Early-stage topological and technological choices for TSN-based communication architectures

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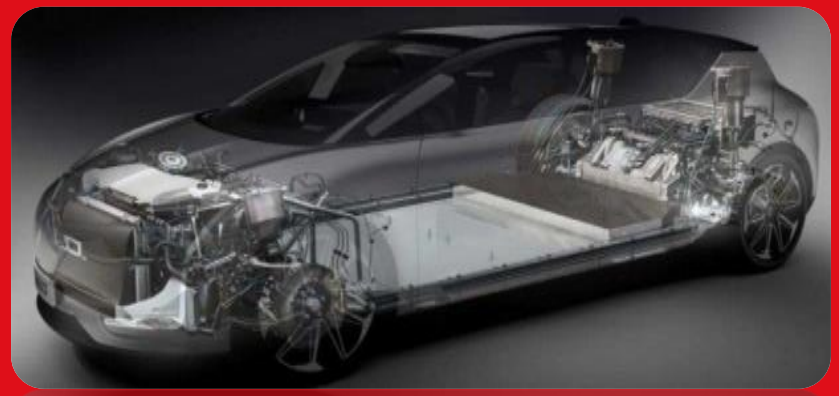


Designing next-generation E/E architectures: Renault FACE service-oriented architecture

FACE : Future Architecture for Computing Environment

RENAULT NISSAN MITSUBISHI

- Zonal EE Architecture
  - PCU : Physical Computing Unit
    - Intelligence
  - PIU : Physical Interface Unit
    - Analog I/O
    - Interface to legacy networks
- Service Communication (SOA)

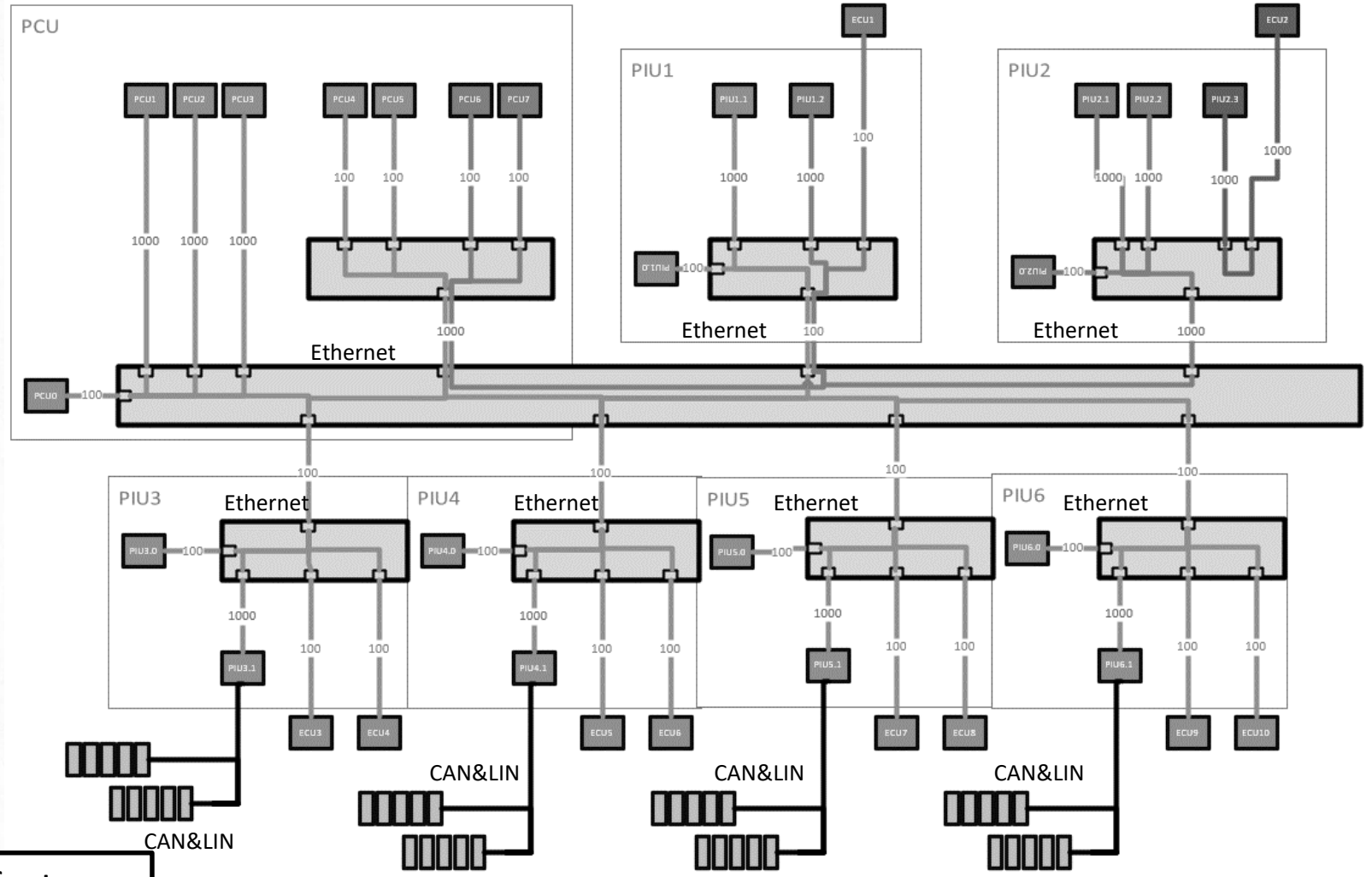
- Ethernet Backbone

→ Mixed domains (Body, chassis, ADAS, …)

→ Mixed safety constraints (QM, ASIL-B, …)

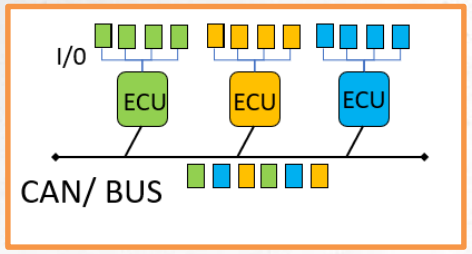
→ Mixed Security levels

→ Mixed QoS requirements
(C&C, Video, Audio, Reprog, …)



MAIN GOAL : Scalability, capability to add new features

Which TSN protocols to meet requirements ? Which are the limits of the architecture?



CAN Snapshot packets aggregate all data from CAN buses

Ps : Snapshot Period (1ms, 5ms, 10ms, …)
Tb : TSN Backbone transfer time
Tec : Ethernet – CAN bridging time

Service Com.

PCU
Switch

Ethernet

Ps
CAN Snapshot

Tb

I/0
I/0
ECU
PIU #1

Tec

Tgtw = Ps + Tb + Tec

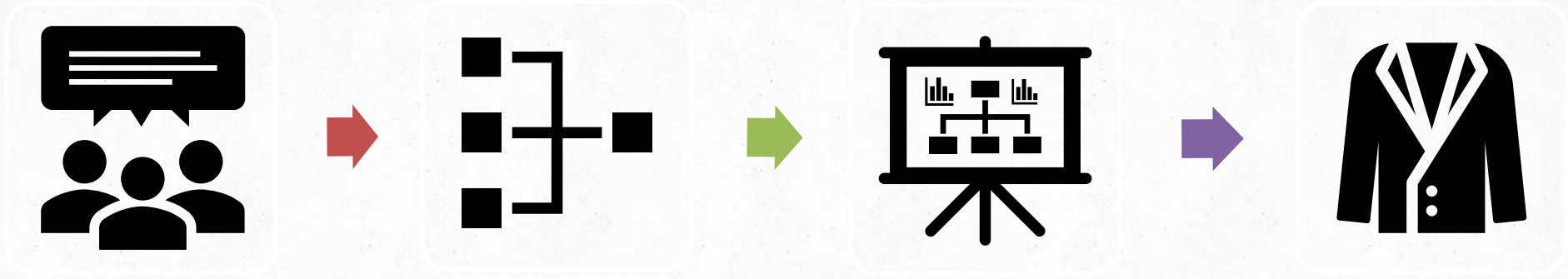
Signal Com.

I/0
I/0
ECU
PIU #2

CAN
CAN

CAN Snapshot: simplified and predictable gatewaying strategy

Simulation Process



Use-Cases
- Latency
- Jitter
- Throughput
- Synchronisation

EE-Architecture
- Allocation of UC

Simulation
- Configurations meeting requirements
- Identified bottlenecks

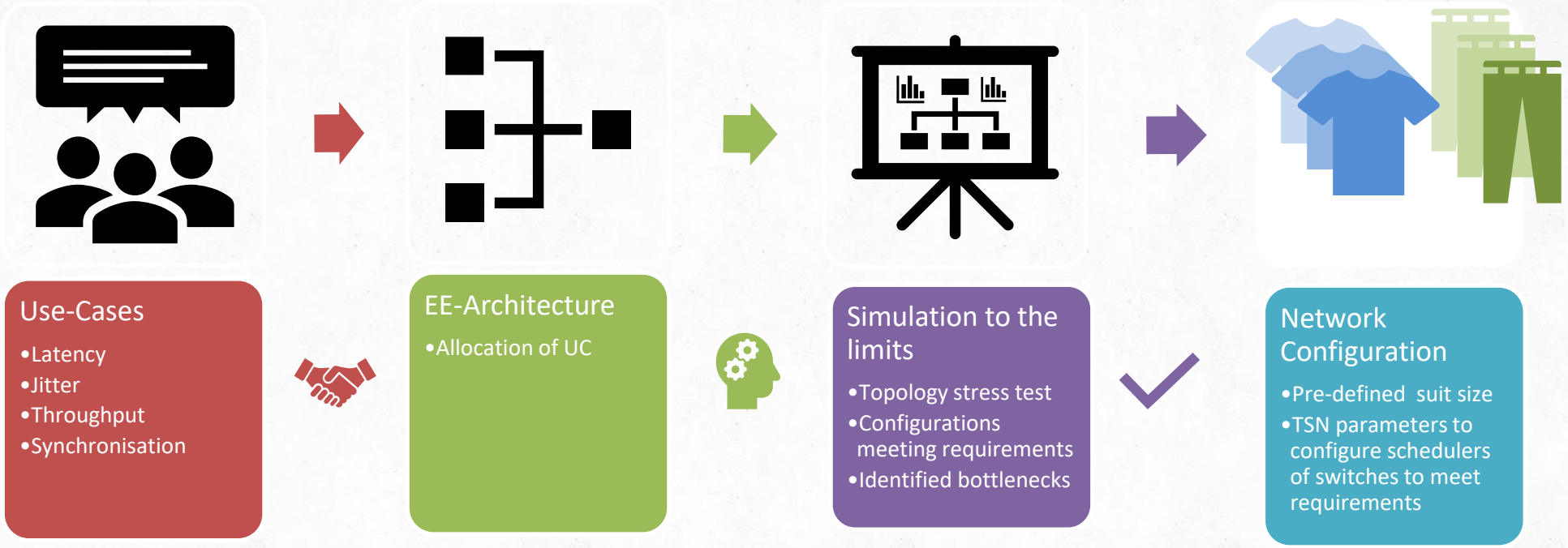
Network Configuration
- Custom Suit
- TSN parameters to configure schedulers of switches to meet requirements

New Use-Case?

Start over again, need to create a new custom suit!

Network configuration process might be the limiting factor for scalability !

Finding the limits of an E/E Architecture



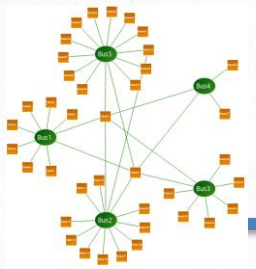
New Use-Case?

Use pre-defined configuration

MAIN GOAL : Network configuration process ready for scalability

Early-stage design choices for TSN networks

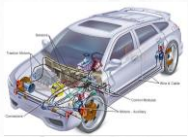
Topological and technological choices



“Early stage”

“Project”

“Real”



We have: “candidate” topologies & hypotheses on the traffic

We want: architecture design & technological choices (e.g. , protocols, data rates, etc)

We have: topology set & traffic known

We want: optimized network configuration

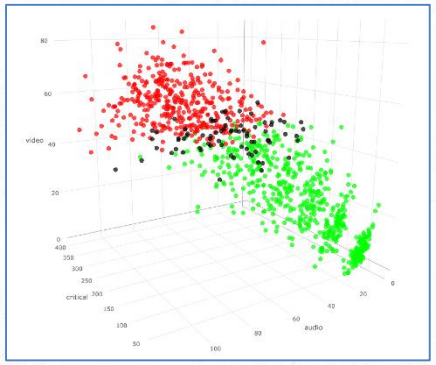
We have: traffic as seen in the network

We want: check that implementation meets specification

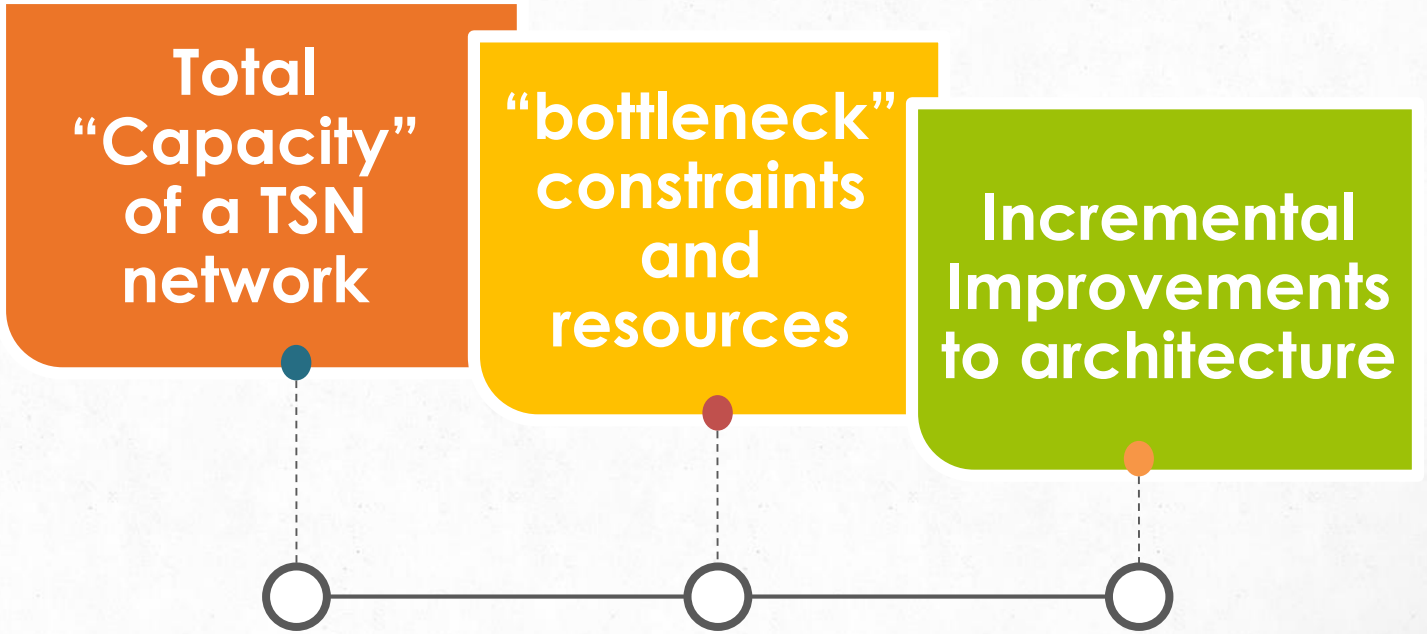
Topology Stress Test

Design choices based on evidence at a time when all communication requirements are not known ?

1. Network dimensioning to add functions & services during car's lifetime? KPI for network extensibility
2. Identifying and removing bottlenecks? KPI for resource congestion



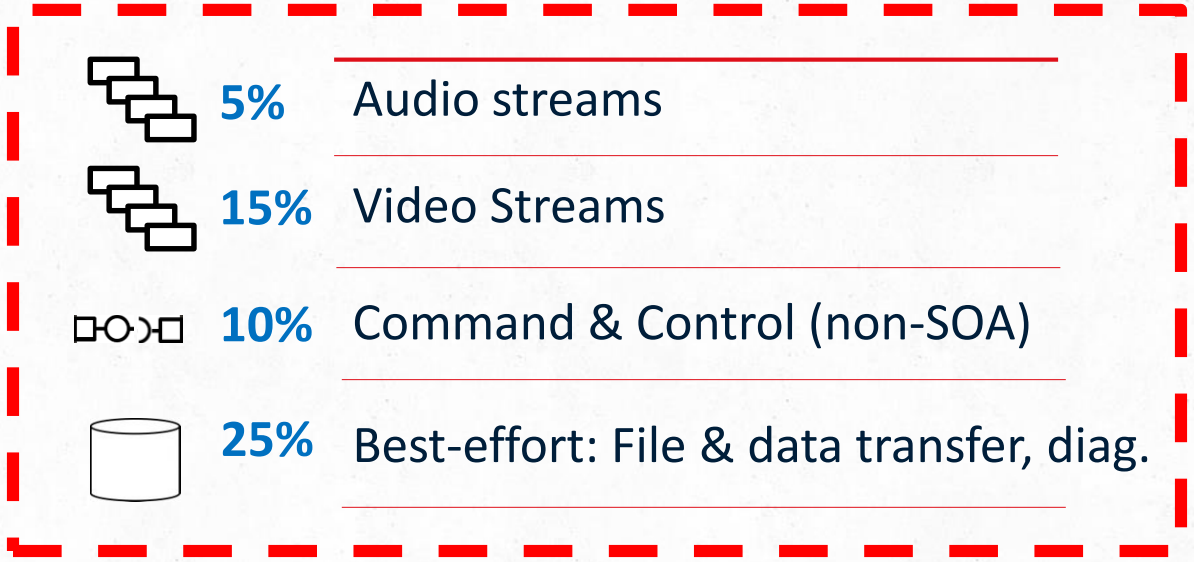
Synthetic data captures what is known and foreseen about communication needs



Artificial data: all possible communication requirements

- ✓ Based on past vehicle projects and what can be foreseen for the current project
- ✓ Assumptions made on the streams and their proportion

- ✓ *Stream characteristics overall well known*
- ✓ *Stream proportion more uncertain → several scenarios may be considered*



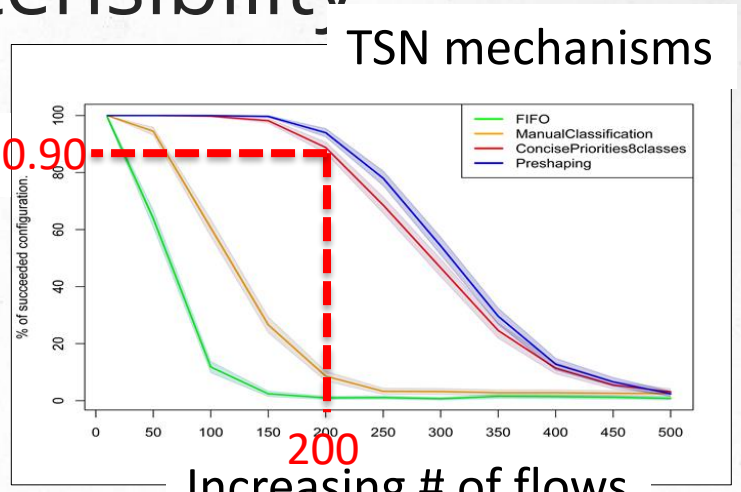
We have a candidate E/E architecture and a baseline traffic, the objective is to

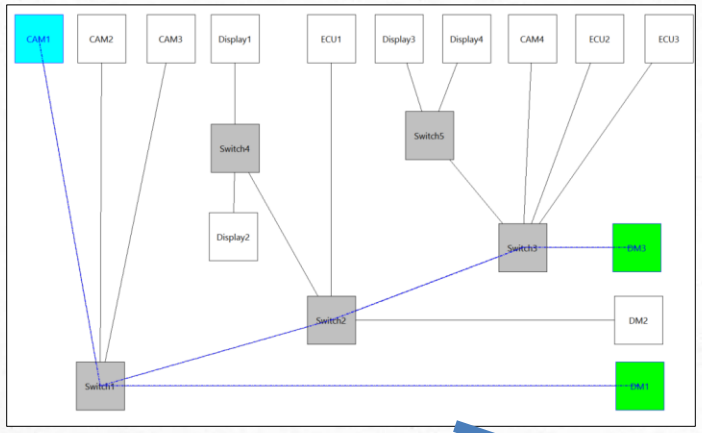
1. Estimate the **max. # of SOME/IP services** that can be supported with each TSN protocol
2. Identify and **remove architecture's bottlenecks**

Total network "capacity": KPI of extensibility

Probability that the network will successfully meet the performance constraints of *a given number of* streams

KPI: "the network capacity is 200 flows at the 90% threshold when no other mechanism than priorities is used"





Command & Control (CC)	✓ 32 streams, 256 to 1024 byte frames ✓ 5ms to 80ms period and deadlines ✓ Hard deadline constraints	2/5
Audio Streams	✓ 8 streams: 128 and 256 byte frames ✓ 1.25ms period and deadline ✓ deadline constraints (soft)	1/10
Video streams	✓ 3 streams (vision): 30x1400 byte frames every 33ms – deadline = 33ms ✓ 4 streams (ADAS): 15x1000bytes frames every 33ms – deadline = 10ms ✓ hard and soft deadline constraints	1/5
Best-effort streams	✓ Bulk data = from 64K to 1MB transfers ✓ 100ms periodic PDUs data, e.g. from CAN networks	3/10

Scheduling Mechanisms

- ☑ Without priorities
- ☑ User priorities
- ☑ Concise priorities
- ☑ PreShaping
- ☐ Credit Based Shaping (CBS)
- ☑ Time Aware Shaping (TAS)
- ☑ Preemption

➢ `Topology-stress-test (topology, traffic assumption, TSN policies)`

Monte-Carlo simulation on synthetic networks

Create

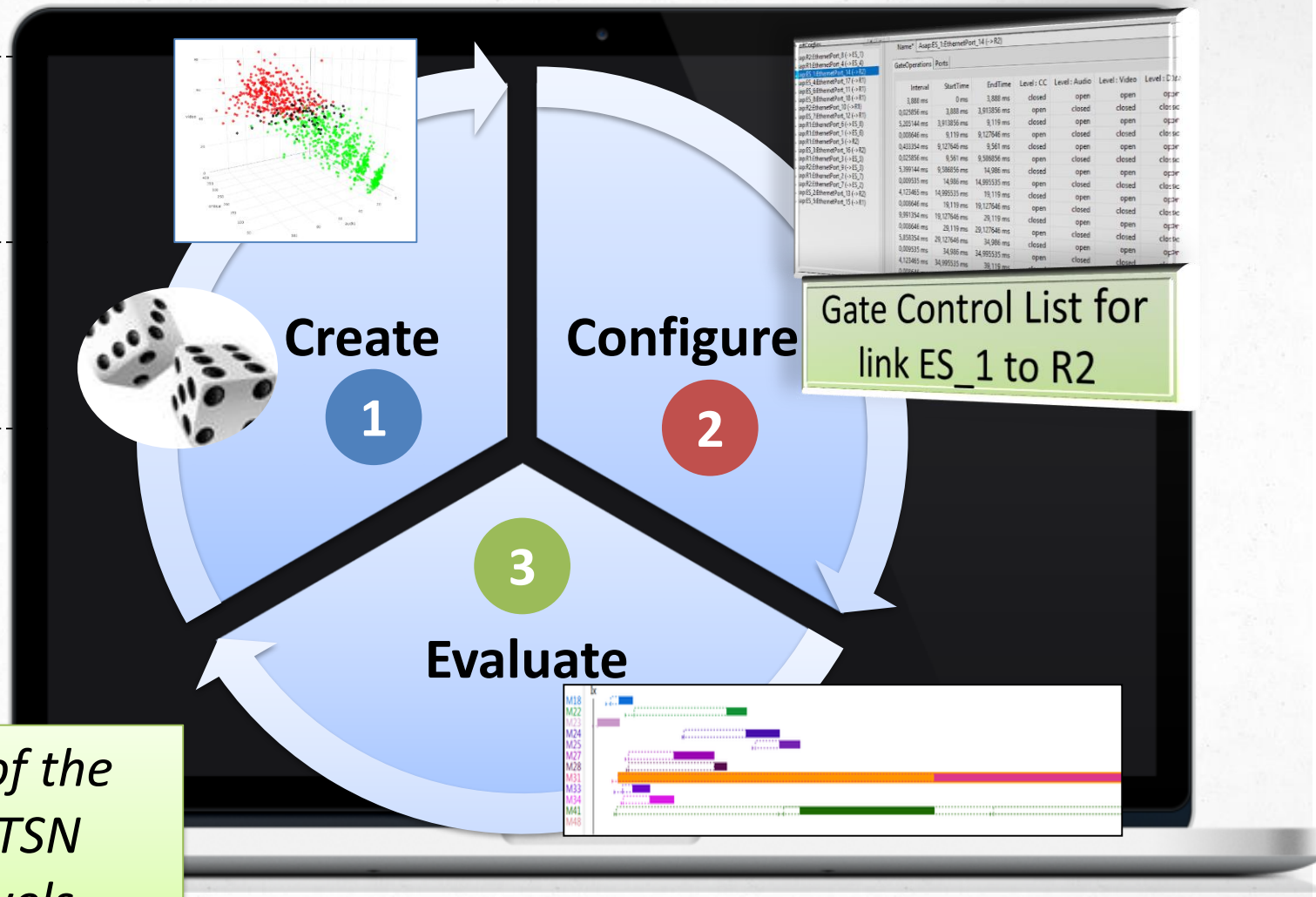
1. Random yet realistic communication needs with increasing load

Configure

2. Configure generated networks

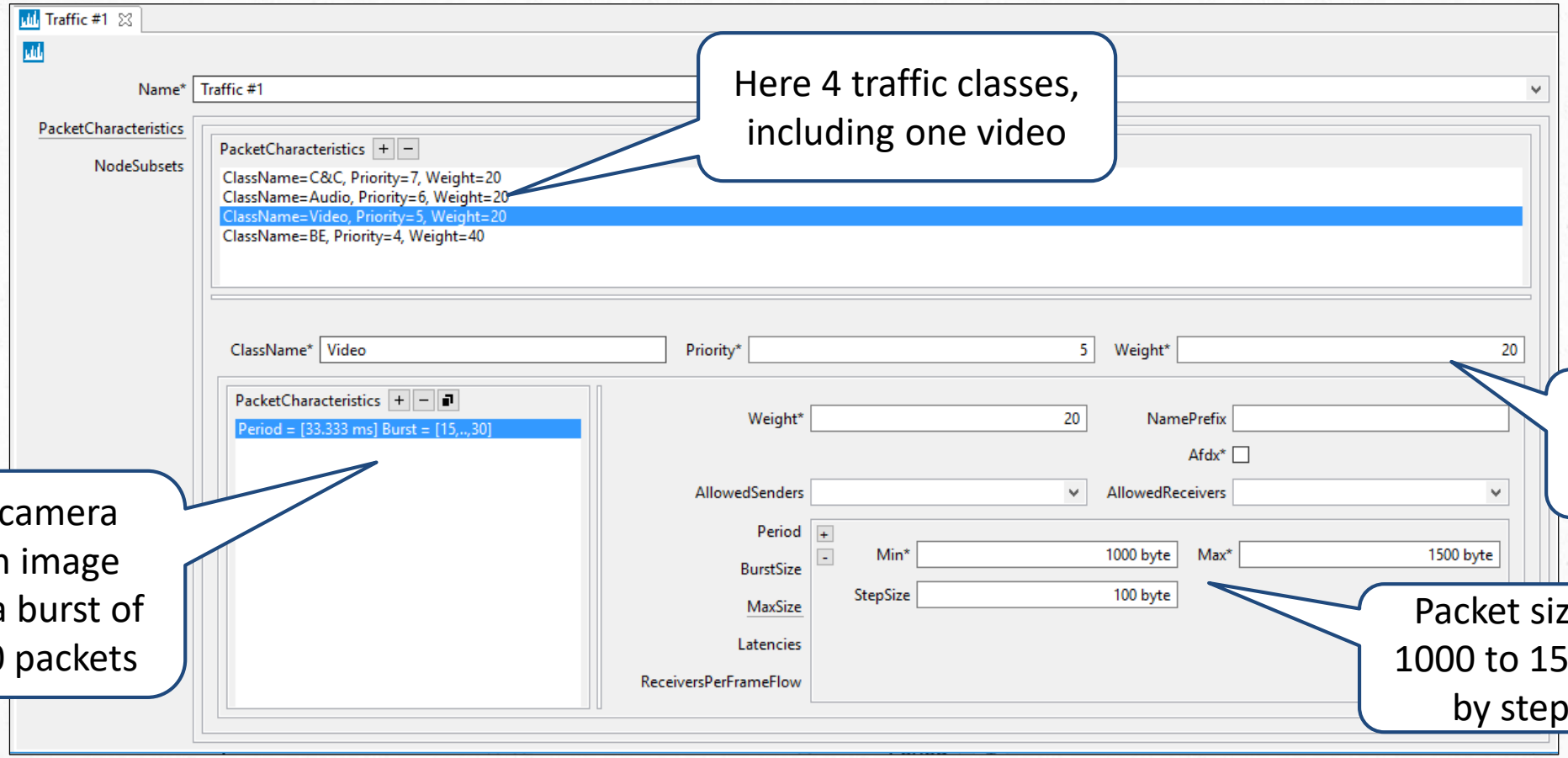
Evaluate

3. Check performance requirements by simulation and worst-case analysis



Gather statistics on the capacity of the architecture with each selected TSN protocol at the different load levels

Specifying characteristics of streams : example of a video stream class



Here 4 traffic classes, including one video

30FPS camera with an image sent as a burst of 15 to 30 packets

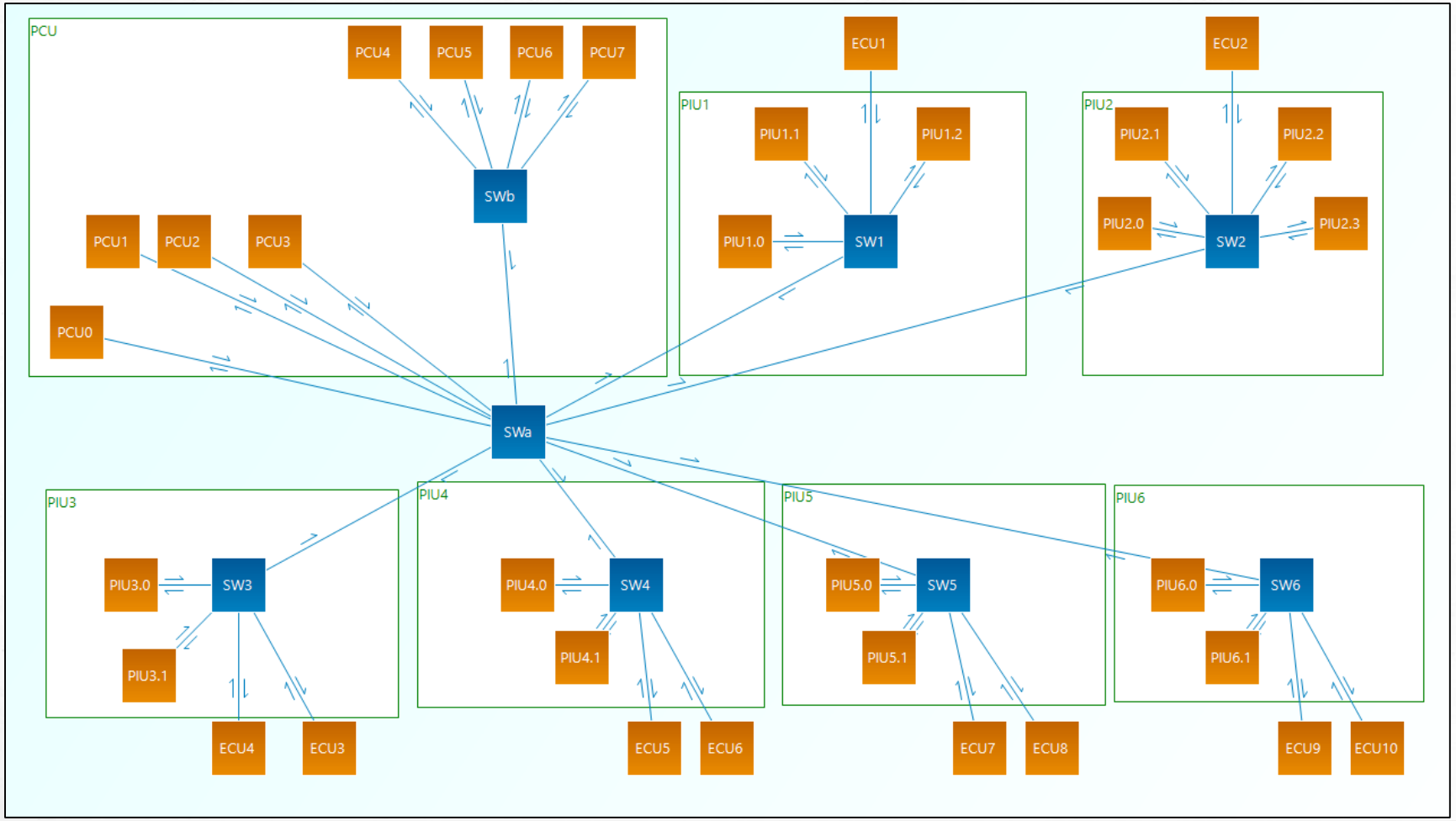
Percentage of video streams among all streams

Packet size from 1000 to 1500bytes by step 100

Case-study: Renault FACE architecture

Renault Ethernet prototype SOA

8 Physical Computing Units (PCU)



10 ECUs

#Nodes	**33**
#Switches	**8**
#streams Services excluded	**52**
Virtual Switch	1 with 4 VMs
Link data rates	**100Mbit/s**

15 Physical Interface Units (PIU) gateways to CAN and LIN buses

[RTaW-Pegase screenshot]

TSN QoS mechanisms considered

#1 User priorities: priorities manually allocated to classes by designer according to criticality and deadlines

#2 8 priority levels assigned to flows by *Concise Priorities* algorithm

#3 User priorities + frame preemption for the top-priority traffic class

#4 User priorities + Time-Aware-Shaping with exclusive gating for top-priority traffic class

#5 AVB/Credit-Based-Shaper with SR-A and SR-B at the two top priority levels

#6 User priorities + Pre-shaping: inserting “well-chosen” idle times between packets of segmented messages

Heterogeneous backbone traffic

Baseline traffic: no services

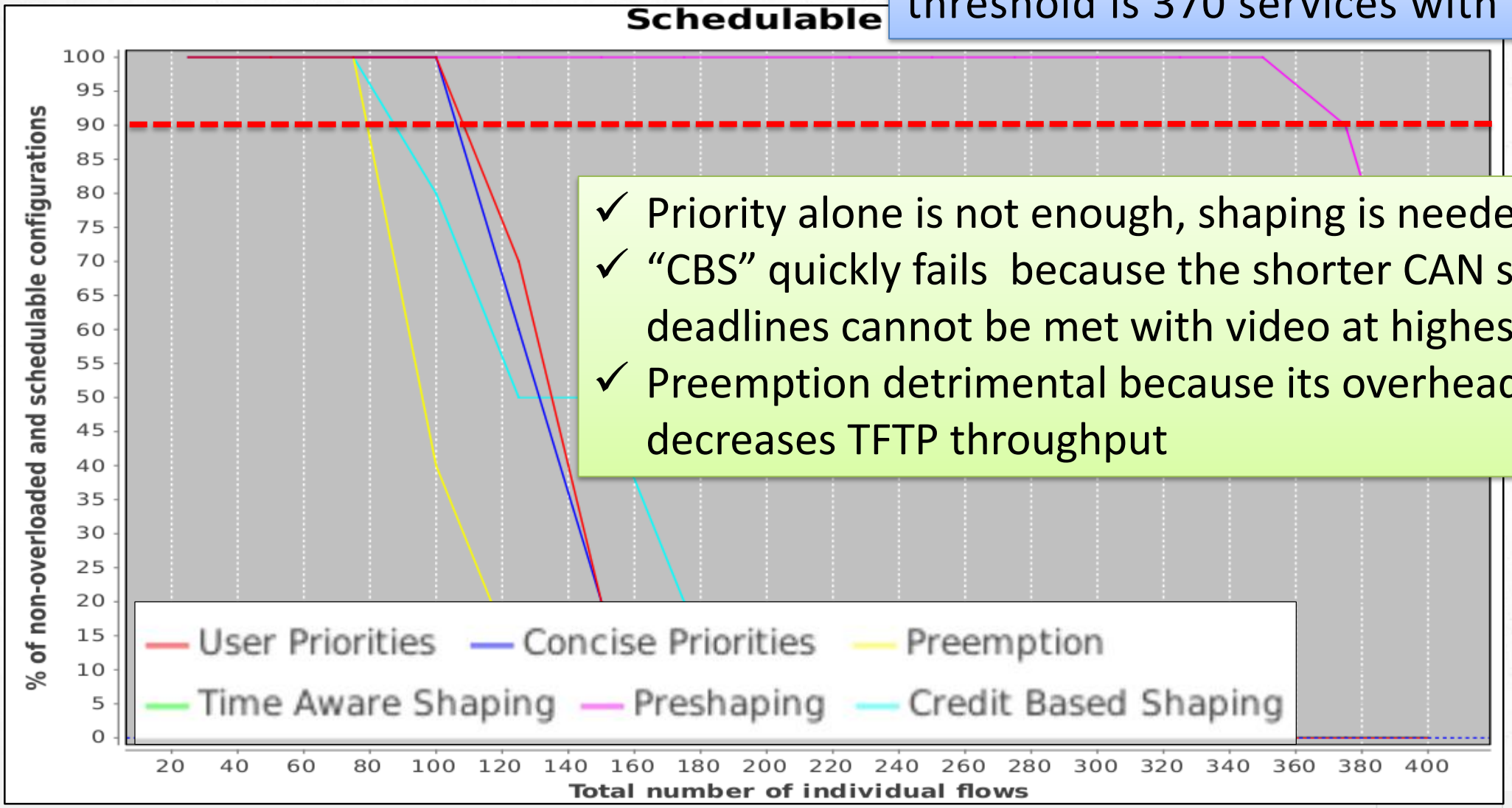
Traffic Class	User Priorities	Type of traffic and constraints
TFTP	1	✓ TFTP (throughput constraints: 5Mbit/s and 9 Mbit/s).
Non-urgent Services & Short Files	3	✓ Services with medium latency constraints (30ms - 100ms)
Multimedia & ADAS	4	✓ Less urgent ADAS UC6.A.x (latency constraint: 33ms) ✓ Multimedia video UC6.B.x (latency constraint: 33ms)
Fusion & ADAS	5	✓ UC6.A.x ADAS Video (latency constraint: 15ms) ✓ UC7 Fusion (latency constraint: 10ms)
CAN snapshots & Urgent Services	6	✓ Services with short latency constraints (<30ms) ✓ UC8 CAN snapshot frames (2ms or 5ms)

Capacity of the network in terms of # of services ?

- ✓ SOME/IP traffic: both urgent and non urgent services
- ✓ Urgent (60%): periods from 5 to 30ms, deadlines = periods, size = 64bytes
- ✓ Non-Urgent (40%): periods from 30 to 100ms, deadlines = periods, size from 128 to 1500bytes

Scenario #1: CAN snapshots with a 2ms deadline

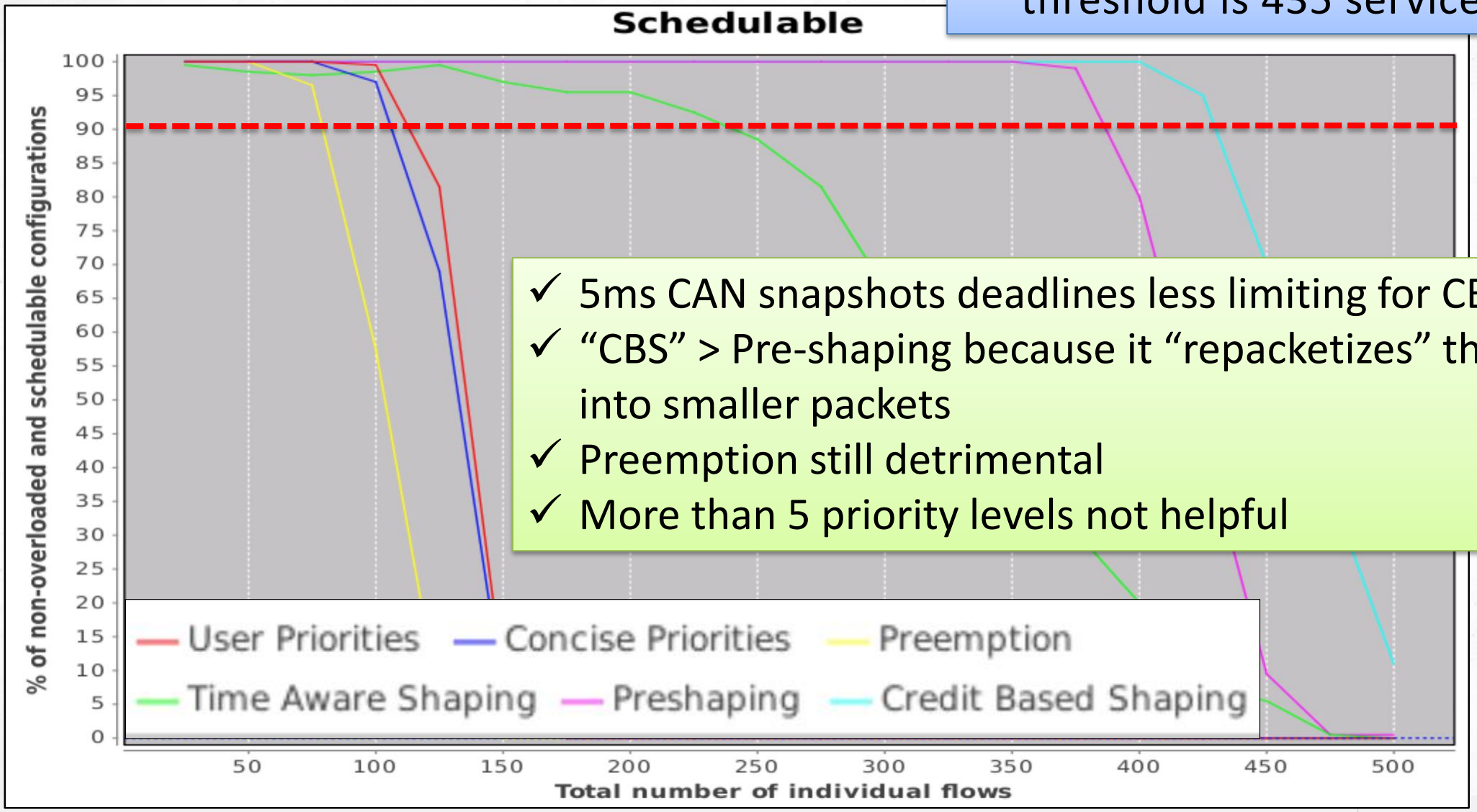
Capacity of the network at the 90% threshold is 370 services with Preshaping



- ✓ Priority alone is not enough, shaping is needed
- ✓ "CBS" quickly fails because the shorter CAN snapshot deadlines cannot be met with video at highest priority
- ✓ Preemption detrimental because its overhead decreases TFTP throughput

Scenario #2: CAN snapshots with a 5ms deadline

Capacity of the network at the 90% threshold is 435 services with CBS

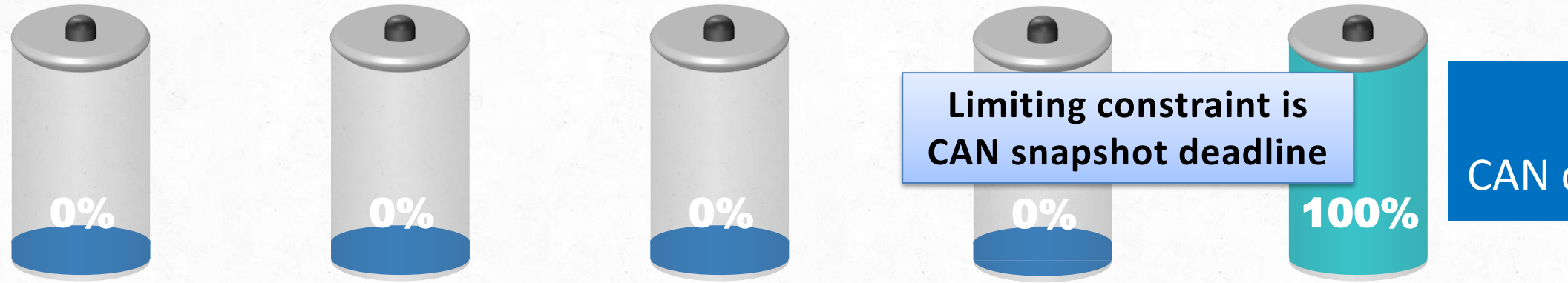


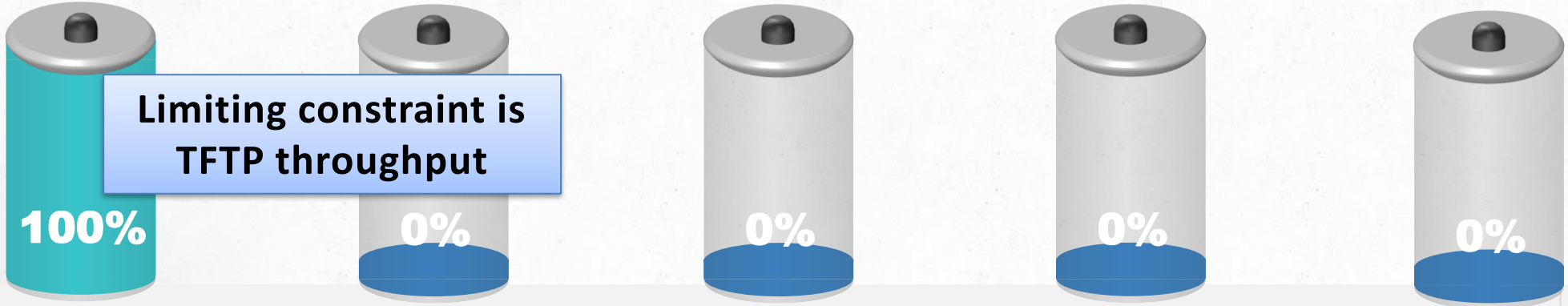
- ✓ 5ms CAN snapshots deadlines less limiting for CBS
- ✓ "CBS" > Pre-shaping because it "repacketizes" the data into smaller packets
- ✓ Preemption still detrimental
- ✓ More than 5 priority levels not helpful

Where are the bottlenecks? Which traffic classes ?
Which constraints? Where in the network?

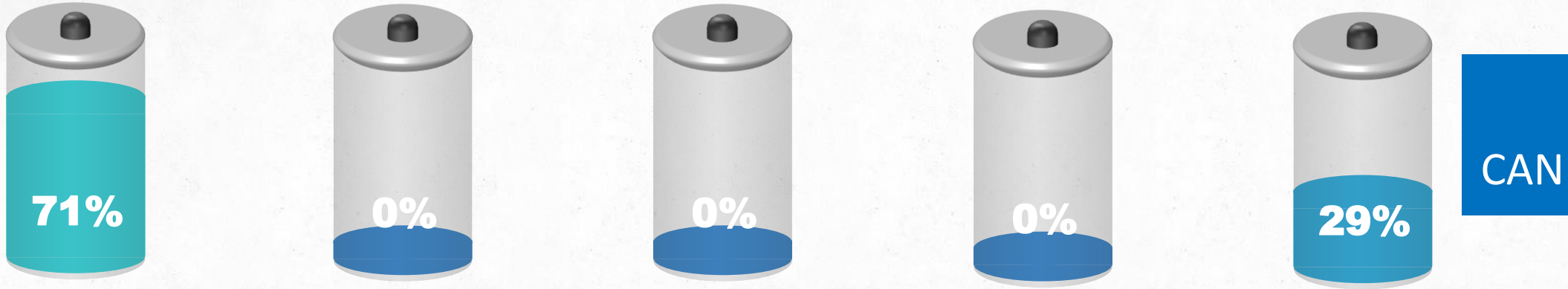
Bottleneck traffic class under CBS

Metric: % of the non-feasible configurations for which at least one stream of a traffic class does not meet its performance constraints





Bottleneck traffic class under TAS



TFTP

Non-urgent Services & Short Files

Multimedia & ADAS

Fusion & ADAS

CAN snapshots & Urgent Services

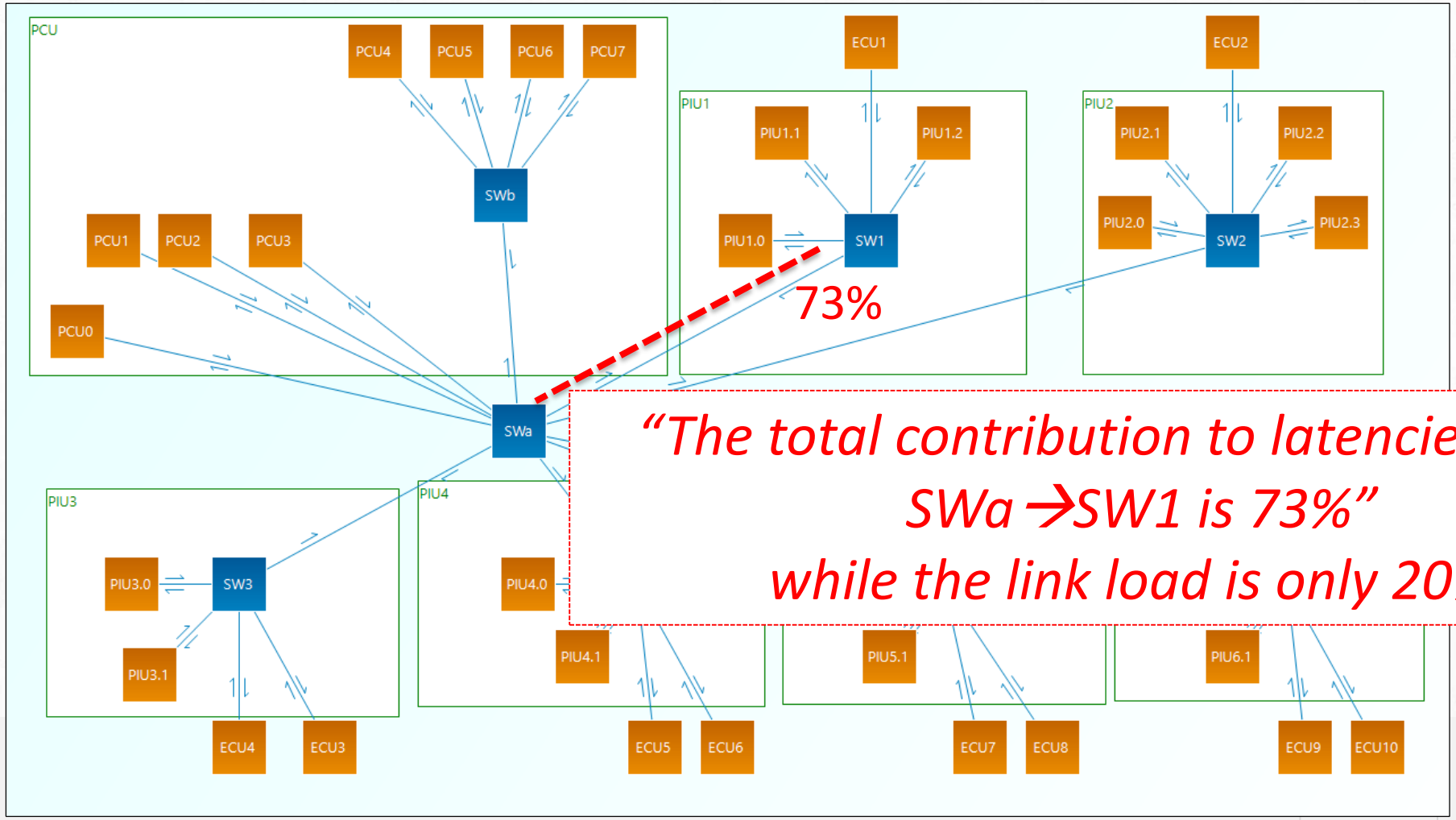
TAS

CAN deadline=5ms

- ✓ Limiting traffic class → limiting constraints → missing TSN mechanisms - here shaping video streams would improve TFTP throughput
- ✓ The bottleneck traffic class may vary depending on the # of flows → use the # of flows corresponding to a fixed probability threshold – here 90%

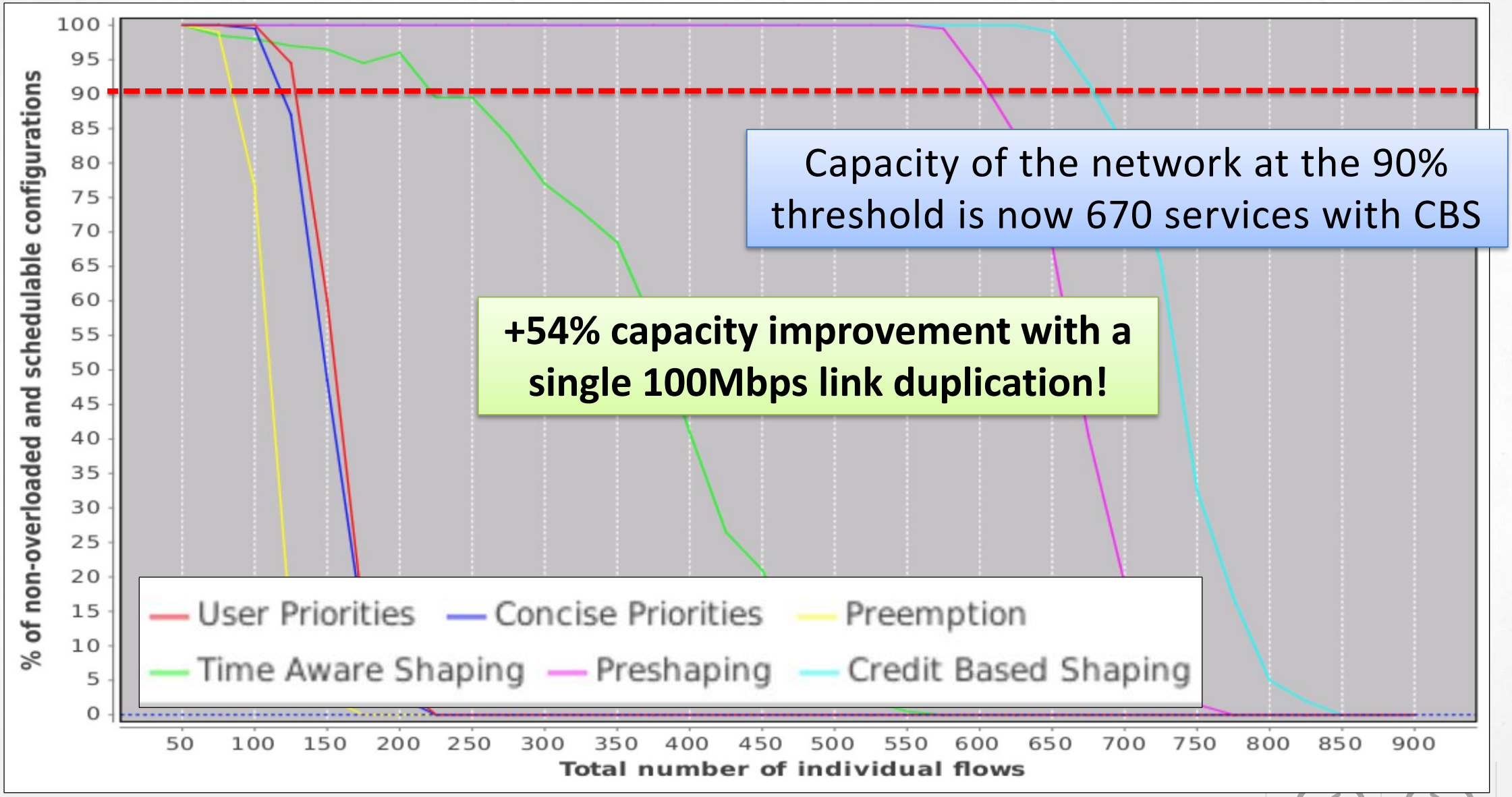
Identifying bottleneck resources

Metric: contribution of a “hop” to the overall latency of the streams that are <u>not</u> meeting their performance requirements



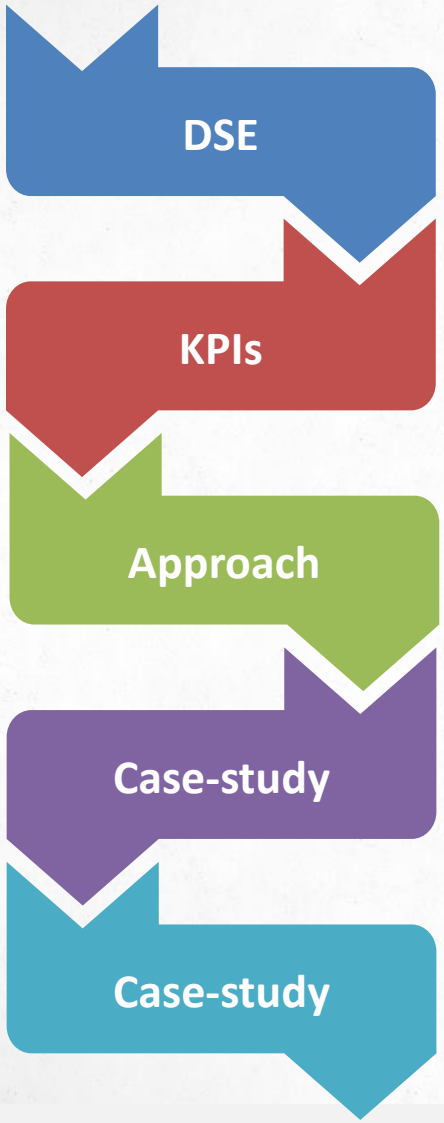
“The total contribution to latencies of link SWa→SW1 is 73%”
while the link load is only 20%!

Improvement: duplicating link SWa → SW1and balancing load



Conclusion and a look forward

Contributions



1. **Design Space Exploration with artificial yet realistic data to support architectural and technological choices** → Topology-Stress-Test in RTaW-Pegase

2. **KPIs to 1) evaluate the evolutivity of a network and 2) measure resources congestion** → link load is insufficient with performance constraints

3. **Tool-supported approach to identify which performance constraints is the limiting factor and where the bottlenecks are in the network**

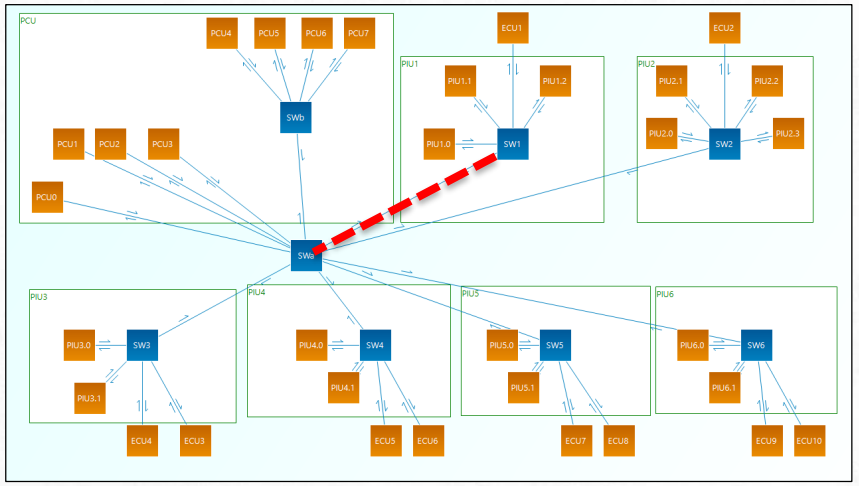
4. **On the FACE E/E architecture duplicating a single 100Mbit/s bottleneck link allows supporting 54% more services!**

5. **No "one fits all" TSN scheduling solution for TSN backbones, need the combined use of several TSN mechanisms** → tool support helps keep up with complexity

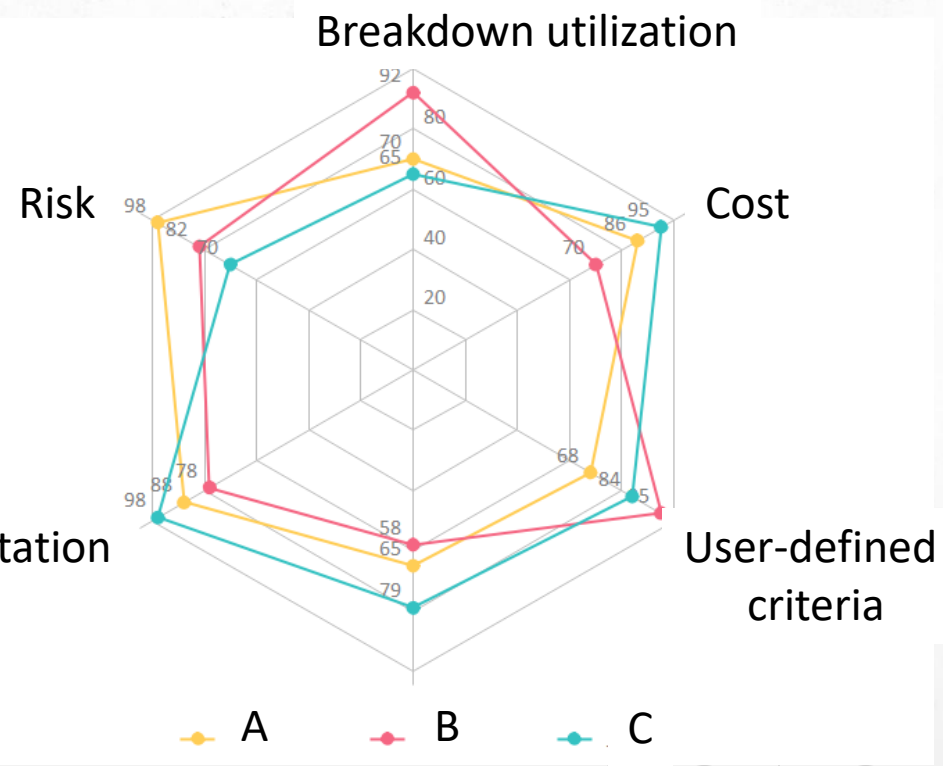
A look forward: towards E/E architecture synthesis

1 **Extensions:** better results explanation and support for combined TSN mechanisms (e.g., priorities+TAS+CBS+preemption), task allocation on ECU/cores/cloud

2 **Propose incremental changes that allow a "minimum gain"** (# of flows, costs, safety, …)



Sol A: duplicate 100Mpbs link and balance load
Sol B: switch to 1Gbps
Sol C: increase switch memory by 150Kb
….



Thank you for your attention!

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Questions ?