# Do We Really Need TSN in Next-Generation Helicopters? Insights From a Case-Study

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# Outline


Ethernet is replacing legacy networks in helicopter's avionics and mission system, but how important is it to adopt Time-Sensitive-Networking standards?

Objectives:

1. Review of the TSN standards relevant to helicopters – focus on timing QoS
2. On a case-study representative of next-generation systems:
   a. Provide quantified insights into what can be expected from TSN in terms of timing, memory usage and extensibility.
   b. Highlight non-obvious behaviours of TSN timing QoS mechanisms,

# 1. Overview of the main Ethernet TSN timing QoS mechanisms and standards relevant to aerospace

# Timing QoS in IEEE 802.1Q (TSN)

| Mechanism | Originally developed in | Also known as |
|---|---|---|
| Strict Priorities | IEEE 802.1p – 1998 | – |
| Forward and Queueing for Time-Sensitive Streams (FQTSS) | IEEE 802.1Qav – 2009 | Credit Based Shaper (CBS) |
| Scheduled Traffic | IEEE 802.1Qbv – 2015 | Time Aware Shaper (TAS) |
| Frame Preemption | IEEE 802.1Qbu – 2016 & IEEE 802.3br – 2016 | – |

- Designed to work together to address different time constraints in the same network.
- With timing in focus, but with important consequences on memory needs of network devices.

Timing QoS in 802.1Q:

# Strict Priorities

Stream priorities are mapped to Traffic Classes (TC) - up to 8.

Streams are then selected for transmission according to their Traffic Class.


+ Adequate priority assignation guarantees satisfaction of deadlines.
- It does not prevent congestion loss.
- Latencies might not be low enough.

Timing QoS in 802.1Q:

# Credit Based Shaper

Transmission of CBS-shaped TC are regulated by a credit:

- Transmission only allowed if credit > 0
- Credit decreases when transmitting & increases when other TC are transmitting.

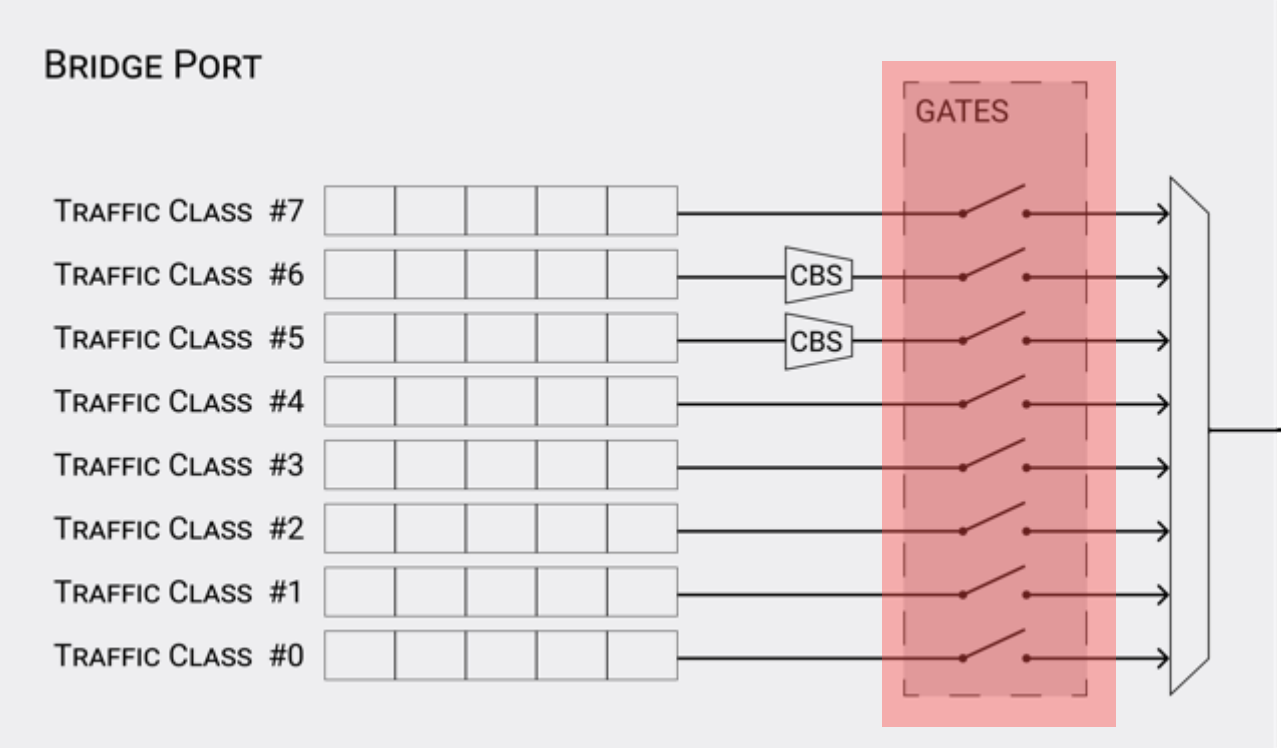

+ Adequate configuration guarantees satisfaction of deadlines.
+ Prevents starvation of low priority traffic
– Latencies might not be low enough.

Timing QoS in 802.1Q:

# Scheduled Traffic

Assigns a gate to each TC. Transmission only allowed if the gate is open.

Gates opening and closing is controlled with a pre-defined schedule.




+ Adequate schedule guarantee very low latencies and low jitter
- Generating a correct schedule can be a complex computational problem
- Bandwidth can be underutilized

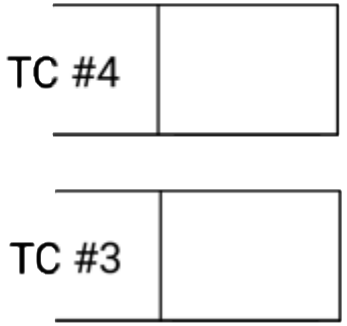
Timing QoS in 802.1Q:

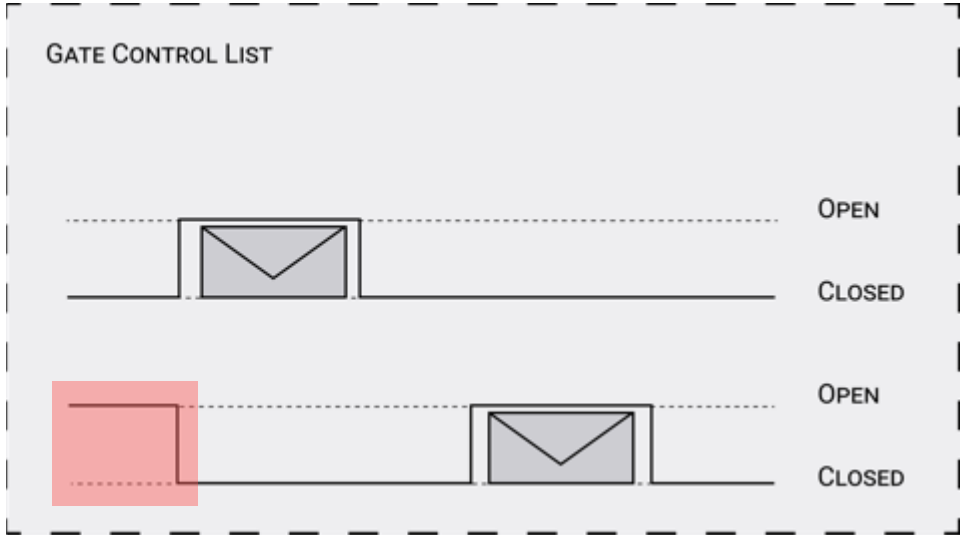
# Scheduled Traffic

- Bandwidth can be underutilized

Frame of TC #3 is ready for transmission and its gate is open

But there is not enough time for the transmission of the full message



Timing QoS in 802.1Q:

# Frame Preemption

Lower priority frames can be preempted by higher priority frames.

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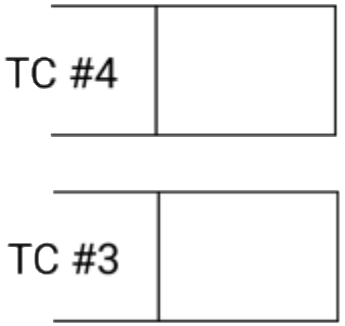


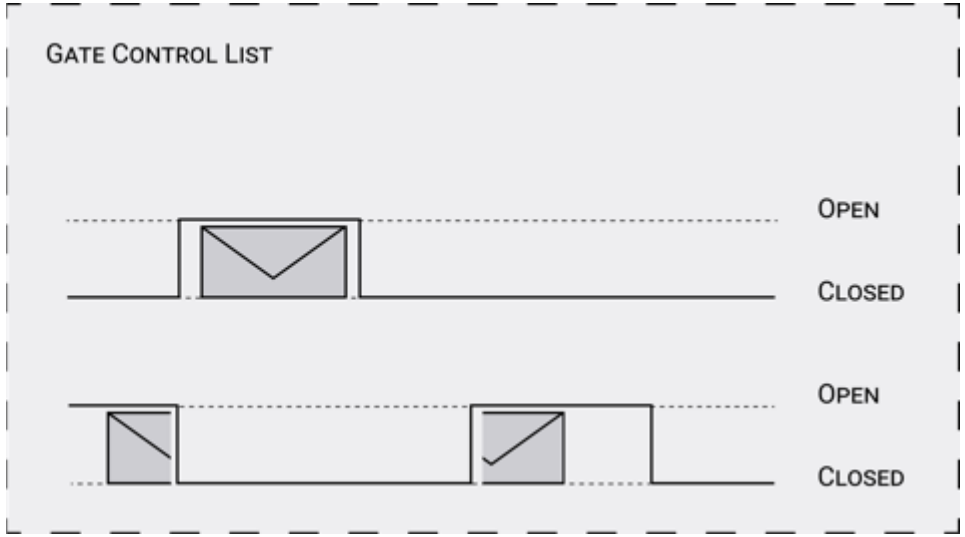

Timing QoS in 802.1Q:

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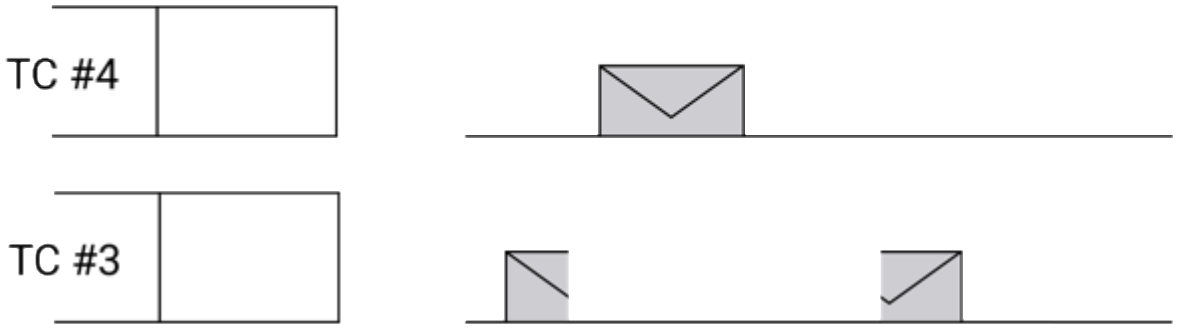

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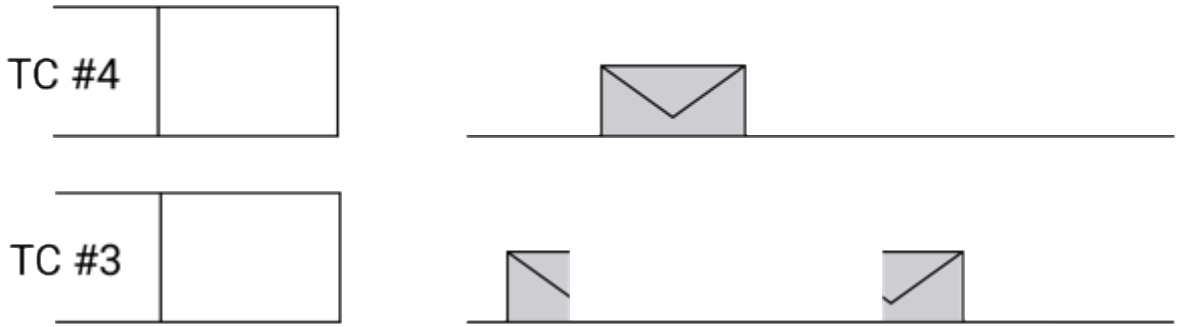



+ Can improve latencies
+ Used together with Scheduled Traffic optimizes bandwidth utilization
– HW implementation is not simple

# Summary

| Mechanism | Guarantees | Limitations |
|---|---|---|
| Strict Priorities | deadlines | congestion loss & tight deadlines |
| Credit Based Shaper | deadlines & throughput | tight deadlines |
| Scheduled Traffic | tight deadlines & low jitter | bandwidth waste & configuration complexity |
| Frame Preemption | bandwidth utilization | |

P802.1DP / SAE AS6675:

# TSN Profile for Aerospace

- Joint work between IEEE 802.1 and SAE Avionics Networks AS-1 A2.
- TSN Profile: selects mechanisms and configurations to satisfy use-case requirements.
- Currently in early stages of development.

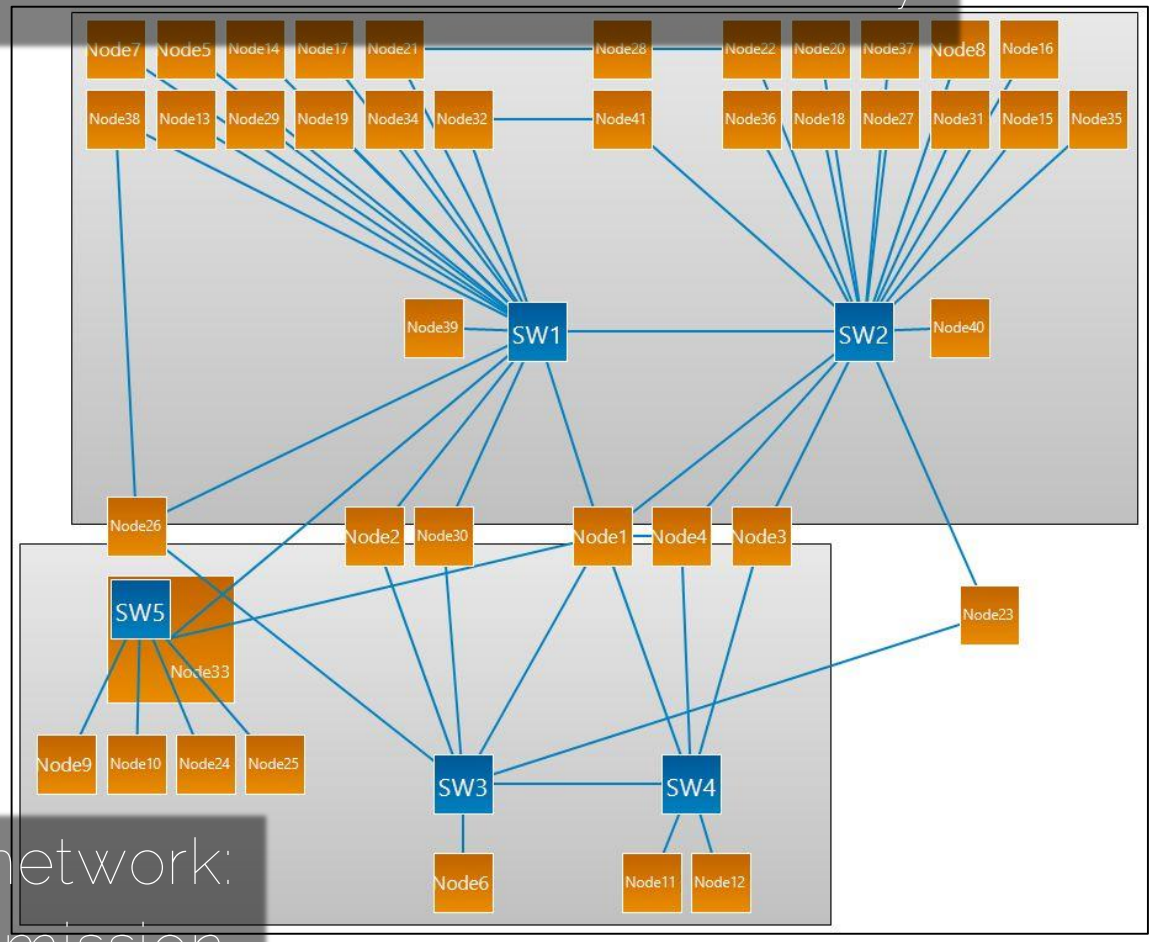
> *This standard specifies profiles for designers, implementers, integrators, and certification agencies of deterministic IEEE 802.3 Ethernet networks that support a broad range of aerospace onboard applications including those requiring security, high availability and reliability, maintainability, and bounded latency.*

- https://1.ieee802.org/tsn/802-1dp/

# 2. Efficiency of TSN scheduling mechanisms on a case study representative of next-generation systems

# Model of the on-board TSN networks

Upper network: core avionics with critical streams → focus of the study



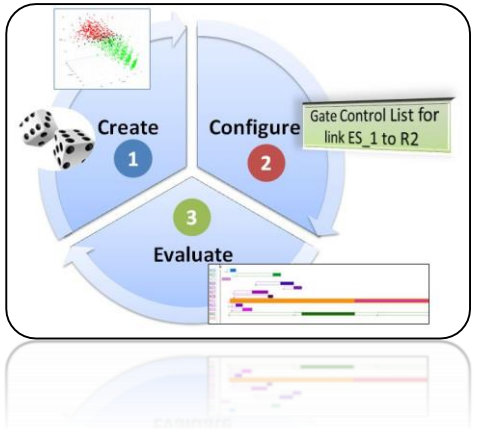

Lower network: mostly mission

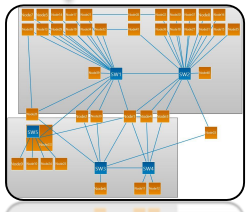
[RTaW-Pegase screenshot]

"core avionics" network only (upper network)

| | |
|---|---|
| # Nodes | 32 |
| # Switches | 2 |
| Link speed | 1Gbit/s: 10 links<br>100Mbit/s: 30 links |
| # TFTP streams<br>(lowest priority) | 6 for 2.5Mbit/s overall<br>Throughput constraints |
| Rest of the traffic (by decreasing priorities) | ▪ Audio ≈ 11% of streams<br>▪ Command & Control ≈19%<br>▪ Video (external) ≈ 1%<br>▪ Data ≈ 65%<br>▪ Video (internal) ≈ 4%<br>Deadlines equal to periods |

# Quantitative assessment



**Overload Analysis** → **Total Network Capacity** → **Memory usage in network devices**

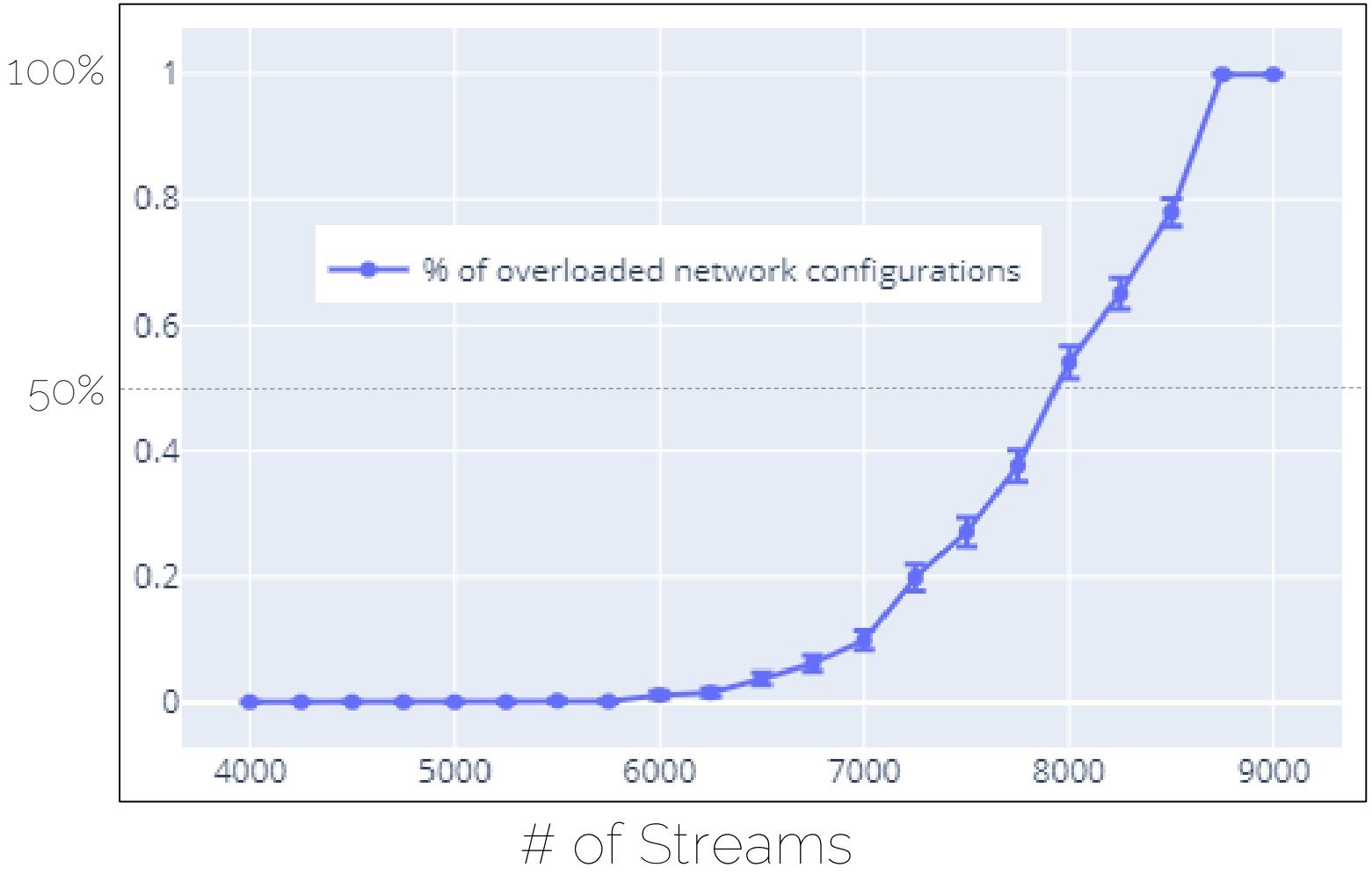
- Determine upper bound on network evolutivity
- Independent of TSN protocols
- Fast, coarse-grained analysis

- Assess the relative ability of each TSN sched. solutions to support additional traffic
- Est. architecture lifetime
- Precise, compute-intensive analysis

- Est. max. memory needed with each TSN scheduling solutions
- Define HW spec.

- Techniques : simulation, worst-case analysis, design-space exploration, synthetic data
- Candidate TSN scheduling solutions: shaping, time-triggered transmission, preemption, manual ("User-Priorities") and automated stream priority allocation ("ConcisePriorities")

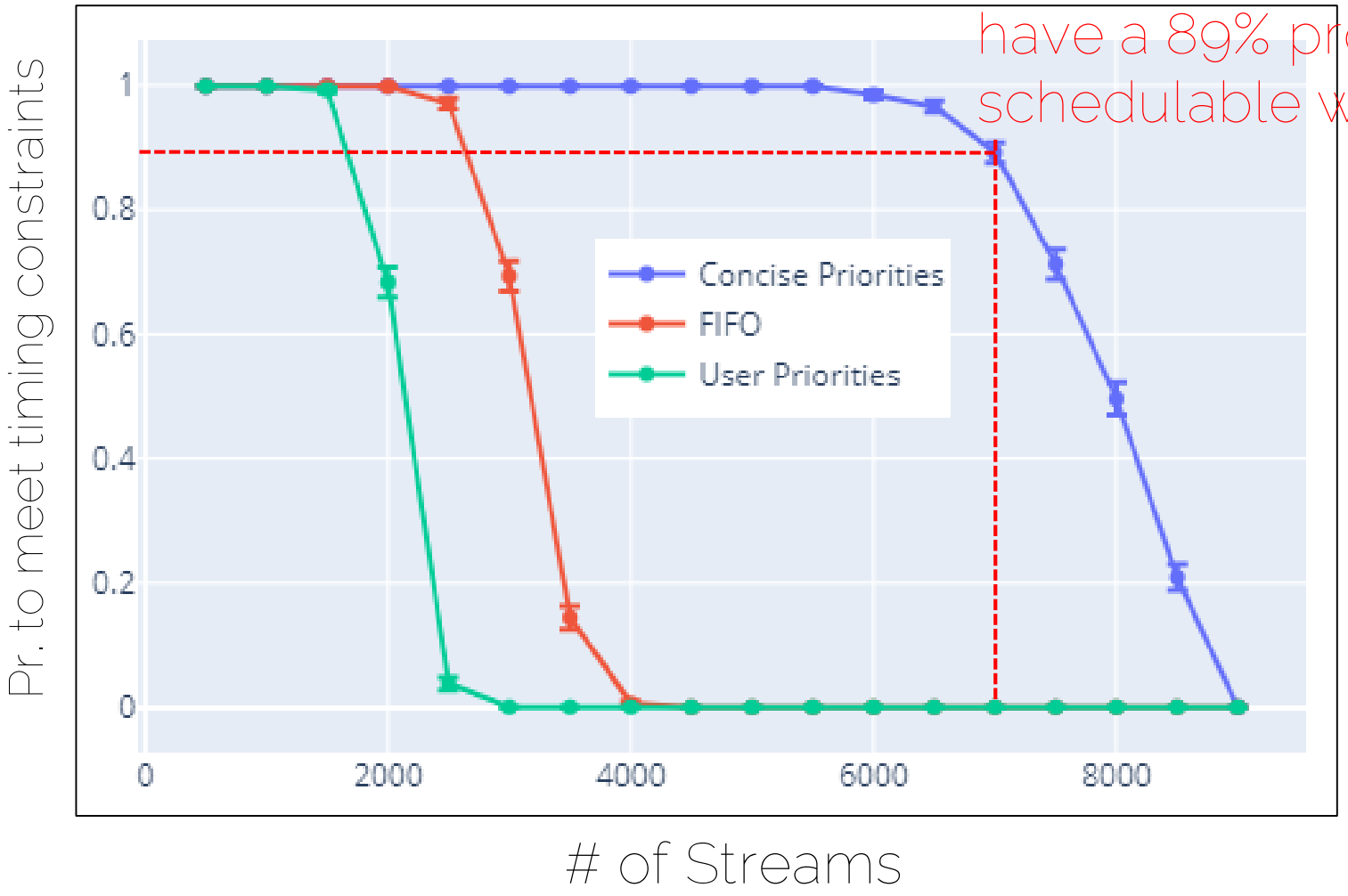
# Overload analysis : how many streams before some links become overloaded ?




- Above 7000 streams, the probability that at least one link is overloaded grows sharply → upper bound on network capacity
- Suggests that network capacity is important, with deadlines equal to periods

# Topology Stress Test® (TST) : probability that a certain # of streams is successfully scheduled by a given TSN scheduling solution

Systems with 7000 streams have a 89% probability to be schedulable with CP

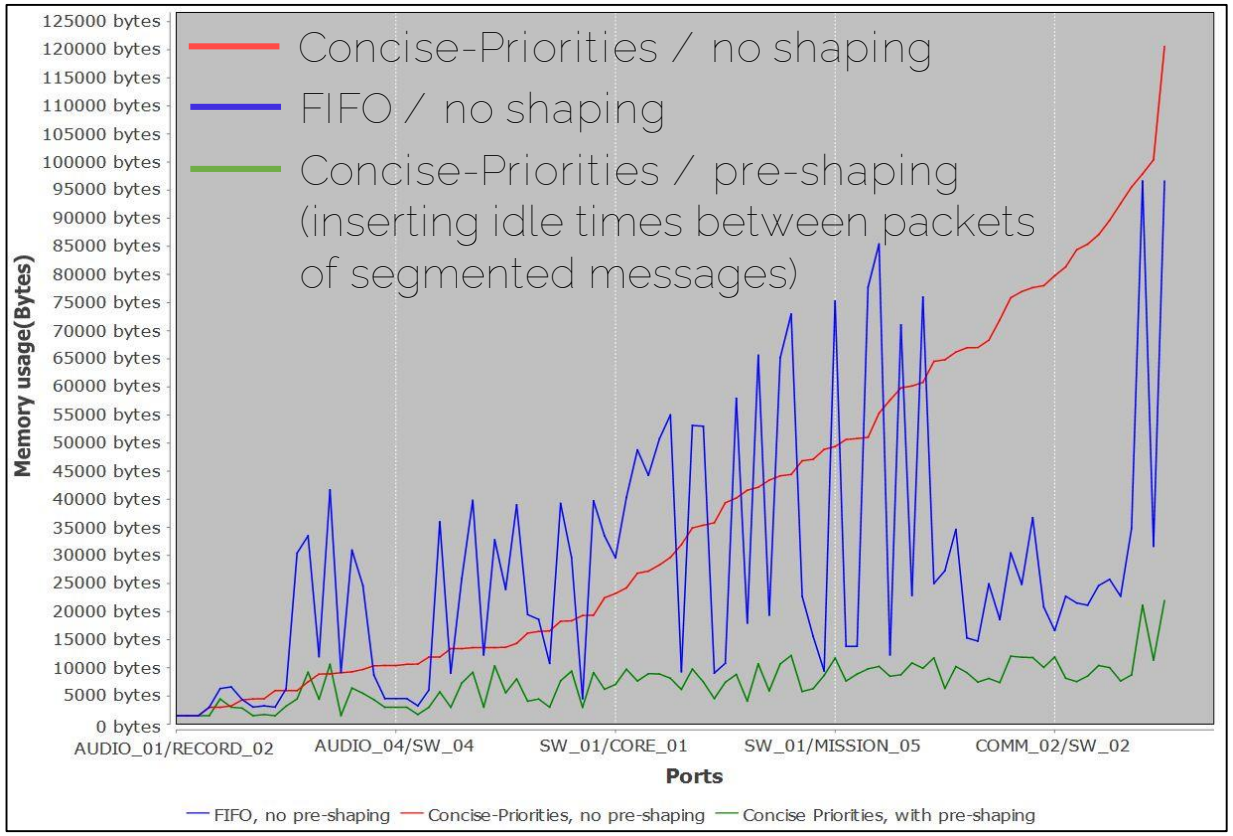



- Concise Priorities (CP) performs near optimally as it schedules 99% of the non-overloaded configurations

→No gain with shaping, time-triggered transmissions or frame pre-emption

- FIFO scheduling outperforms "User Priorities", which makes use of 6 priority levels !

# Max. Memory Usage: considering a medium-size 1000 streams network




Egress ports (interfaces, switches)

[RTaW-Pegase screenshot]

- Shaping, SW-implemented pre-shaping here, reduces average memory usage by 80% in this case-study
- Total memory per switch up to 568KB without shaping and 168KB with shaping
- Priorities do not reduce memory usage over FIFO
- CBS tend to perform very well wrt memory too. CBS not used here as priority allocation algorithm not optimized for CBS

# Conclusion

- Not everything in TSN is needed for all systems as in our case-studies
- QoS mechanisms at strategic locations can be cost-effective
- Choice of TSN mechanisms: where do most of the interferences come from?
  - Higher priority traffic → shaping can help
  - Lower priority traffic → time-triggered transmission or preemption
  - Same priority traffic → more priorities, better priority allocation, shaping
- In our case-study, priorities is the only QoS mechanism needed for timing
- Memory can be as much as a constraint as timing, and shaping does help in that respect
- Non purely technical concerns like weight, costs and certification efforts come into consideration too

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# Thank you for your attention!

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