Pre-shaping Bursty Transmissions under IEEE802.1Q as a Simple and Efficient QoS Mechanism

Nicolas NAVET, University of Luxembourg
Jörn MIGGE, RealTime-at-Work (RTaW)
Josetxo VILLANUEVA, Groupe Renault
Marc BOYER, Onera

RTaW RealTime-at-Work
GROUPE RENAULT
UNIVERSITÉ DU LUXEMBOURG
ONERA THE FRENCH AEROSPACE LAB

Use-cases for Ethernet in vehicles

Infotainment

- Synchronous traffic
- Mixed audio and video data
- MOST like

Cameras

- High data rates
- Continuous streaming
- Can be used by ADAS

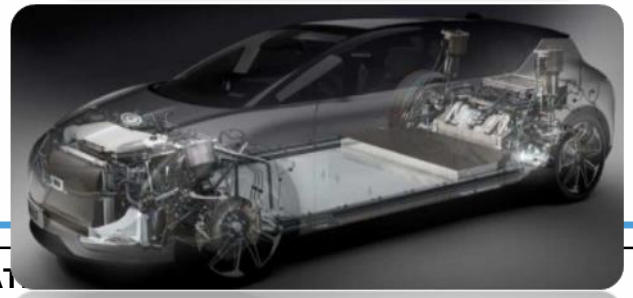
Diag. & flashing

- Interfacing to external tools
- High throughput needed

Bandwidth guarantees: e.g. 10Mbit/s

e.g. 10-30ms latency constraints per image (e.g. 42 frames)

Control functions ADAS



- Time-sensitive communication
- Small and large data payload
- Cover CAN / Flexray use cases

e.g., sub-10ms latency constraints

1 TWISTED-PAIR

Main TSN QoS protocols on top of Ethernet

Temporal QoS = managing interfering traffic

Priority-based

IEEE802.1Q

8 priority levels for streams

Benefits:

✓standard and simple

✓efficient at the highest priority

✓can be used with shaping in transmission (“pre-shaping”)

Limitations:

✓ not fine-grained enough to for all kinds of requirements

✓starvation at lowest priority levels with bursty traffic

Traffic Shaping

AVB / Credit-Based Shaper (CBS)

Two egress queues shaped + 6 priority levels below

Benefits:

✓ Perf. guarantee for AVB classes

✓ No starvation for best-effort traffic

Limitations:

✓ Per class (not stream) shaping

✓ Not for control traffic

✓ Not flexible enough with standard configuration (CMI)

Time-triggered (TT)

TSN / Time-Aware Shaper (TAS)

TAS defines egress ports’ gate schedule (open/close)

Benefits:

✓ Strong time constraints can be met

✓ Can be combined with AVB

Limitations:

✓ Hard to configure

✓ Rely on a global clock

✓ Task sched. must be tailored to communication for best perf.

Main TSN QoS protocols on top of Ethernet

Temporal QoS = managing interfering traffic

Priority-based

IEEE802.1Q

8 priority levels for streams

Benefits:

✓standard and simple

✓efficient at the highe

✓can be used with sh
transmission (“pre-sha

Limitations:

✓ not fine-grained enough to for all kinds of requirements

✓starvation at lowest priority levels with bursty traffic

Traffic Shaping

AVB / Credit-Based Shaper (CBS)

Two egress queues shaped + 6 priority levels below

✓ Per class (not stream) shaping

✓ Not for control traffic

✓ Not flexible enough with standard configuration (CMI)

Time-triggered (TT)

TSN / Time-Aware Shaper (TAS)

TAS defines egress ports’ gate schedule (open/close)

s:

g time constraints can

e combined with AVB

ons:

✓ Hard to configure

✓ Rely on a global clock

✓ Task sched. must be tailored to communication for best perf.

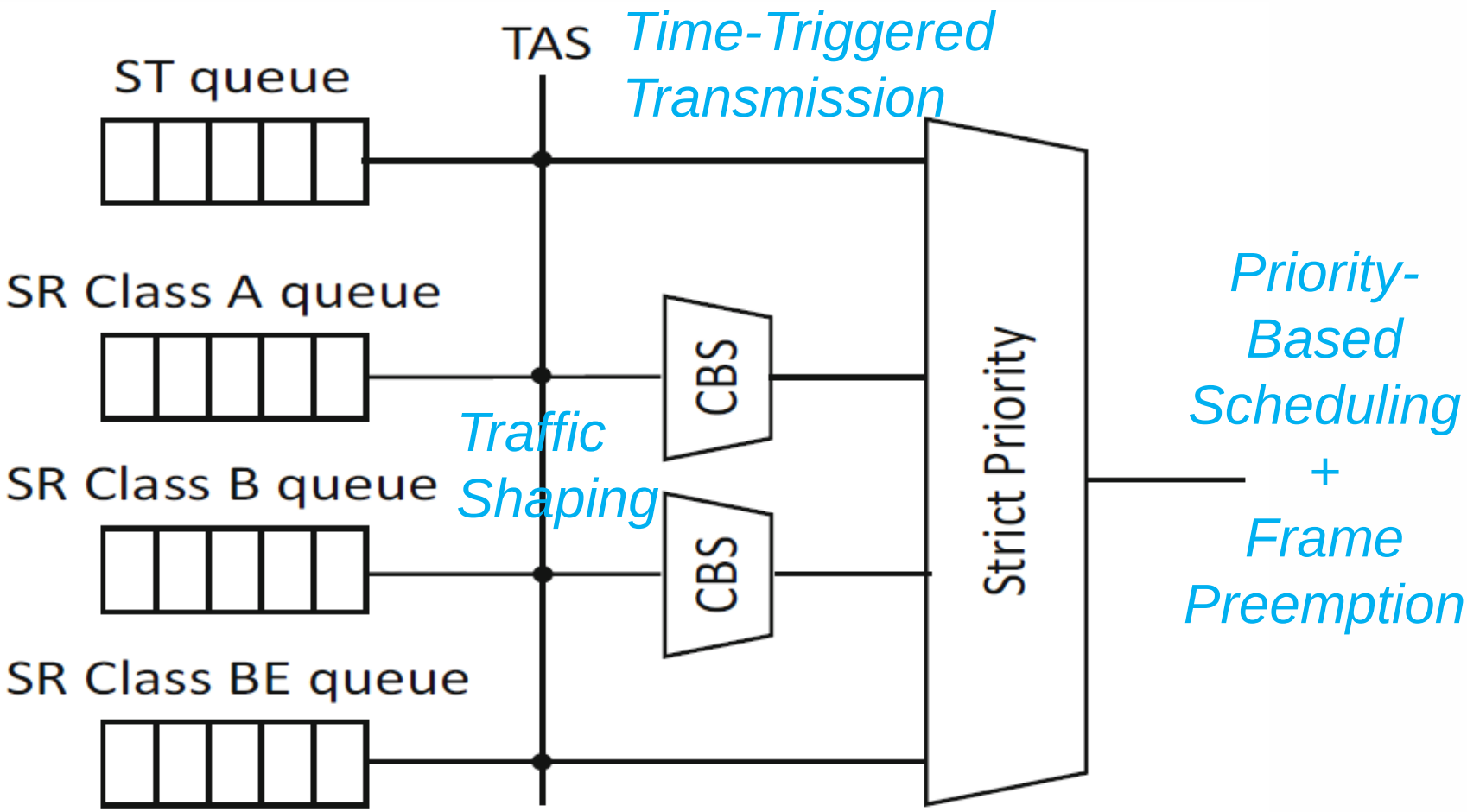
In the picture too

✓ Frame-preemption (Qbu+3br)

✓ Asynchronous traffic shaping (Qcr)

✓ Cyclic Queuing & Forwarding (Qch)

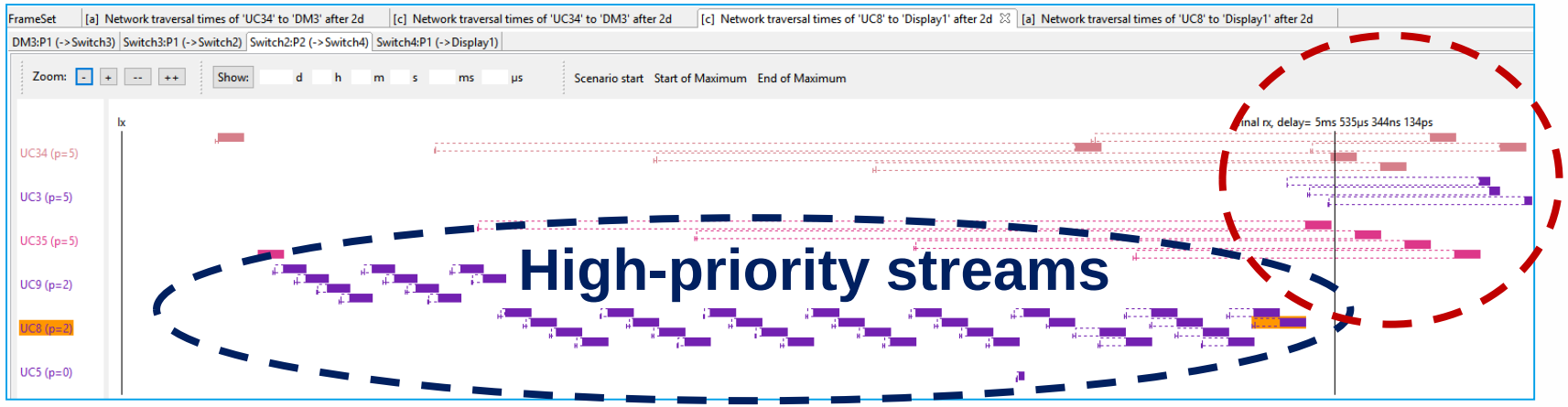
QoS support in the switches – on each output port



Up to 8 priority level overall

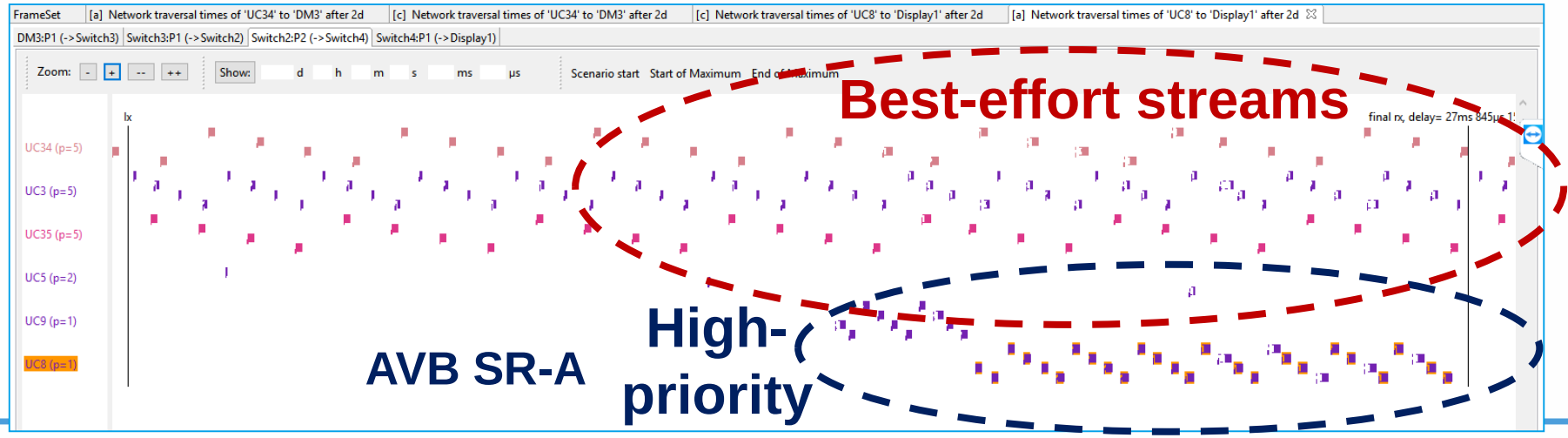
[Figure inspired from Ashjaei2017]

Under IEEE802.1Q – 3rd hop

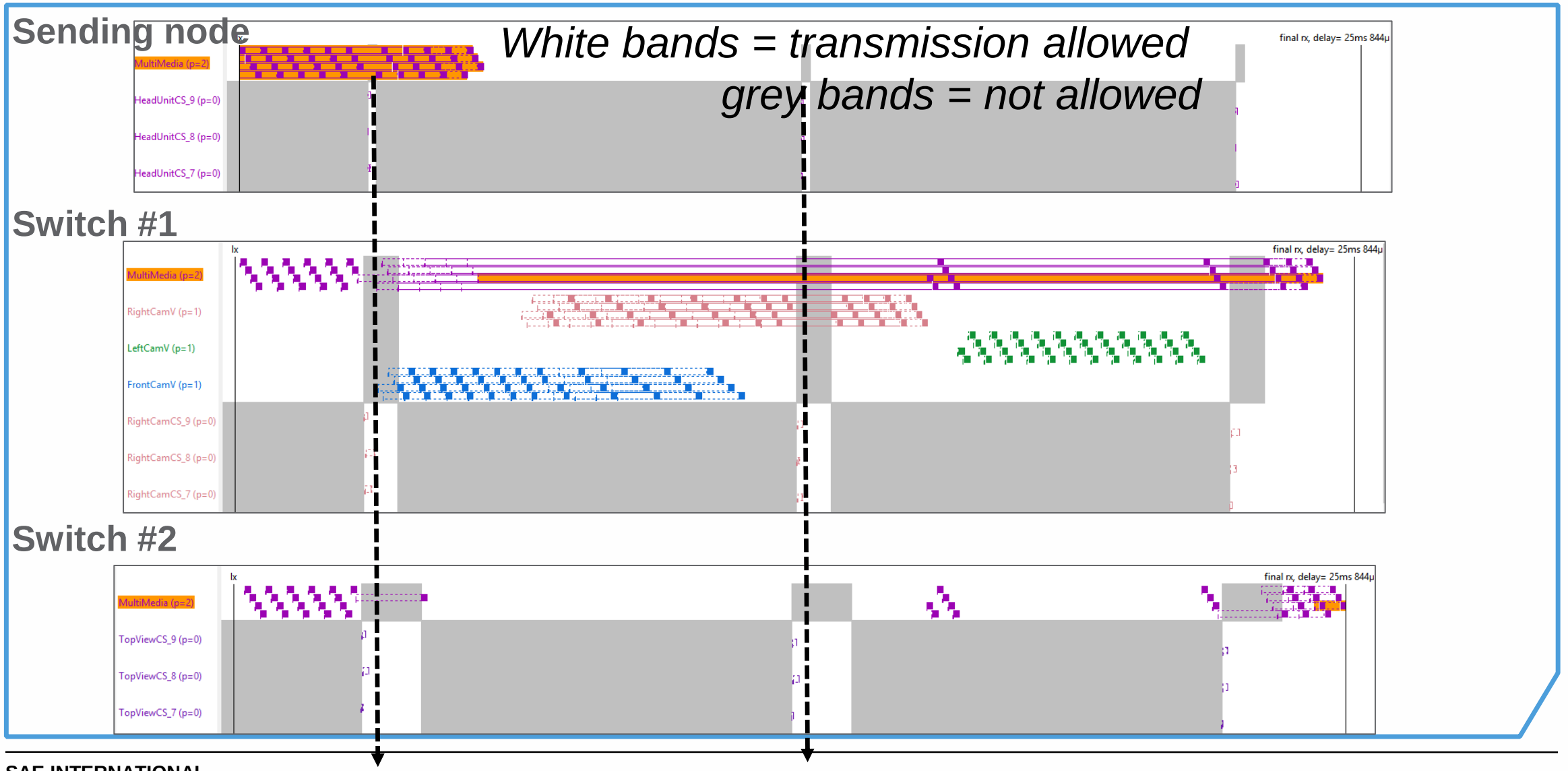


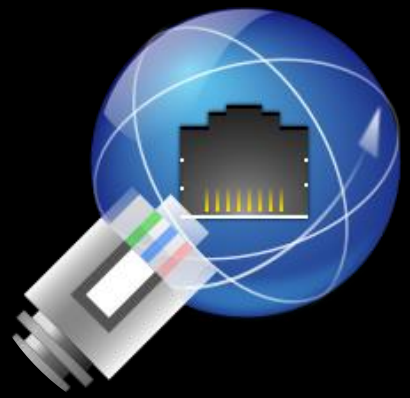
Obtained by simulation in RTaW-Pegase

Under AVB/CBS – 3rd hop



TSN/TAS: coordinating gate scheduling tables



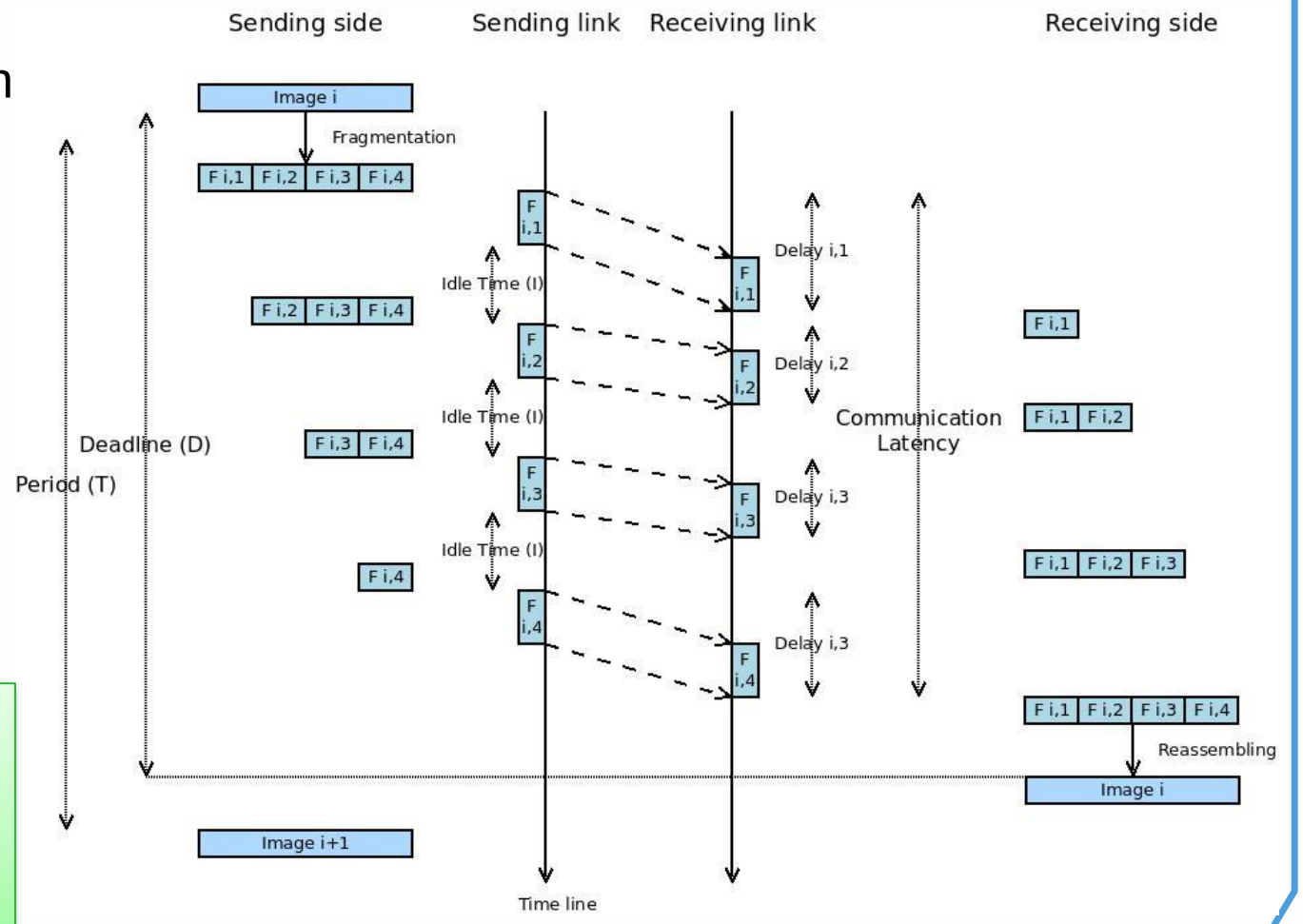


Pre-shaping mechanism

IEEE802.1Q with pre-shaping in transmission

- Pre-shaping = inserting “well-chosen” minimum distance between frames of a segmented message ***on the sender side only*** – other characteristics of traffic unchanged
- Objective is to spread out transmissions to **reduce latencies of lower priority traffic**
- Pre-shaping typically applies to video streams to improve perf. of best-effort

The last packet of the segmented message must be received by the deadline, typically 16.66ms for 60FPS camera

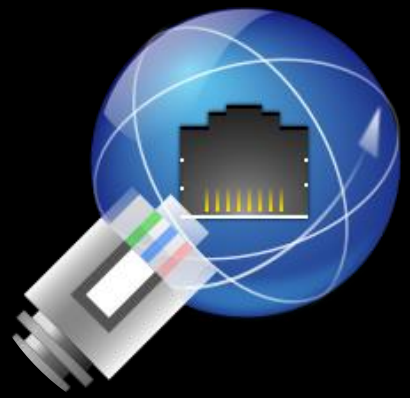


Pre-shaping in practice

- No need for dedicated HW unlike CBS & TAS, implemented in SW in end-systems
- Not part of TSN but not forbidden!
- Find priorities and transmission pauses between frames of segmented messages such that
  - all bursty frames subject to pre-shaping meet their deadlines,
  - while minimizing as much as possible the latency of frames in lower priority traffic classes

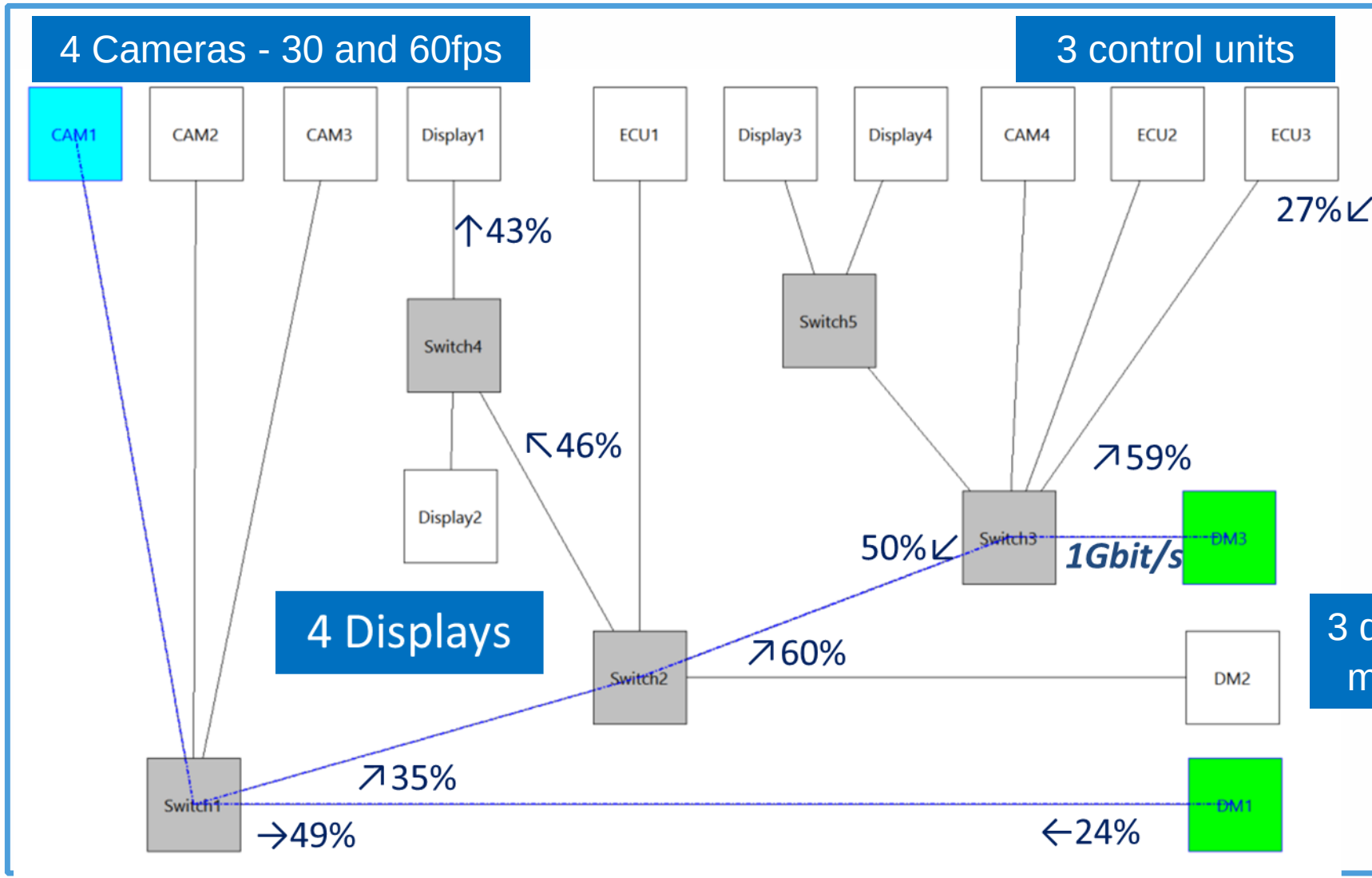
Setting idle-times by hand is not practical
– "PRESH" algorithm in RTaW-Pegase automates it

Name	Priority	MinDistance	MaxSize	Sender	Receiver
UC27	0	10 ms	256 byte	CAM1	DM3
UC27	0	10 ms	256 byte	CAM1	DM1
UC33	0	10 ms	256 byte	CAM4	DM3
UC22	0	8 ms	1024 byte	DM1	ECU3
UC13	1	1,25 ms	256 byte	DM3	ECU2
UC14	1	1,25 ms	128 byte	DM3	ECU2
UC15	1	1,25 ms	128 byte	DM3	ECU2
UC16	1	1,25 ms	128 byte	DM3	ECU2
UC17	1	1,25 ms	128 byte	DM3	ECU2
UC18	1	1,25 ms	128 byte	DM3	ECU2
UC19	1	1,25 ms	256 byte	DM3	ECU2
UC23	1	1,25 ms	256 byte	ECU2	DM3
UC9	2	3 ms / 32 ms	10 x 1246 byte	DM3	Display2
UC8	2	1 ms / 32 ms	30 x 1446 byte	DM3	Display1
UC10	2	1 ms / 32 ms	30 x 1046 byte	DM3	Display3
UC11	2	1 ms / 32 ms	30 x 1046 byte	DM3	Display4
UC26	2	1 ms / 32 ms	30 x 1446 byte	CAM1	DM3
UC32	2	0,5 ms / 16 ms	30 x 1446 byte	CAM4	DM3
UC36	2	0,324 ms / 32 ms	30 x 1446 byte	CAM3	DM1
UC37	2	0,324 ms / 32 ms	30 x 1446 byte	CAM2	DM1



Case-study

Renault Ethernet prototype network



#Nodes	**14**
#Switches	**5**
#streams	**41**
Workload per link	Min: <1%, med:11% max:60%
Link data rates	100Mbit/s and 1Gbit/s (1 link)

Case-study: 4 types of traffic

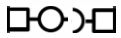
Audio streams	• 8 streams • 128 and 256 byte frames • up to sub-10ms periods and deadlines • soft deadline constraints
Video Streams	• 2 ADAS + 6 Vision streams • up to 30*1446byte frame each 16ms (60FPS) or each 33ms (30FPS) • 10ms (ADAS) or 30ms deadline (Vision) • hard and soft deadline constraints
Command & Control	• 11 streams, 256 to 1024 byte frames • up to sub-10ms periods and deadlines • deadline constraints (hard)
Best-effort: File, data transfer, diagnostics	• 14 streams including TFTP traffic pattern • up to 0.2ms periods • both throughput guarantees (up to 20Mbits per stream) and deadline constraints (soft)

With pre-shaping in transmission

Name	Priority	MinDistance	MaxSize	Sender	Receiver
UC9	2	3 ms / 32 ms	10 x 1246 byte	DM3	Display2
UC8	2	1 ms / 32 ms	30 x 1446 byte	DM3	Display1
UC10	2	1 ms / 32 ms	30 x 1046 byte	DM3	Display3
UC11	2	1 ms / 32 ms	30 x 1046 byte	DM3	Display4
UC26	2	1 ms / 32 ms	30 x 1446 byte	CAM1	DM3
UC32	2	0,5 ms / 16 ms	30 x 1446 byte	CAM4	DM3
UC36	2	0,324 ms / 32 ms	30 x 1446 byte	CAM3	DM1
UC37	2	0,324 ms / 32 ms	30 x 1446 byte	CAM2	DM1

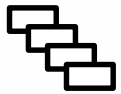
Pre-shaping parameters for the 8 video streams

Case-study: IEEE802.1Q priorities



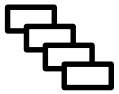
Command & Control (C&C)

Top priority



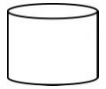
Audio Streams

Second priority level



Video Streams

Third priority level

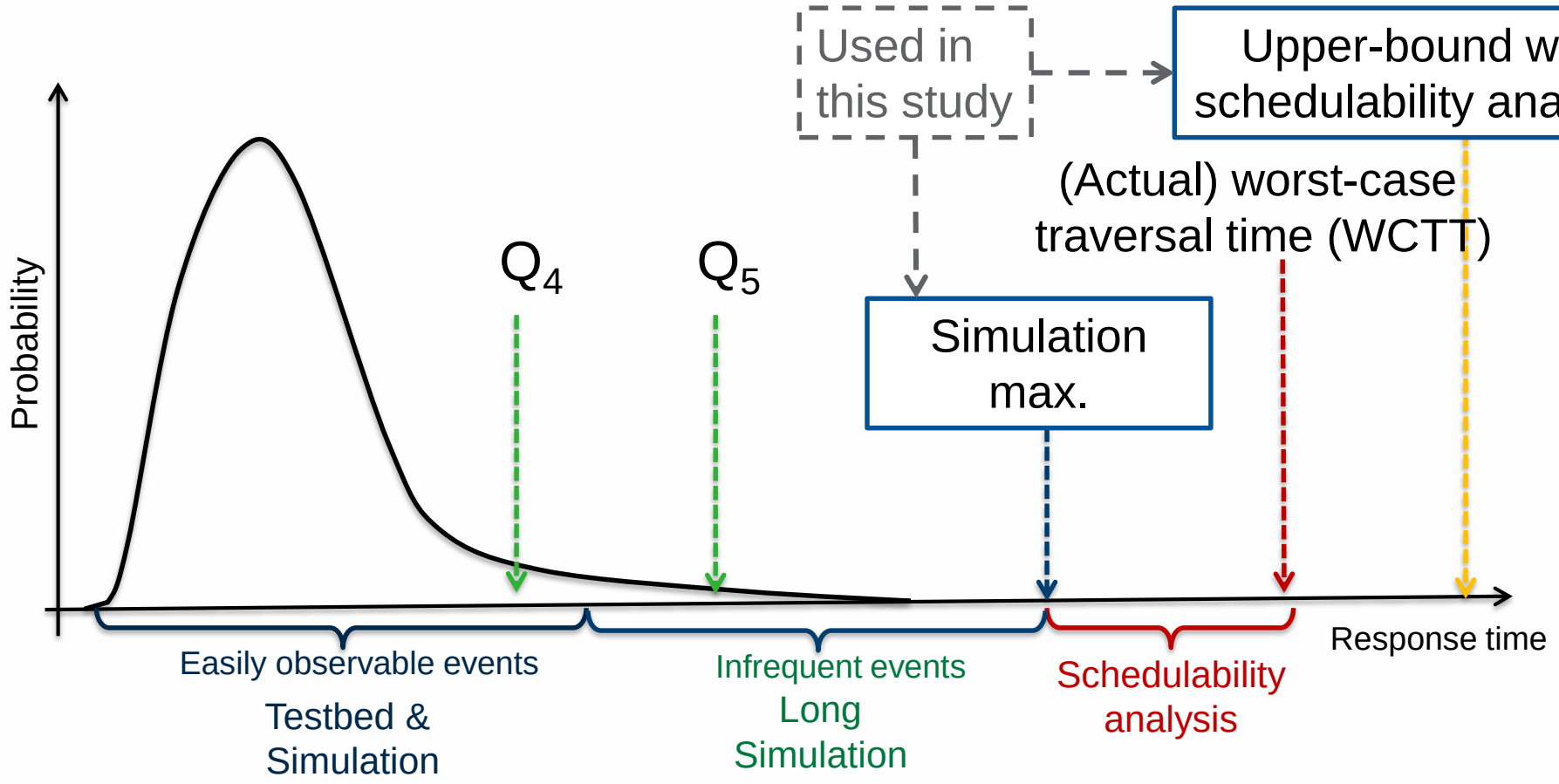


File & data transfer, diag.

Best-effort

Decreasing priorities

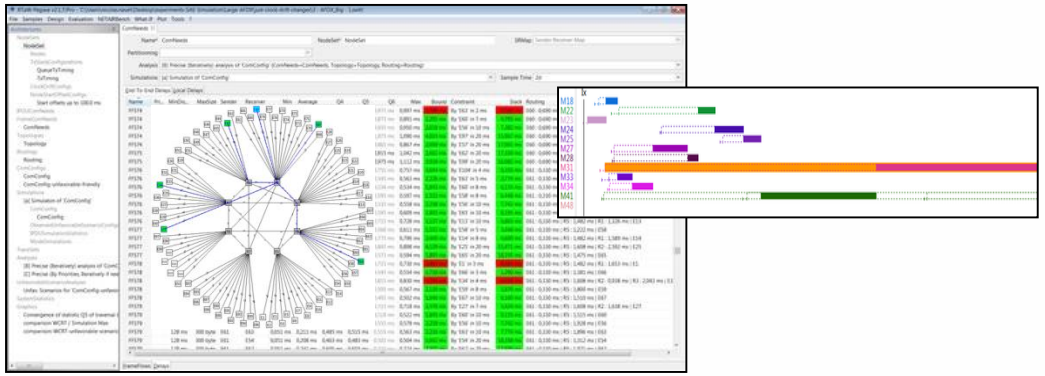
Verification techniques



- ✓ Long simulation here = 48 hours of driving → 350 000 transmissions for 500ms frames
- ✓ Metrics: communication latencies, bandwidth usage and buffer occupancies

Toolset & Techniques

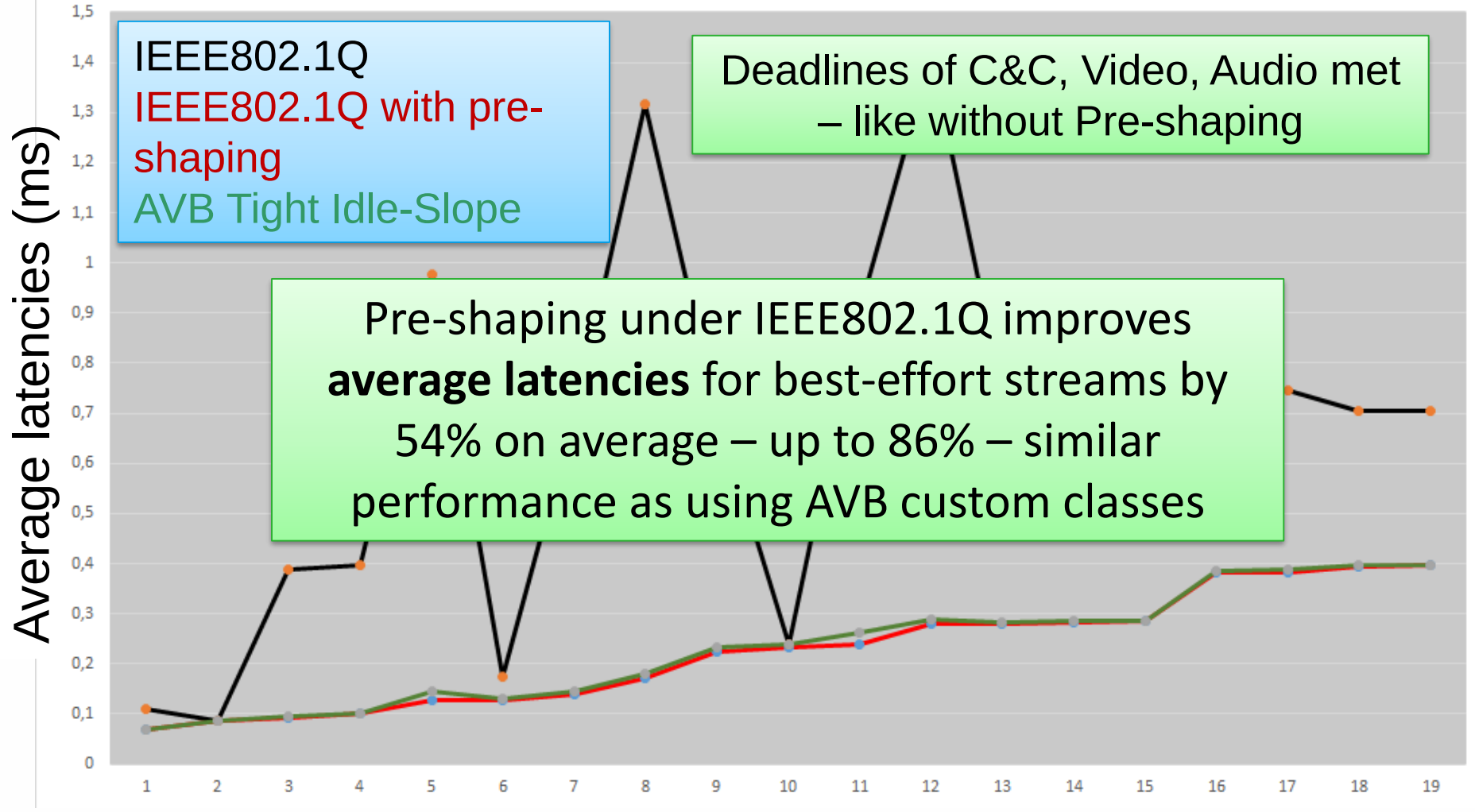
- ***RTaW-Pegase*: modeling / analysis / configuration of Ethernet TSN** (automotive, avionics, industry) + CAN (FD)
- Developed since 2009 in partnership with Onera
- Users across several industries, e.g; Daimler Cars, Airbus Helicopters, CNES, ABB



Techniques used

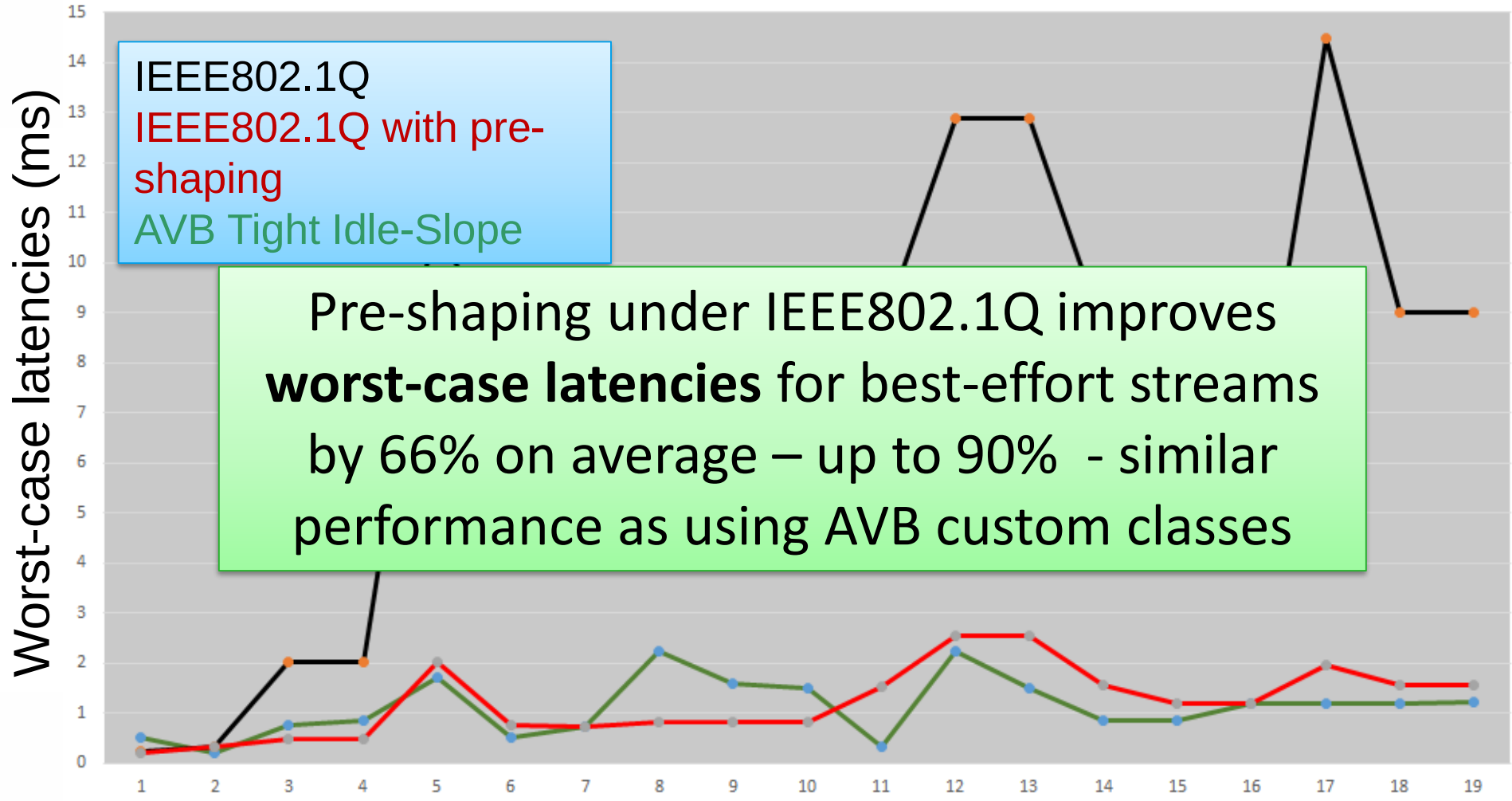
- **Worst-case Traversal Time (WCTT) analysis** – used for deadline constraints
- **Timing-accurate Simulation** – used for average & throughput constraints
- **Optimization algorithms** for setting the parameters of all supported protocols

IEEE802.1Q with pre-shaping for Video Average latencies for best-effort streams

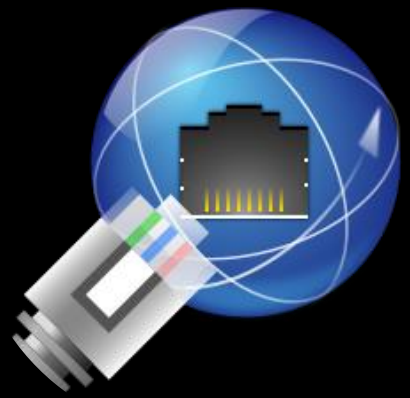


Best-effort streams only

IEEE802.1Q with pre-shaping for Video
Worst-case latencies for best-effort streams



Best-effort streams only



Discussion & conclusion

Pre-shaping Pros and Cons

- **Simple, compatible with standard IEEE801Q HW and as effective as AVB/CBS in our experiments but**

1. No protection against “babbling idiots” unlike CBS and TAS – per stream policing of Qci could offer a solution
2. Adding frames to the system may require a reconfiguration of all flows subject to pre-shaping (unlike AVB with standard parameters)
3. Setting pre-shaping parameters requires dedicated tool support
4. As there is no reshaping along a path, efficiency decreases with the number of hops
5. Pre-shaping is an additional specification to ECU suppliers which has a cost for OEMs, **but pre-shaping can be implemented on a subset of nodes only** (e.g., 5 out of 14 in our case-study)

Any questions? Contact us

nicolas.navet@uni.lu
jorn.migge@realtimeatwork.com