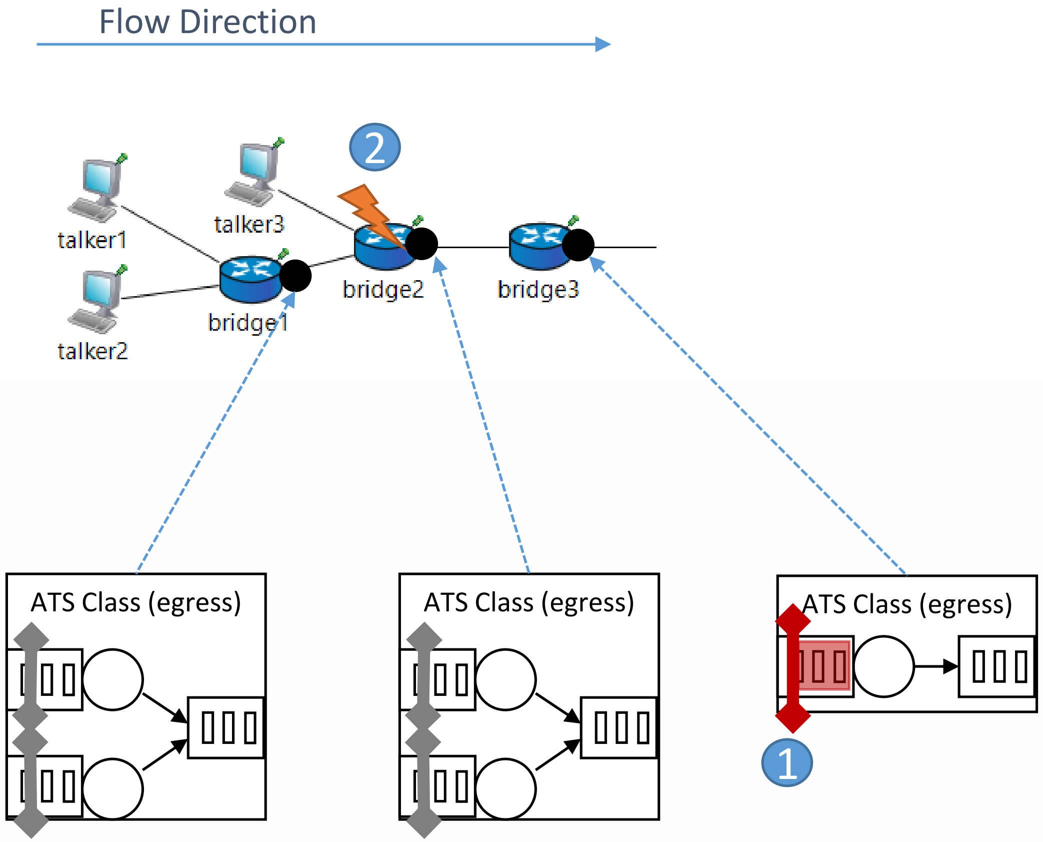
Robustness, Protection and Isolation

1. **Asynchronous**
   - No global clock sync. dependency
2. **Policing Included**
   - Token Bucket shaping
     1. Delaying (shaping), not only dropping (policing)
     2. Re-shaping per hop: No growing disturbance/burstiness along paths

        → No need for increasing CommittedBurstSize values
        (avoid false-positive policing reactions)

        → Low delay impact
        (no need to account for traffic form interfering babbling idiots maxing out increased CommittedBurstSize limits until policing reaction)
   - Possible mutual exclusion
     - Token Bucket state machines (shapers & flow meter) share similarities
     - (Re-)shaped traffic may not need extra flow meters
     - ASIC Implementers may design for this
3. **Traffic Isolation in (virtual) queues**
   - At least at per Port resolution
   - Mindset
     - Stations can break, not only in the nice way (i.e., become babbling idiots)
     - All traffic from a broken station is broken and lost (i.e., no separation in classes/streams)
     - Traffic on paths without broken boxes shall not be affected by interfering broken traffic

Separate (virtual) queuing at least on a per port resolution

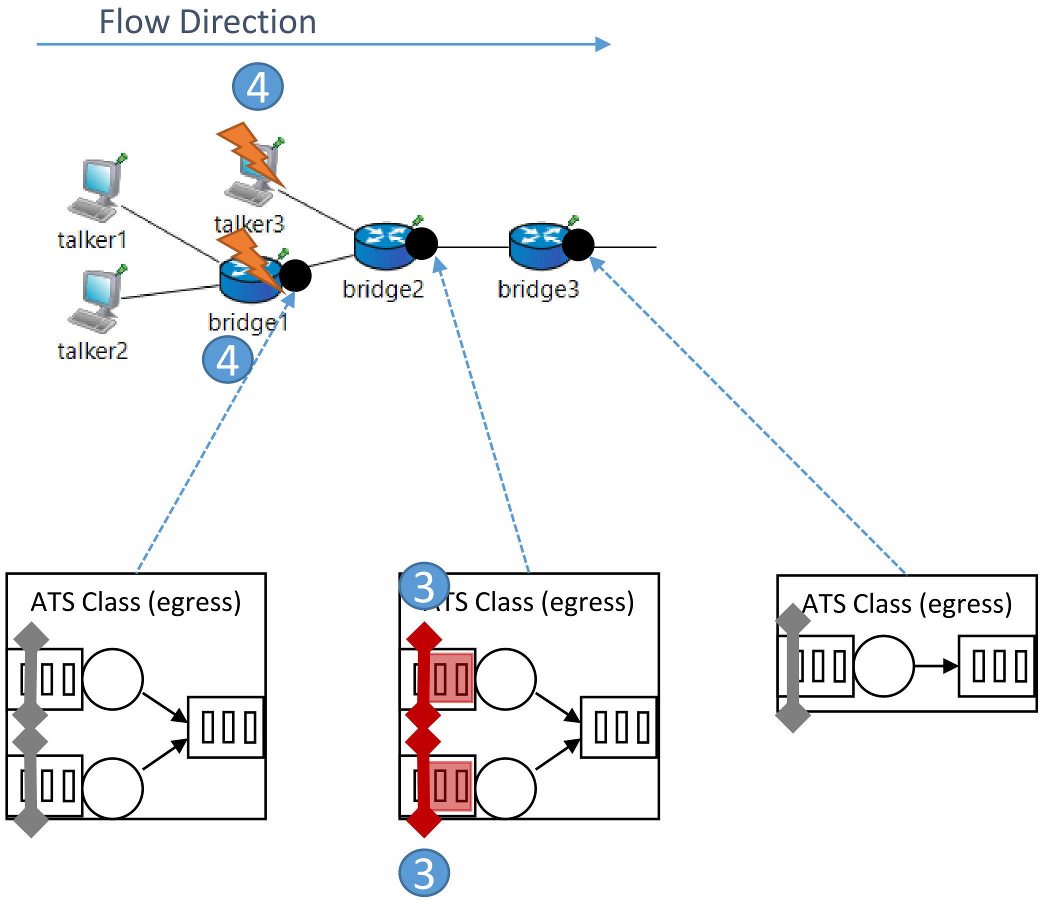


Fault isolation Logic

1.If the queue limit in *bridge3* is exceeded…

2.… only *bridge2* can be the babbling idiot.

Separate (virtual) queuing at least on a per port resolution



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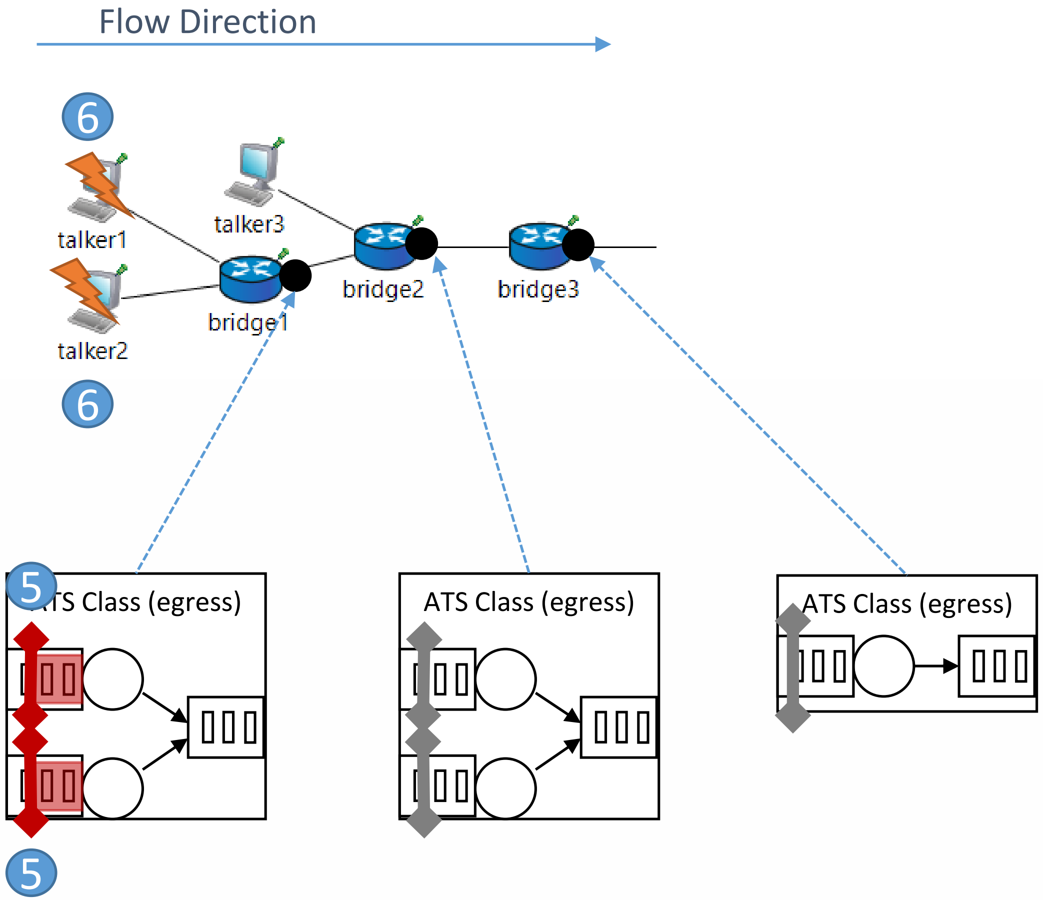
Contradiction

3.If the queue limit in *bridge3* is exceeded and *bridge1* or *talker3* would be the babbling idiot…

4.… limits in *bridge2* would prevent the overload to propagate to *bridge3*.

Separate (virtual) queuing at least on a per port resolution



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… Continuing …

5.If a queue limit in *bridge2* is exceeded, *bridge1* would be fault free and *talker1* or *talker2* would be the babbling idiot…

6.… queue limits in *bridge1* would prevent the overload to propagate to *bridge2*.

Thank you for your Attention!

Time for Questions & Answers

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