HAW HAMBURG

Asynchronous Traffic Shaping and Redundancy: Avoiding Unbounded Latencies in In-Car Networks

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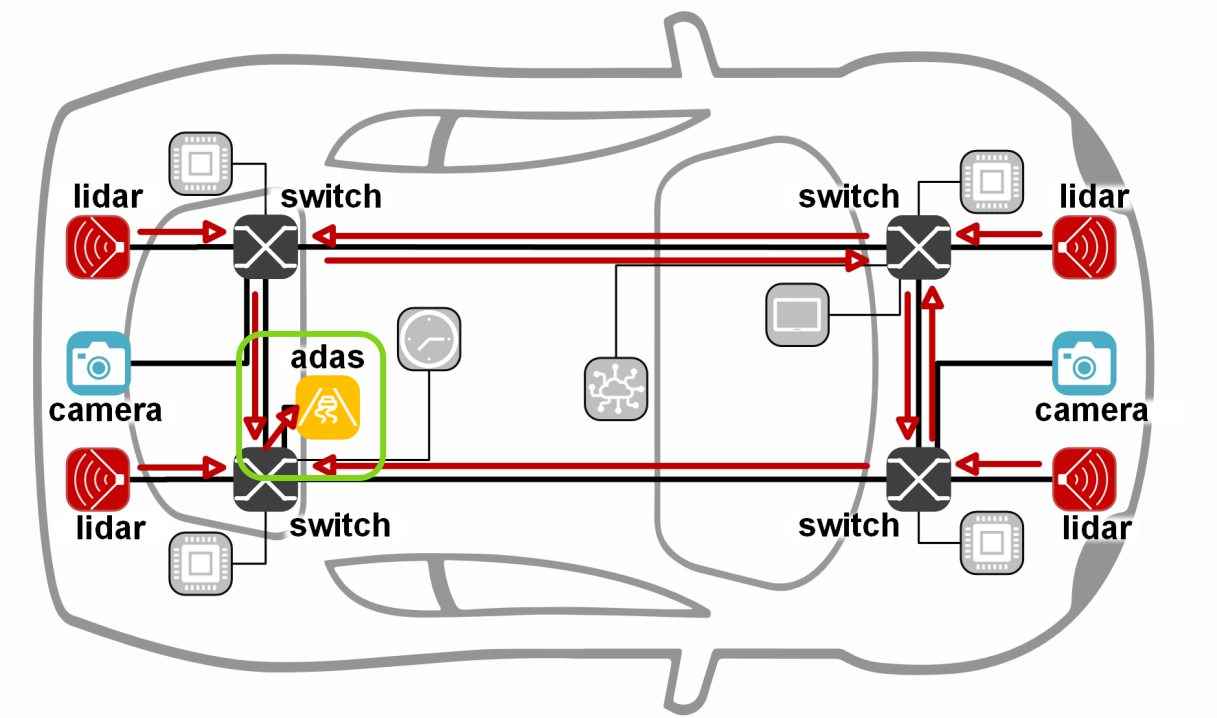
Agenda

1. Unbounded Latencies in Time-Sensitive Networks
2. Asynchronous Traffic Shaping and Redundancy
3. Solutions for Bounded Latencies
4. Apply Solutions to In-Vehicle Network

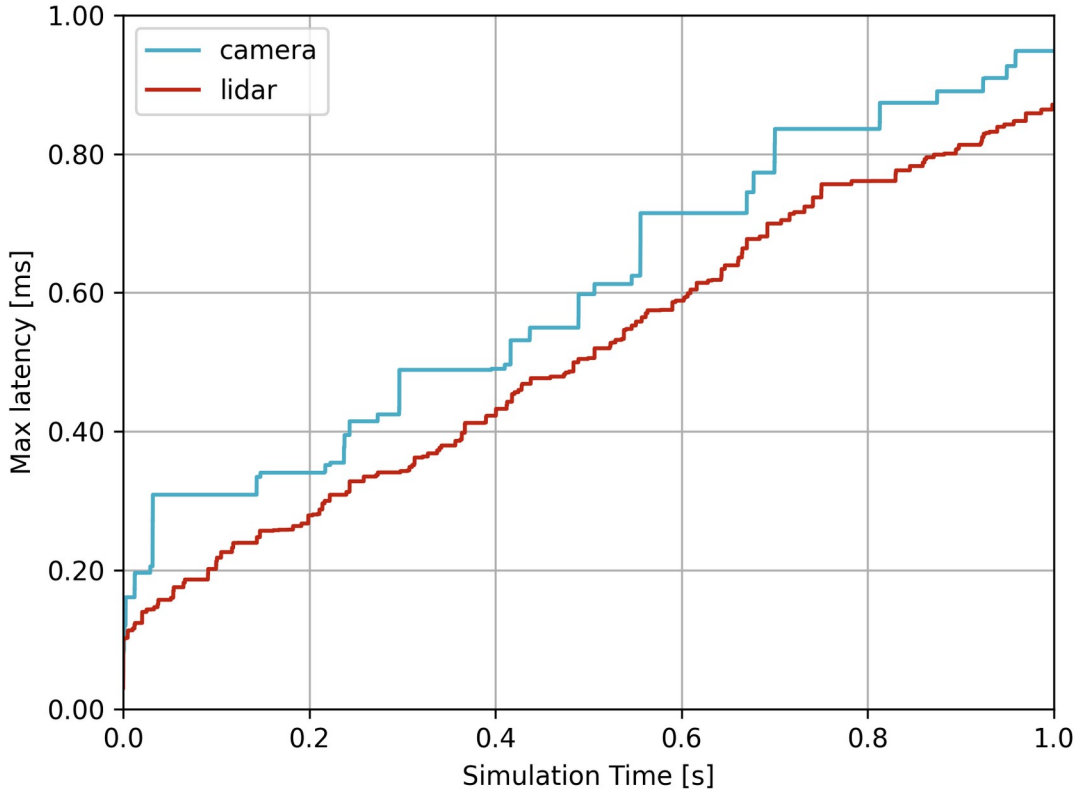
Unbounded Latencies in In-Car Networks



L. Thomas et al., “Worst-Case Delay Bounds in Time-Sensitive Networks With Packet Replication and Elimination,” IEEE/ACM Trans. Netw., vol. 30, pp. 2701–2715, 2022.

- Try combining ATS and FRER in our network
- Latencies increase over time

Unbounded Latencies in In-Car Networks



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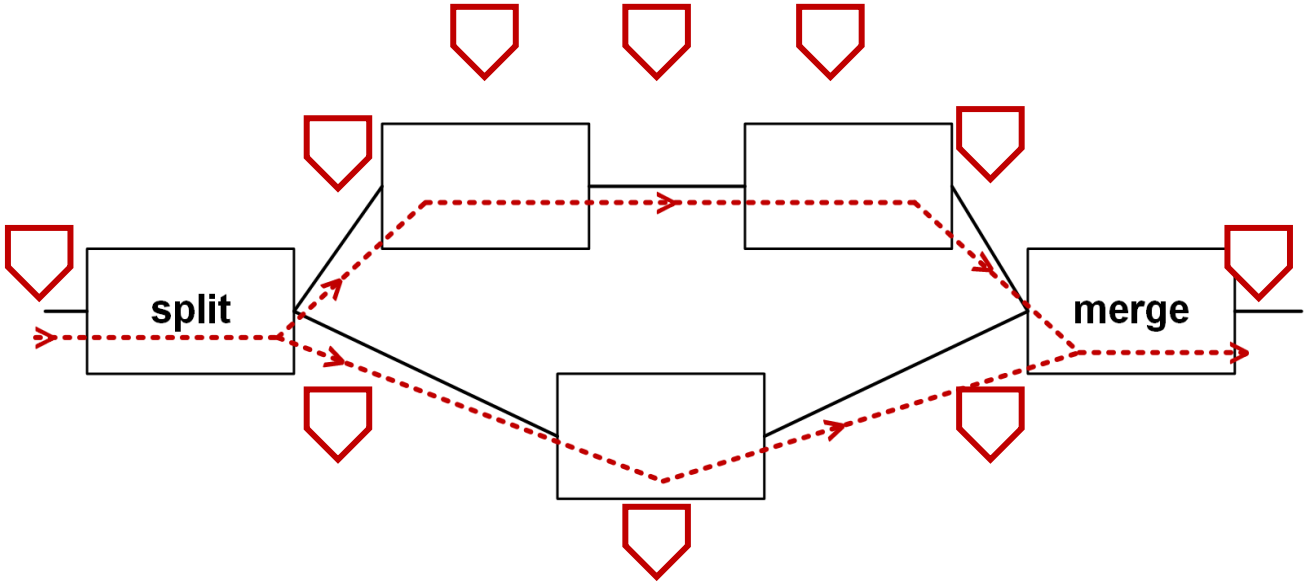
Frame Replication and Elimination for Reliability (FRER)

- IEEE 802.1CB
- Splitting duplicates
- Transmission over separate paths
- Merging deduplicates

→ Can reorder frames

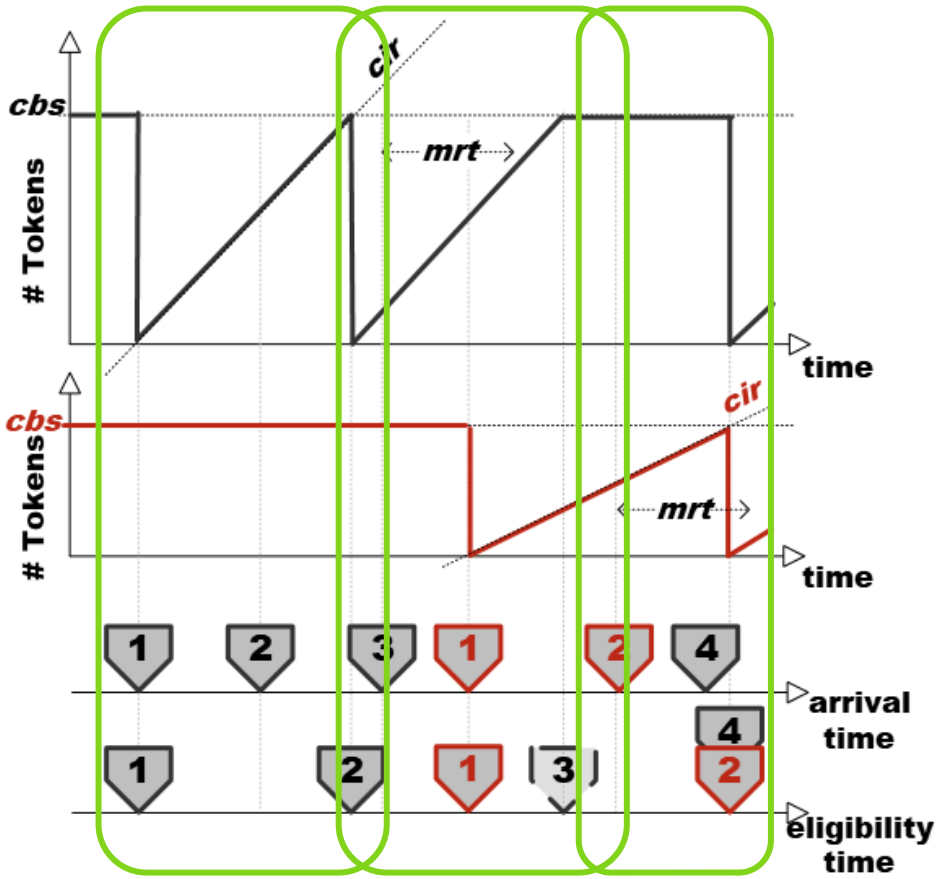
→ Can cause bursts



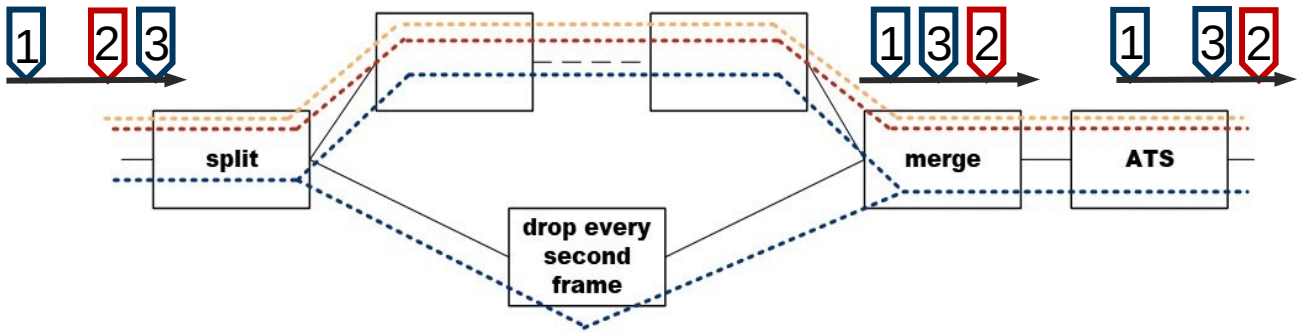
Asynchronous Traffic Shaping (ATS)

- Part of IEEE 802.1Q
- Per-stream shaping
- Token bucket based
  - CommittedInformationRate (*cir*)
  - CommittedBurstSize (*cbs*)
- Limits delay
  - MaximumResidenceTime (*mrt*)

→ Preserves frame order



Unbounded Latencies with ATS and FRER

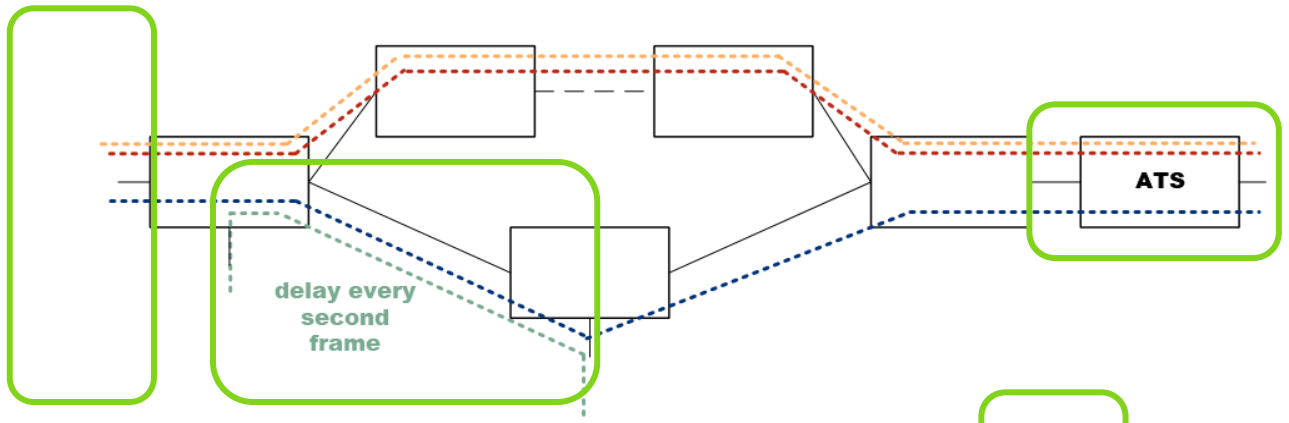


→ We find TSN standard-conform solutions to prevent unbounded latencies

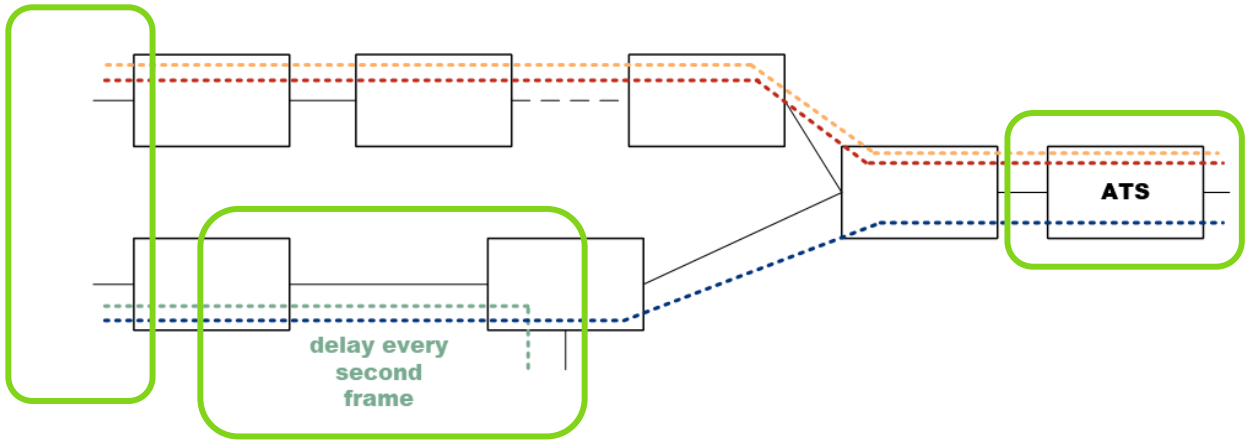
L. Thomas and J.-Y. Le Boudec, “Network-calculus service curves of the interleaved regulator,” Performance Evaluation, vol. 166, 2024.

1. Generate frame sequence
2. FRER merger mis-orders frames
3. ATS delays frames in mis-ordered sequence
4. Repetition for infinite delays

Unbounded Latencies without FRER



ATS can cause unbounded latencies in various networks



→ We simulate three synthetic networks to validate our solutions

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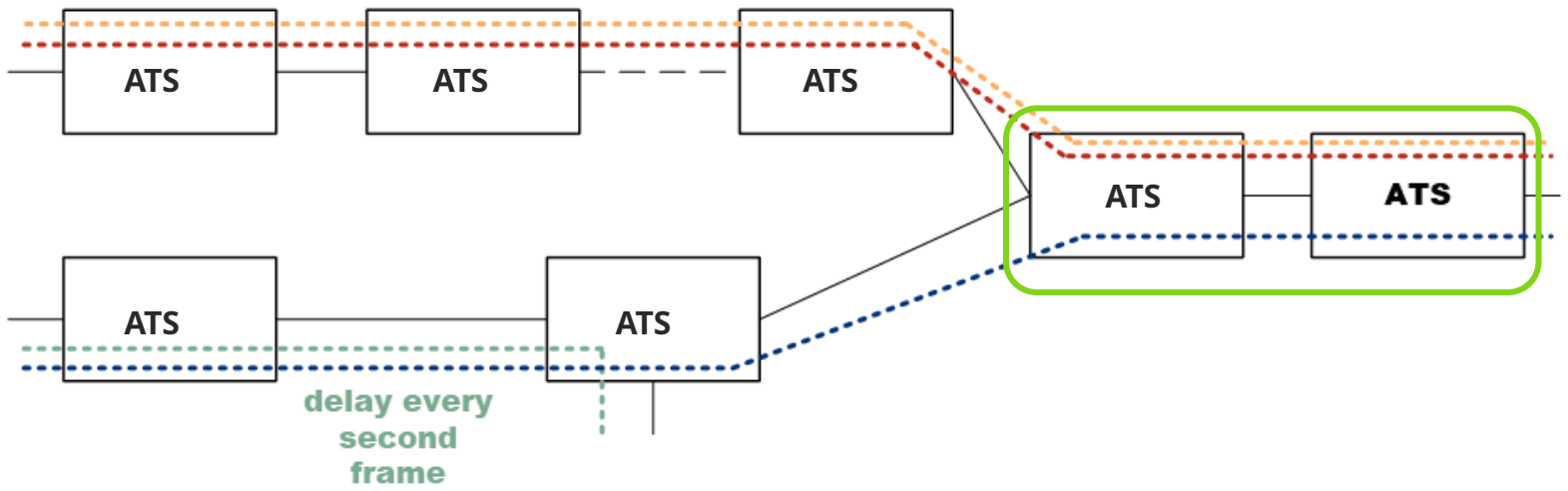
3. **Solutions for Bounded Latencies**
4. Apply Solutions to In-Vehicle Network

Configurations for Bounded Latencies

A. Use ATS on all hops
B. Modify token bucket parameters
C. Do not place ATS behind FRER merger
D. Limit ATS scheduling delay

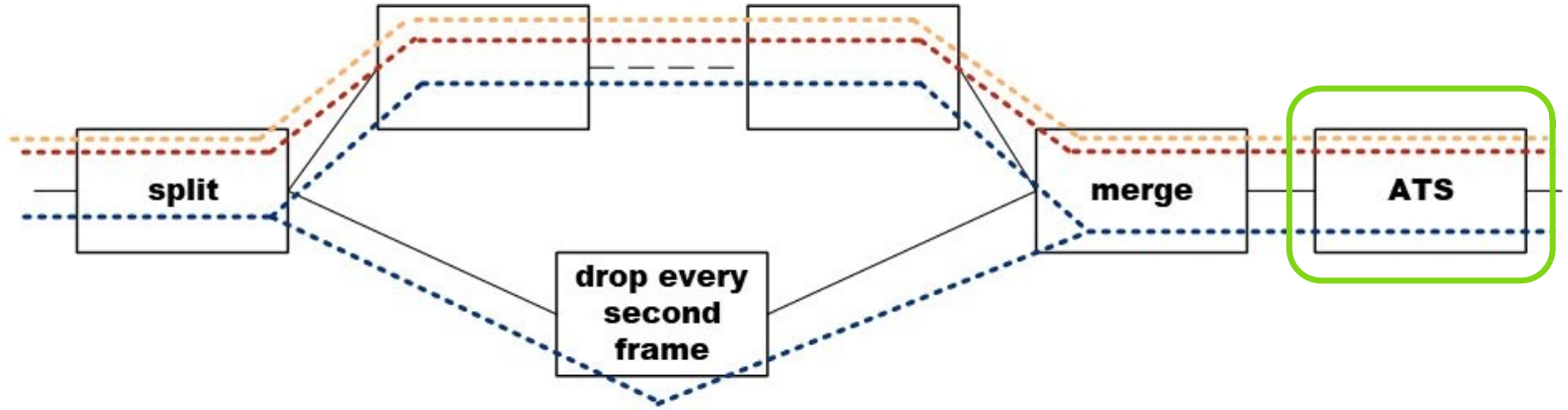
Solution A: Use ATS on All Hops



→ For networks without FRER

→ Drawback: All switches have to be ATS capable

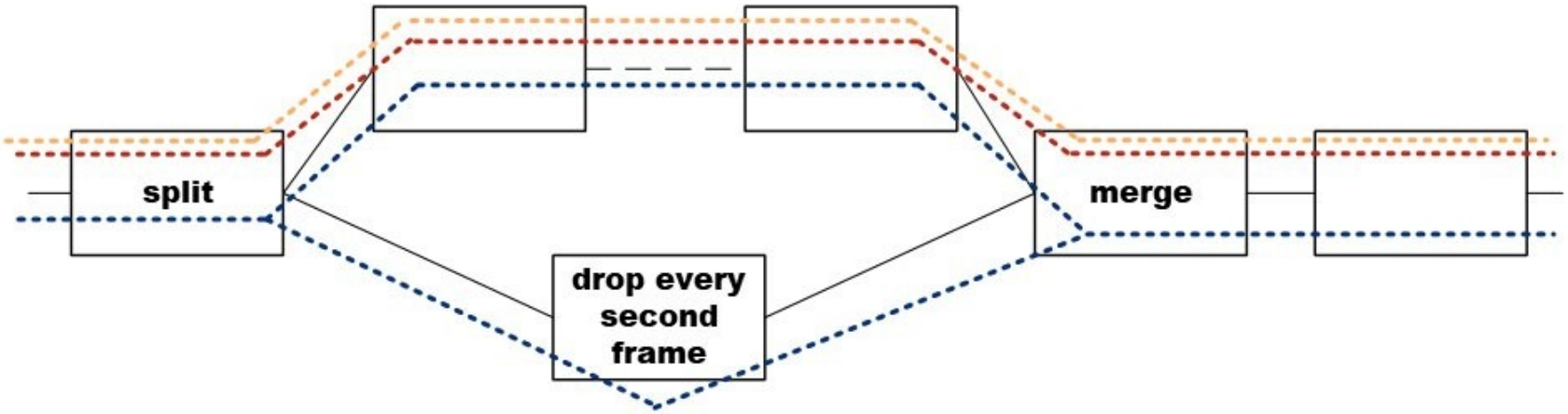
Solution B: Modify Token Bucket Parameters



→ For networks with FRER

→ Drawback: Increases stream resources

Solution C: Do not Place ATS behind FRER merger



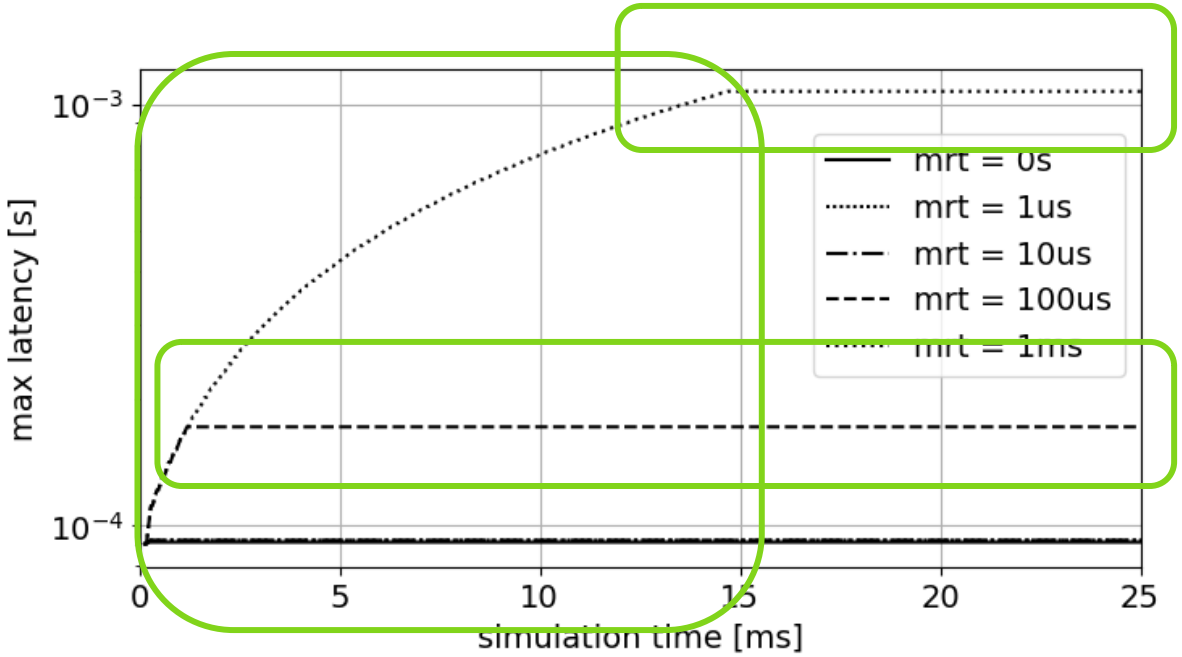
→ For networks with FRER

→ Drawback: Traffic not shaped

Solution D: Limit ATS Scheduling Delay

- *mrt* limits ATS scheduling delay
- **Drops** delayed frames

→ Counteracts redundancy target of FRER



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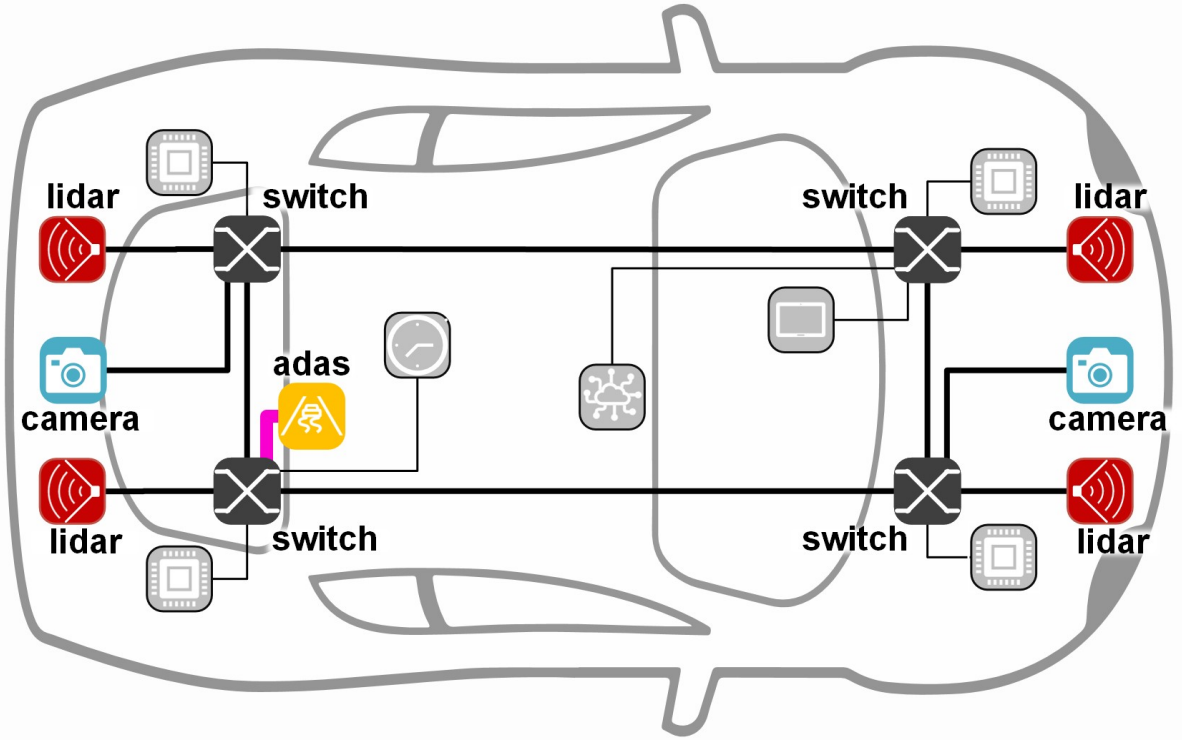
Case Study: In-Vehicle Network Placement of ATS schedulers



(A) Place ATS on every hop

(C) but not after the FRER merger

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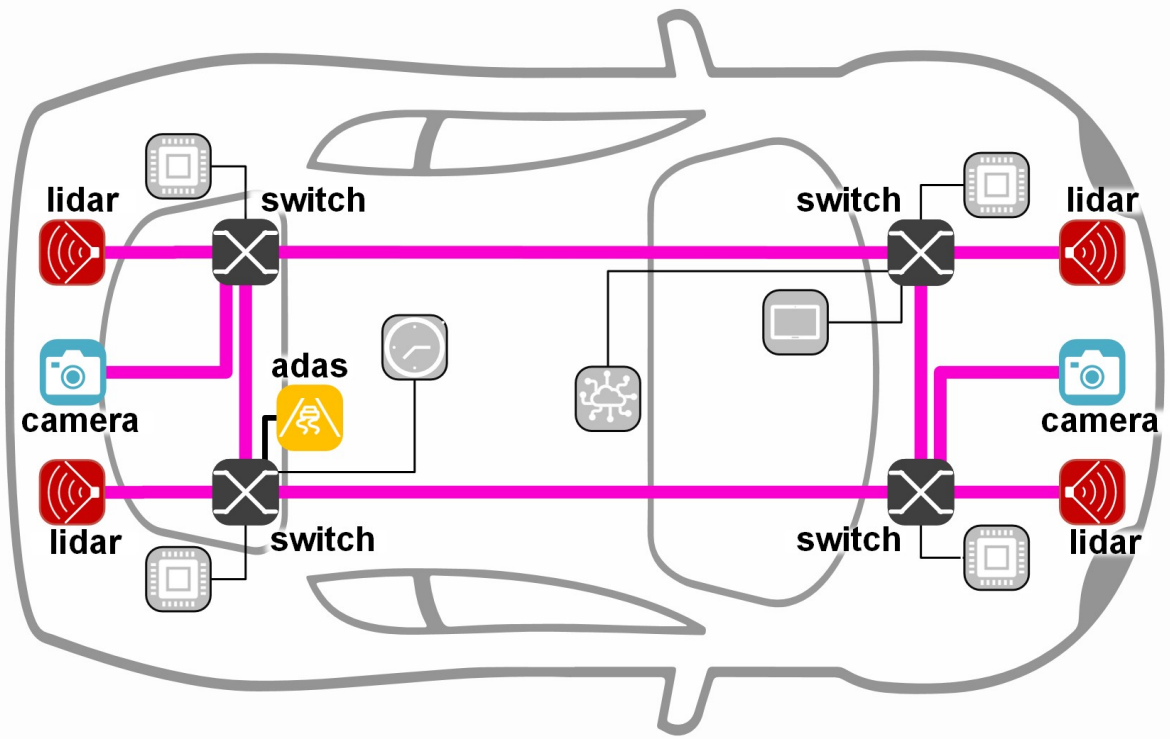

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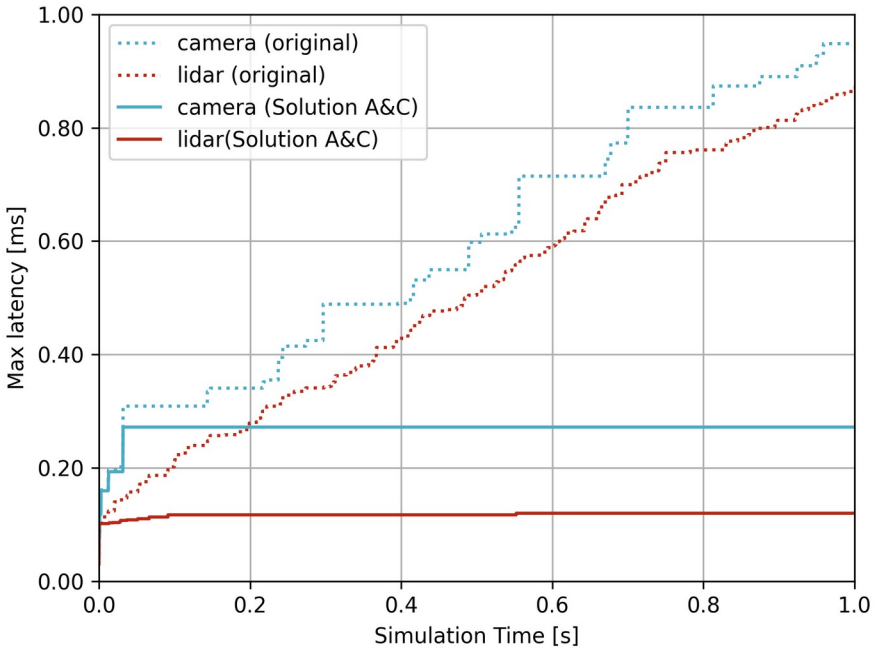

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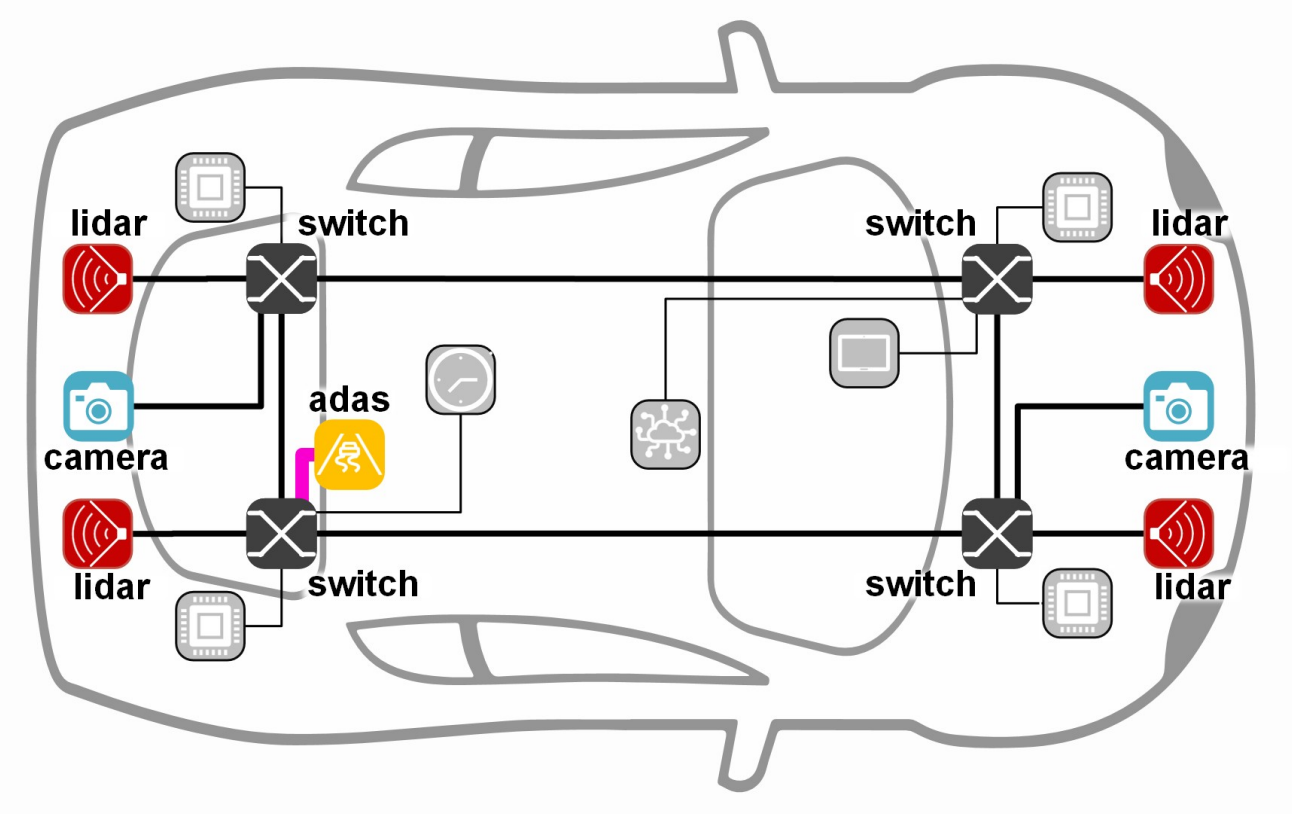
Case Study: In-Vehicle Network ATS parameter configurations



(B) Increase ATS parameters on scheduler after FRER merger

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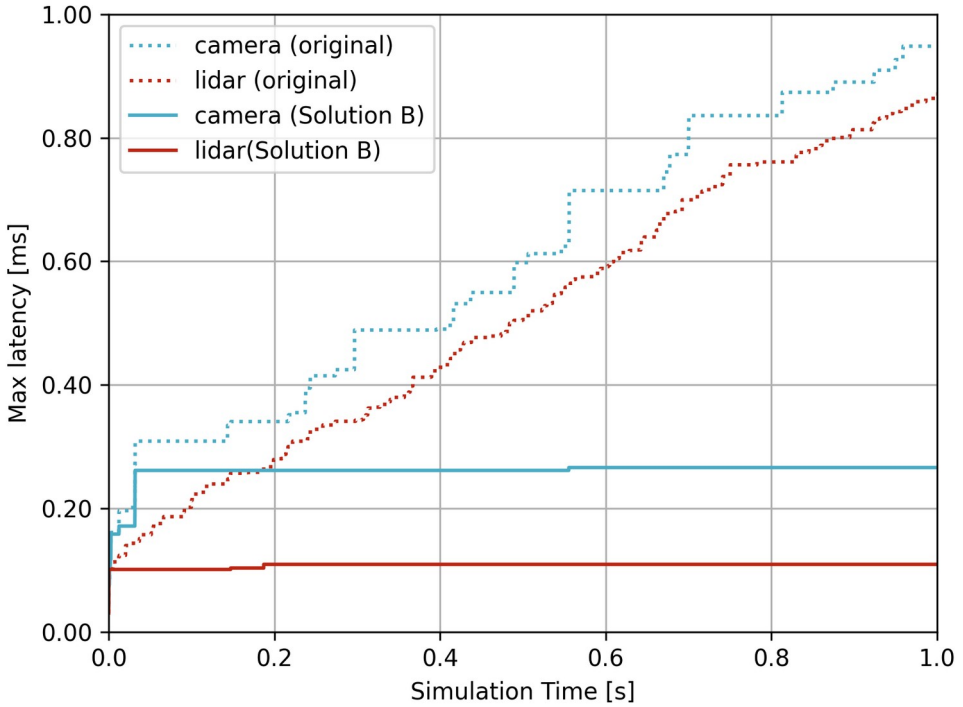

(B) Increase ATS parameters on scheduler after FRER merger

Conclusion and Outlook

- ATS causes unbounded latencies in various TSN networks
- We proposed four standard-conform mitigation strategies
- Synthetic and realistic IVN simulations show effectiveness

→ Future Work:

- Formal validation
- Performance comparison

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Thank you!

Try our simulations!

https://github.com/CoRE-RG/NIDSDatasetCreation

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