Timing verification of automotive communication architecture using quantile estimation

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1 Outline

✓ Early-stage timing verification of wired automotive buses – CAN-based communication architectures

- Schedulability analysis versus simulation
- Performance metrics : the case for quantiles derived by simulation
- 2 typical automotive use-cases

2 Automotive communication architectures

✓ Increased bandwidth requirements & timing constraints

✓ More complex & heterogeneous architectures with black-box ECUs

✓ Optimized CAN networks for higher bus loads: priorities, frame offsets, gateways, communication stacks, etc

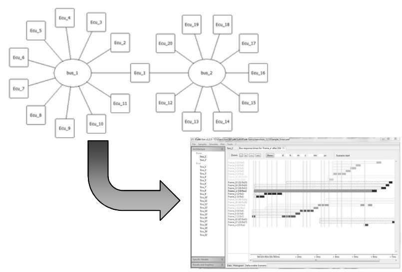
✓ Verification activity of higher importance today, higher load levels calls for more accurate verification models → no margin for errors

✓ Main performance metrics: frame response time = communication latency

Schedulability analysis *"mathematic model of the worst-case possible situation"* VS **Simulation** *"program that reproduces the behavior of a system"*

$$K_i^k(t) \stackrel{\text{def}}{=} \left\lfloor \frac{J_i^k + \varphi_i^k(\phi^i)}{T_i^k} \right\rfloor + \left\lfloor \frac{t - \varphi_i^k(\phi^i)}{T_i^k} \right\rfloor + 1$$

- first term: max number of instances that can accumulate at critical instants
- second term: max number of instances arriving after critical instants



☺ Upper bounds on the perf. metrics → Safe if model is correct and assumptions met

☹ Often pessimistic → over-dimensioning

☹ Might be a gap between models and real systems! → unpredictably unsafe then

☺ Models close to real systems

☺ Fine grained information

☹ Worst-case response times are out of reach! Occasional deadline misses must be acceptable

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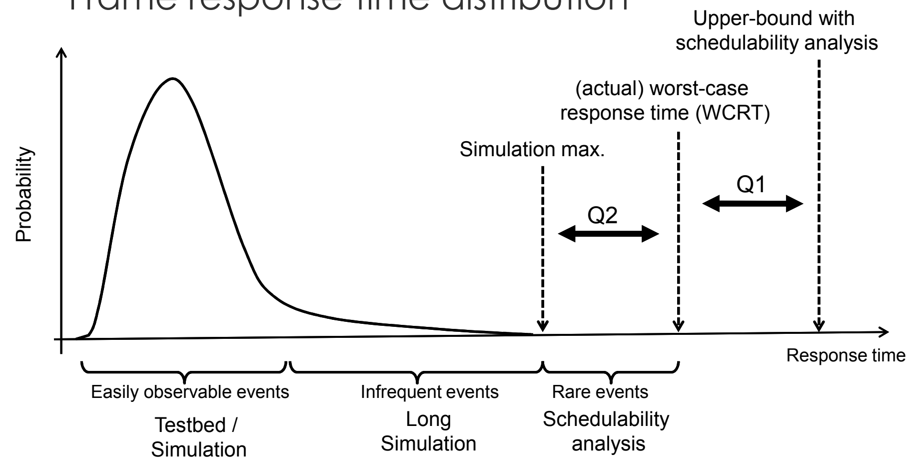
Metrics for the evaluation of frame latencies: the case for quantiles

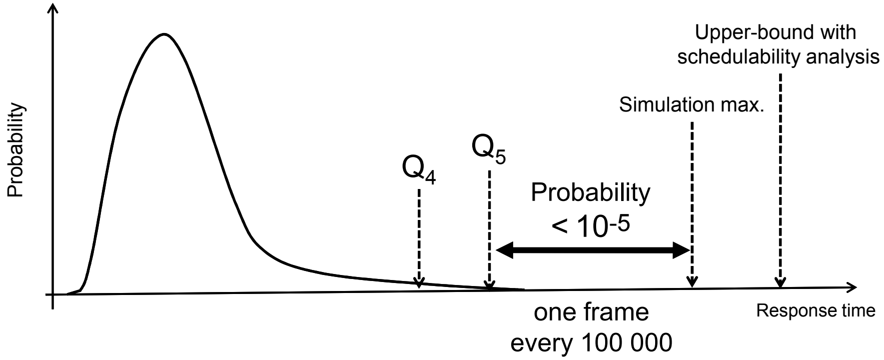
Frame response time distribution



Q1: pessimism of schedulability analysis ?!
Q2: distance between simulation max. and WCRT ?!

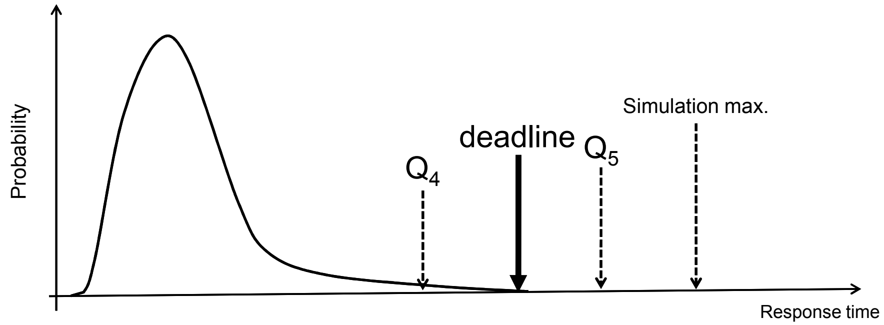
Using quantiles means accepting a ***controlled*** risk

Quantile Q_n: $P[\text{ response time} > Q_n] < 10^{-n}$



✓ No extrapolation here, won't help to say anything about what is too rare to be in simulation traces

Identifying both deadline and tolerable risks



1. Identify frame deadline
2. Decide the tolerable risk → target quantile
3. Simulate "sufficiently" long
4. If target quantile value is below deadline, performance objective is met

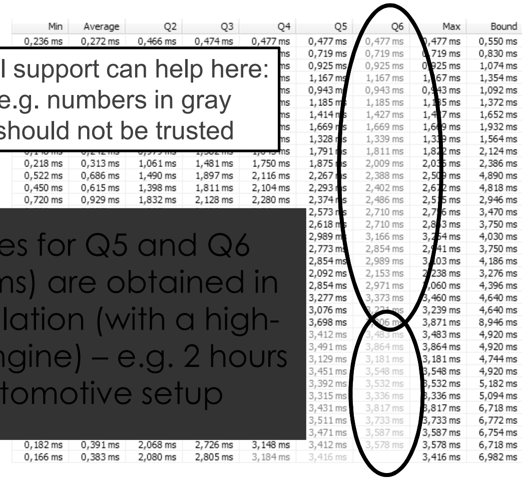
1) Quantiles vs average time between deadline misses

Quantile	One frame every …	Mean time to failure Frame period = 10ms	Mean time to failure Frame period = 500ms
Q3	1 000	10 s	8mn 20s
Q4	10 000	1mn 40s	≈ 1h 23mn
Q5	100 000	≈ 17mn	≈ 13h 53mn
Q6	1000 000	≈ 2h 46mn	≈ 5d 19h
…	…	…	

Warning : successive failures in some cases might be temporally correlated, this must be assessed!
Use of distributions of successive quantile overshoots, linear and non-linear dependency analysis

2) Determine the minimum simulation length

✓time needed for quantile convergence
✓ reasonable # of values: a few tens …



Tool support can help here: e.g. numbers in gray should not be trusted

Reasonable values for Q5 and Q6 (with periods <500ms) are obtained in a few hours of simulation (with a high-speed simulation engine) – e.g. 2 hours for a typical automotive setup

[RTaW-sim screenshot]

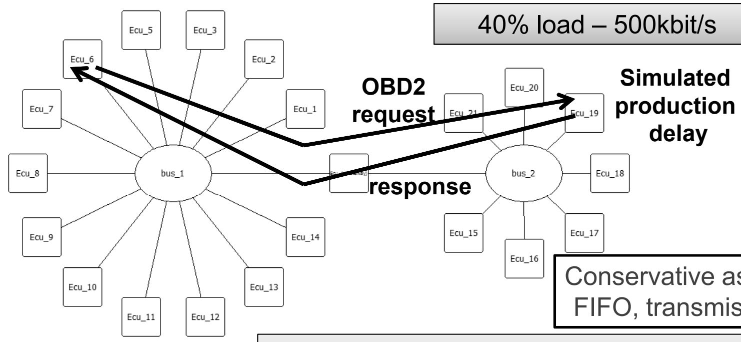
3

Typical use-cases of quantile-based performance evaluation

Use-case 1: OBD2 request through a gateway

50% load – 500kbit/s

40% load – 500kbit/s



Conservative assumptions: FIFO, transmission errors

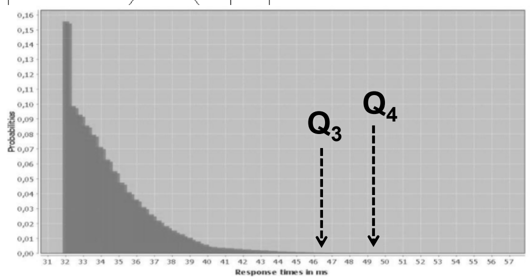
[RTaW-sim screenshot]

Time between the OBD2 request frame and reception of the first answer frame must not be greater than 50ms once every 1000 requests

Use-case 1: OBD2 request through a gateway

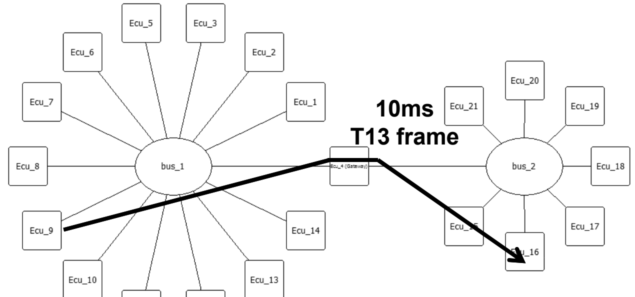
Time between the OBD2 request frame and reception of the first answer frame must not be greater than 50ms once every 1000 requests

Metrics	OBD response times
Min	31.94
Average	34.29
Q3	**46.55**
Q4	**49.31**
Q5	53.45
Q6	55.32
Max	56.57



Response time distribution

Use-case 2: end-to-end response time of a 10ms control frame



Functional level impact: less than 1 frame every 10^6 above deadline=10ms is acceptable

$Q_6 = 8.9$
max= 12.1

T10	6	P	10	0	0,684	0,924	2,241					
T11	4	P	10	0	0,166	0,341	1,681					
T12	8	P	10	0	0,424	0,658	2,153					
T13	8	B			0,522	0,866	2,573	4,149	6,244	7,593	8,87	12,129
T14	8	P	20	0	0,72	1,058	2,726	3,258	3,511	3,614	3,719	3,735
T15	8	P	20	0	1,168	1,588	3,094	3,511	3,741	3,784	3,962	3,977

Concluding remarks

1 Timing verification techniques & tools should not be trusted blindly

2 Simulation is well suited to systems that requires timing guarantees but

- ✓ Are not well amenable to schedulability analysis
- ✓ Or can tolerate deadline misses with a controlled level of risk

3 Some methodological aspects

- ✓ Determine quantile wrt criticality, and simulation length wrt to quantile
- ✓ Simulator and models validation
- ✓ High-performance simulation engine needed for higher quantiles