An innovative traffic management scheme for deterministic/event-based communications in automotive applications with a focus on Automated Driving Applications

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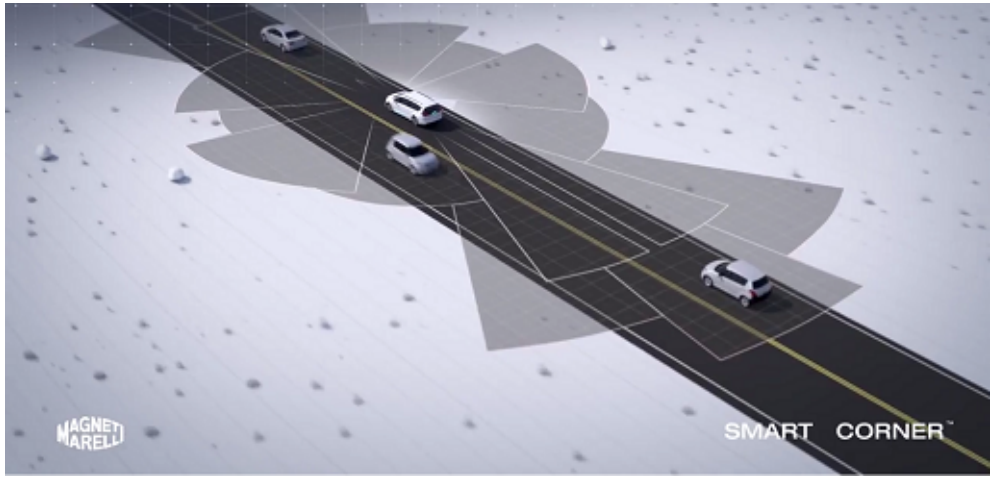
Presentation outline

- Event-driven traffic in automated vehicles
- Support offered to event-driven traffic in TSN standards
- A novel approach to deal with event-driven traffic
- Performance evaluation
- Automated Driving application
- Summary and conclusions



The need for Event-driven Traffic Support

Fact 1: The external world in which the cars move is non-deterministic

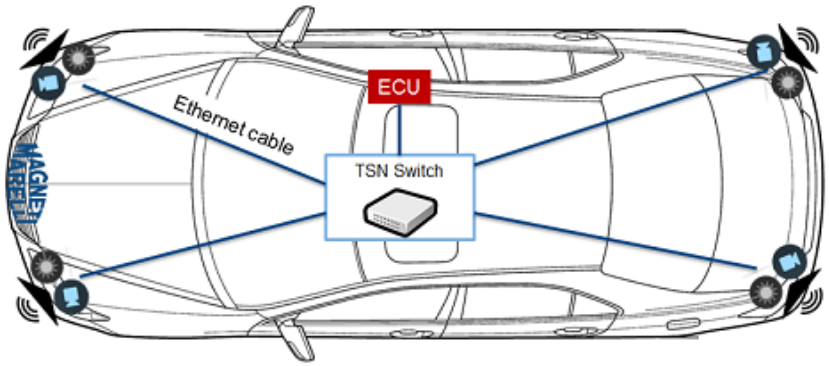
Unpredictable events may occur and determine unforeseen situations.

Fact 2: Autonomous vehicles need to properly react to such situations

The communication system has to support event-driven transmissions with minimum delay.

Question 1: How to handle event-driven traffic with real-time constraints?

Question 2: How and under which conditions is it possible to guarantee a latency bound for event-driven flows?



Let's have a look on the TSN standards…

TSN support for Event-driven Traffic

Fact 3: TSN standards offer a limited support for event-driven real-time traffic

- Some shaping mechanisms have been defined, but
  - they do not care much about the latency of event-driven traffic

  or

  - they can be complex

- The easiest way to deal with event-driven traffic is to serve it in the Best-effort class, but
  - no guarantees, even in the case the event-driven traffic has a known minimum inter-arrival time, can be provided.

This presentation is about

An innovative traffic management scheme for IEEE 802.1Q bridges and end nodes that

- introduces explicit support for the Event-Driven (ED) real-time traffic

- enables the transmission of ED traffic over TSN networks while
  - maintaining the support for Scheduled Traffic
  - providing delay guarantees to the Stream Reservation classes.

The proposed approach:

- works at the MAC layer
- relies on the forwarding mechanisms defined in the IEEE 802.1Q-2018 standard, with suitable modifications

System model

Traffic type	Characteristics
Scheduled traffic	High priority real-time traffic transmitted according to a time schedule (time-driven) with no interference from other traffic.
Stream Reservation	Periodic, guaranteed
Event-driven traffic	Aperiodic bursts, generated by events, with real-time constraints
Best-effort traffic	No guarantees, performance is statistical

Advantages of the proposed solution

Main features

- Scheduled Traffic is handled through the gate mechanism defined in the IEEE 802.1Qbv

- ED bursts are handled with a novel traffic management

Low latency for ED flows is achieved

- If the minimum interarrival time for ED bursts and the maximum burst size are known, the maximum E2E latency for ED traffic is bounded and can be calculated.

- E2E latency for SR Class A and Class B are bounded and guaranteed.

- Feasibility: The proposed approach can be implemented on devices that support TSN standards. No special hardware modifications to the standard devices are required.

Simulations

Simulations were run using the OMNeT++ and the INET framework, modified so as to model the TSN protocols (i.e., IEEE 802.1Q-2018, etc.)

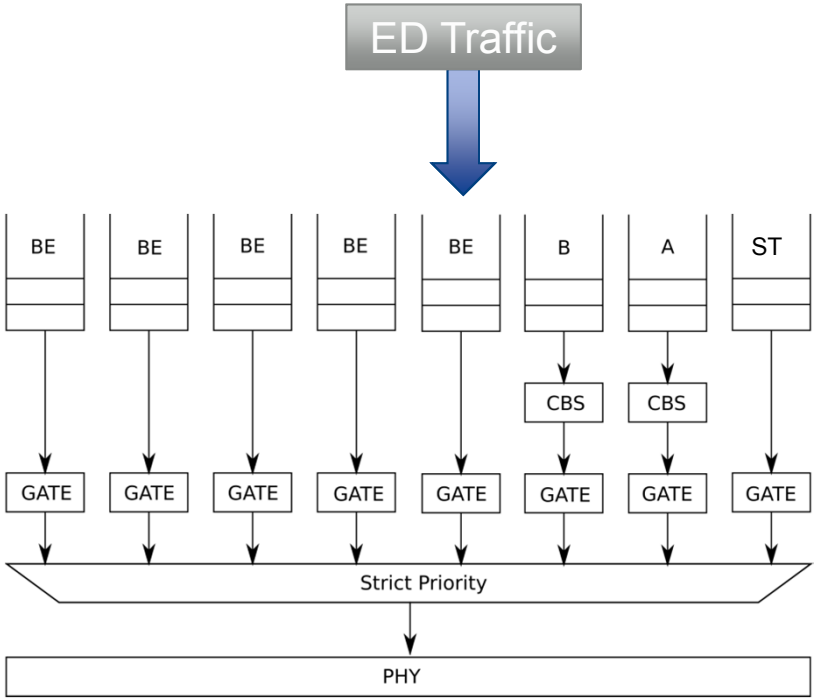
Aims

- Evaluate the E2E performance of the proposed approach in realistic automotive scenarios
- E2E Latency performance with different data rates (i.e., 100Mbps, 1Gbps, 10Gbps).

Simulations

The proposed solution was compared with an alternative approach, that handles the ED traffic as best-effort, in the highest priority queue for that class.

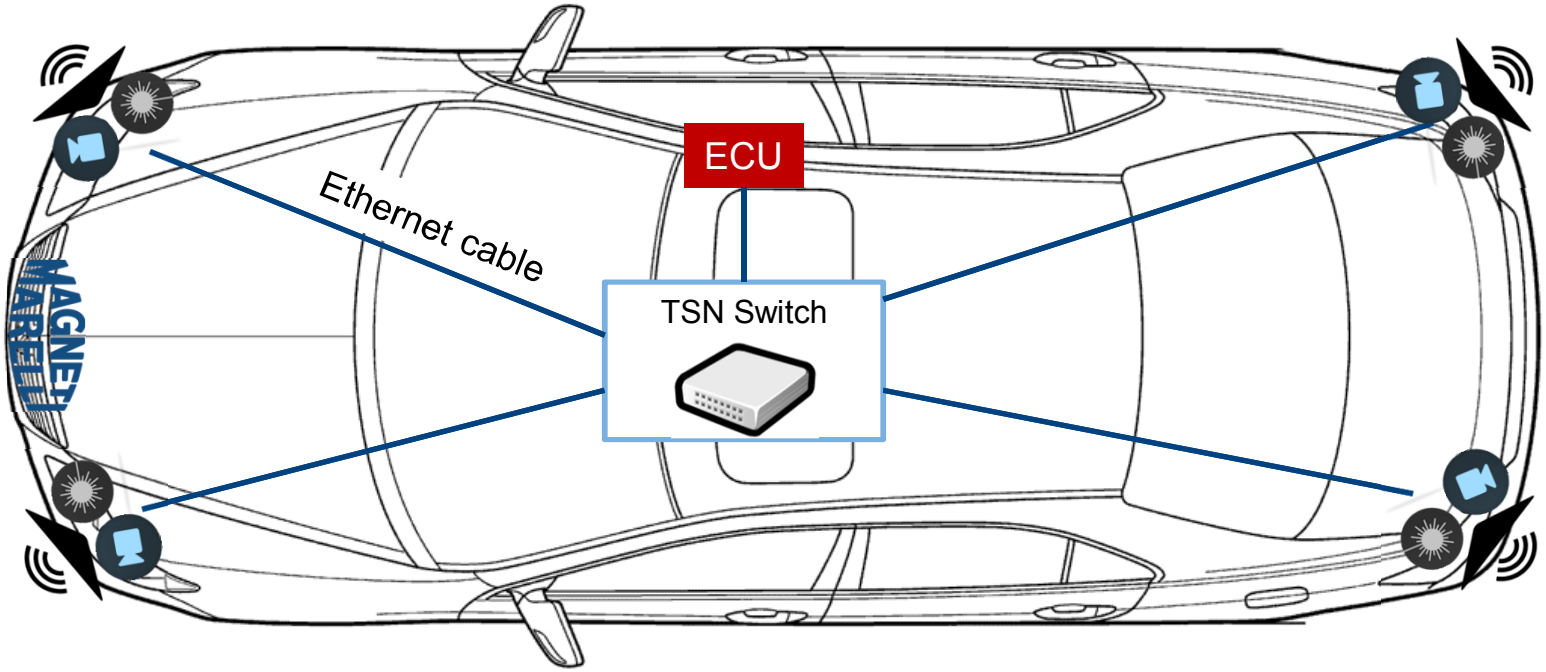
Alternative approach



Simulation scenarios

- Each node transmits sensor data to the ECU
- 3 configurations:
  - **100Mbps**: 30 fps compressed video streams, relative deadline 33ms.
  - **1Gbps**: 60 fps compressed video streams, relative deadline 10ms .
  - **10Gbps**: 30 fps uncompressed video streams, relative deadline 10ms .

Node
- Radars
- Lidars
- Ultrasonics
- Cameras



Scenarios

Case A: 100 Mbps Scenario – ADAS

Flow	Number of flows	Total MAC Bandwidth
Lidar	4	0.93 Mbps
Ultrasonic	4	0.23 Mbps
ADAS Sensors	4	Max 34 Mbps
30 fps compressed Video	4	~52 Mbps

Case B: 1 Gbps Scenario – ADAS

Flow	Number of flows	Total MAC Bandwidth
Lidar	4	0.93 Mbps
Ultrasonic	4	0.23 Mbps
ADAS Sensors	4	Max 34 Mbps
60 fps compressed Video	4	~103 Mbps

Scenarios

Case C: 10 Gbps Scenario – Automated Driving

Flow	Number of flows	Total MAC Bandwidth
Lidar	4	0.93 Mbps
Ultrasonic	4	0.23 Mbps
ADAS Sensors	4	Max 34 Mbps
30 fps uncompressed Video	4	~7 Gbps

Flow Parameters and Mapping

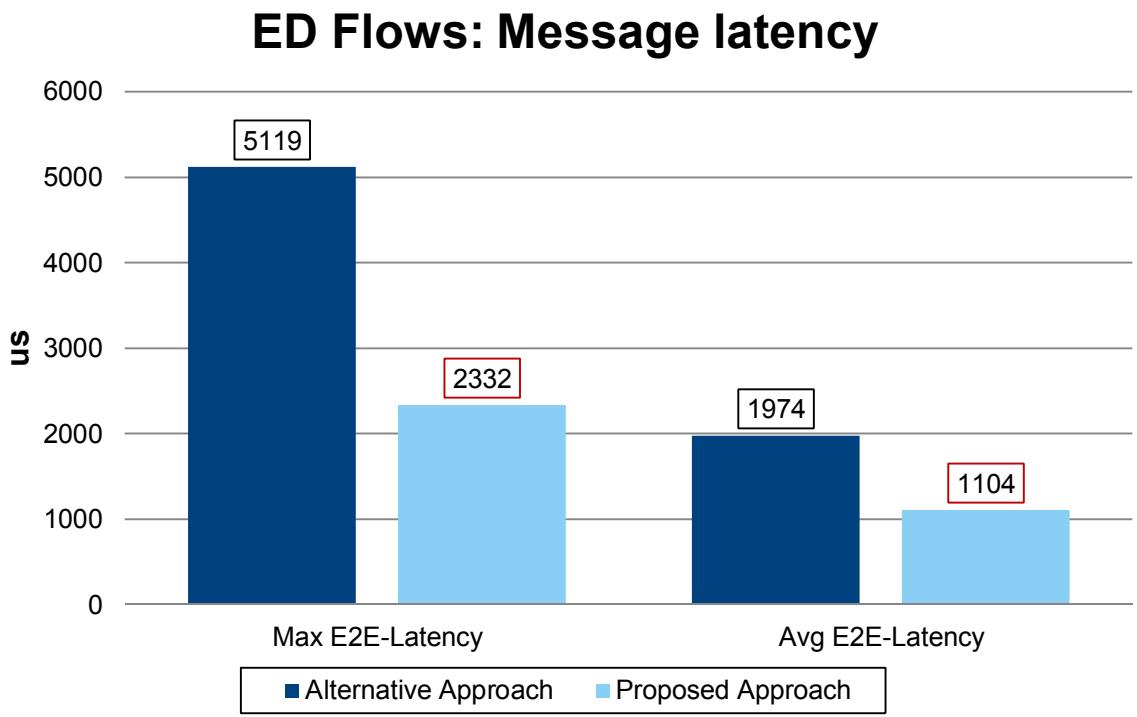
Flow	Length	Rel. Deadline	Sampling Time	Arrival pattern	Traffic Class
Lidar	250 B	10 ms	10 ms	Periodic	ST
Ultrasonic	100 B	20 ms	20 ms	Periodic	ST
ADAS Sensors	~10 KB	10 ms	[10-100] ms	Event-driven	ED/BE
30fps Video - ADAS (100 Mbps)	~43 KB	33 ms	33 ms	Periodic	SR_A
60fps Video - ADAS (1 Gbps)	~43 KB	10 ms	16 ms	Periodic	SR_A
Raw 30fps Video – Automated Driving (10 Gbps)	6.9 MB	33 ms	33 ms	Periodic	SR_A

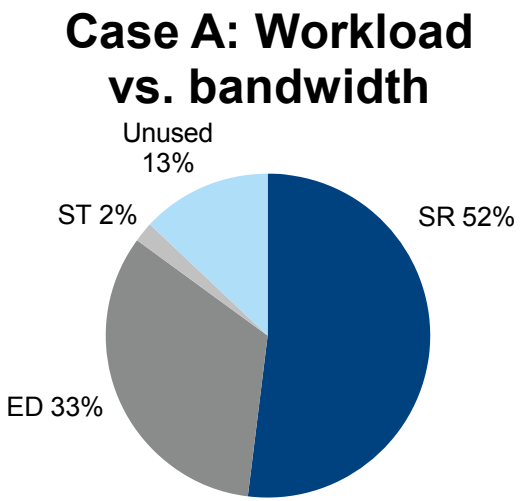
Class A video frames are segmented in small Ethernet frames, each one transmitted by the application every 125us.

Performance metrics: *End-to-end latency*, defined as:
reception time – generation time (measured at the application)

Simulation Results – Case A: 100 Mbps scenario

Event-driven flows





The proposed approach
- halves the maximum E2E latency
- reduces the average message latency by 870us

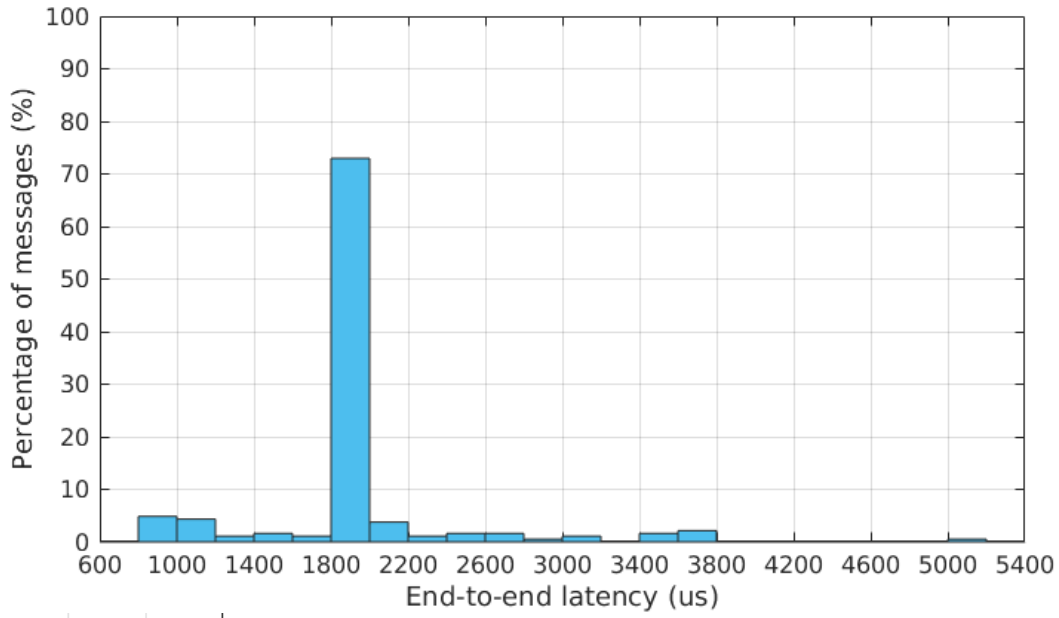
Simulation Results – Case A: 100 Mbps scenario

Event-driven flows – End-to-end latency distribution

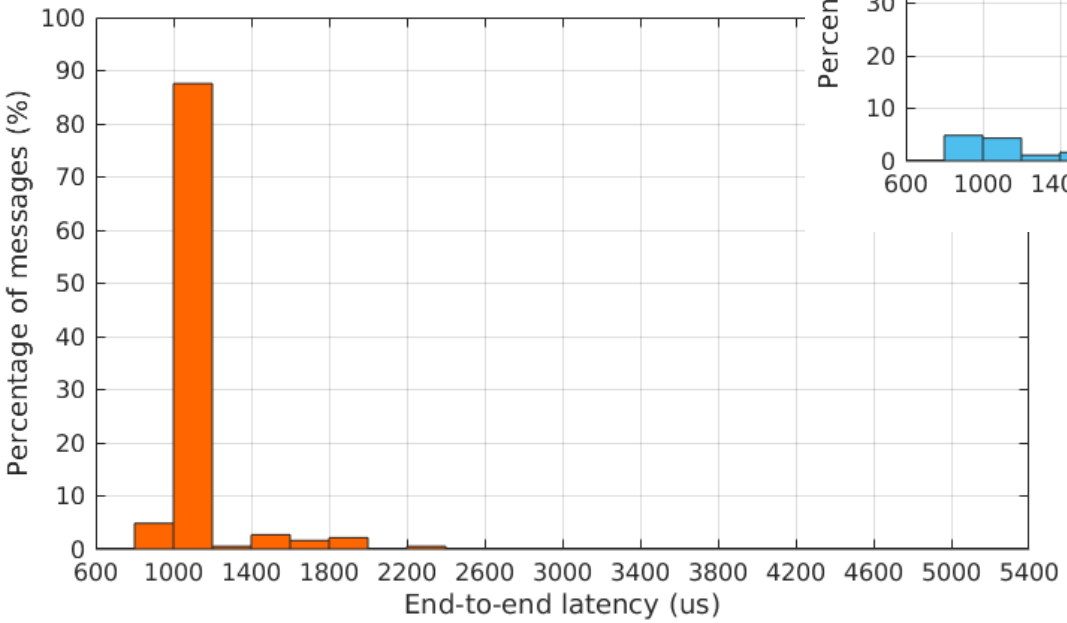
The ED traffic with the proposed approach obtains

- lower latency values
- lower latency variability

Alternative Approach

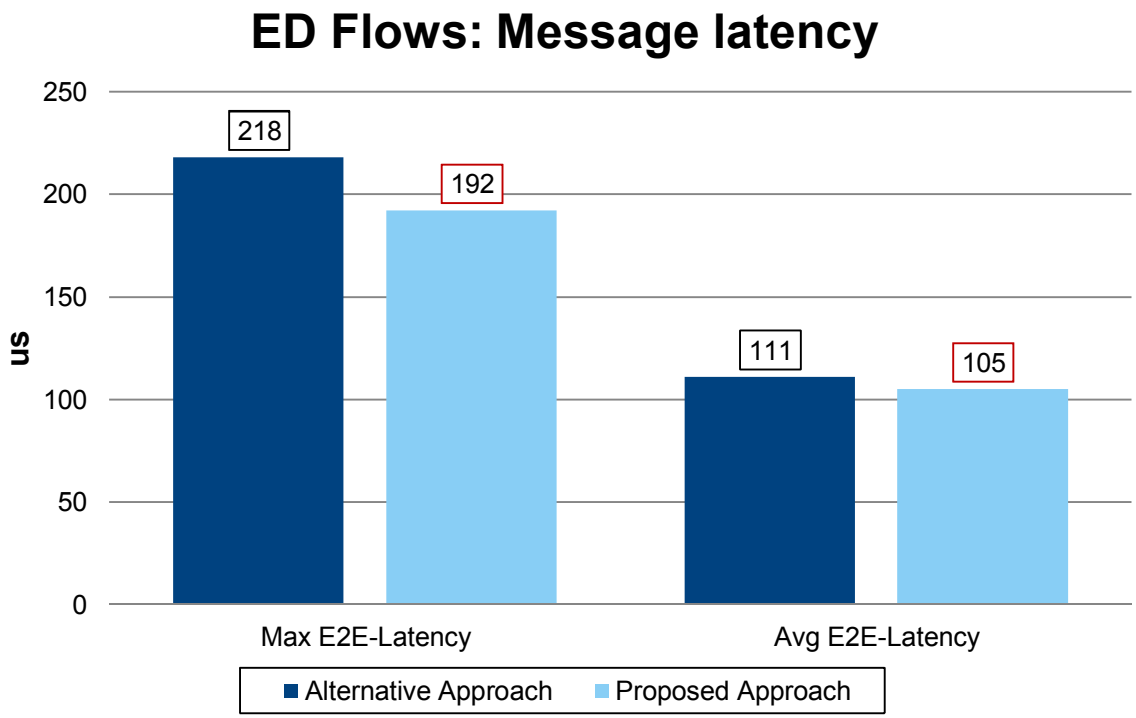


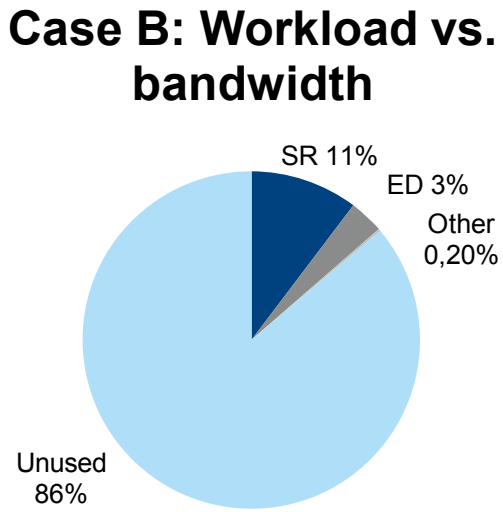
Proposed Approach



Simulation Results – Case B: 1 Gbps scenario

Event-driven flows





The max latency of event-driven messages is almost the same in both configurations.

Reason:
Very low workload, the SR workload is 11% of the available bandwidth.

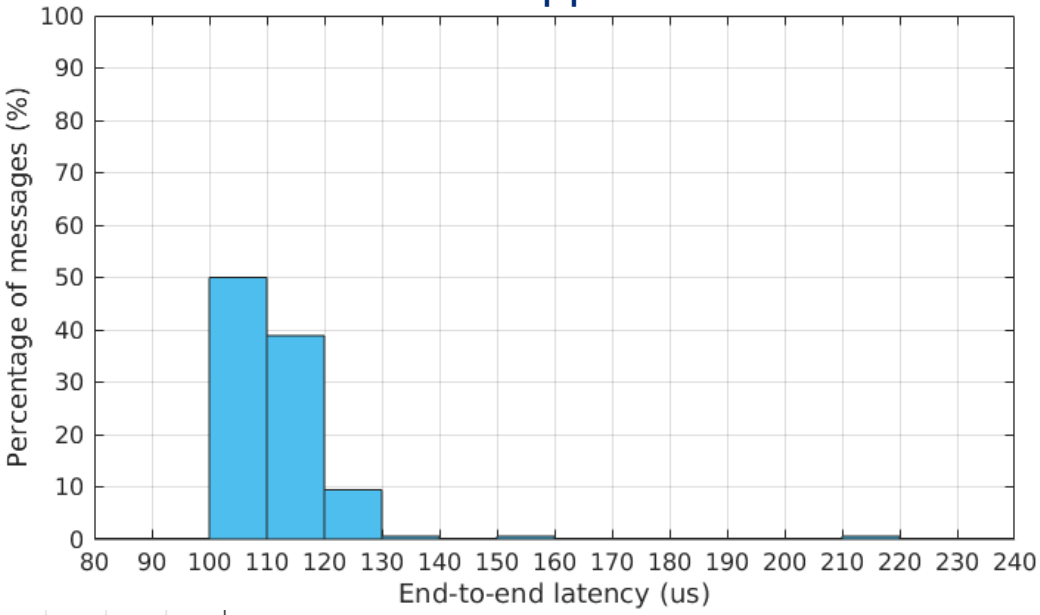
Simulation Results – Case B: 1 Gbps scenario

Event-driven flows – End-to-end latency distribution

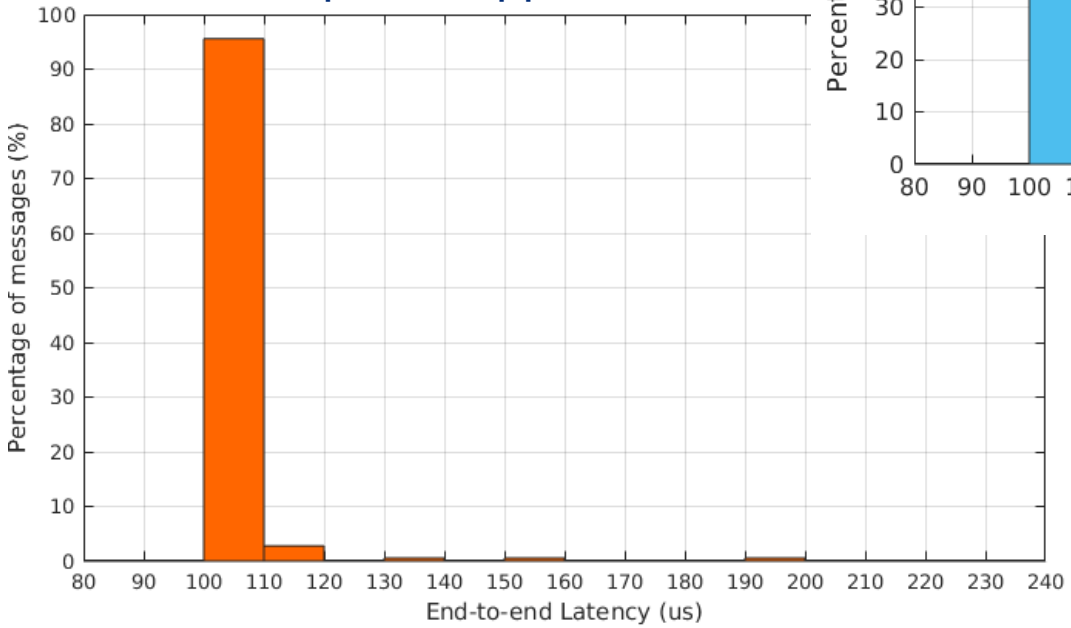
The ED traffic with the proposed approach obtains

- lower latency values
- lower latency variability

Alternative Approach

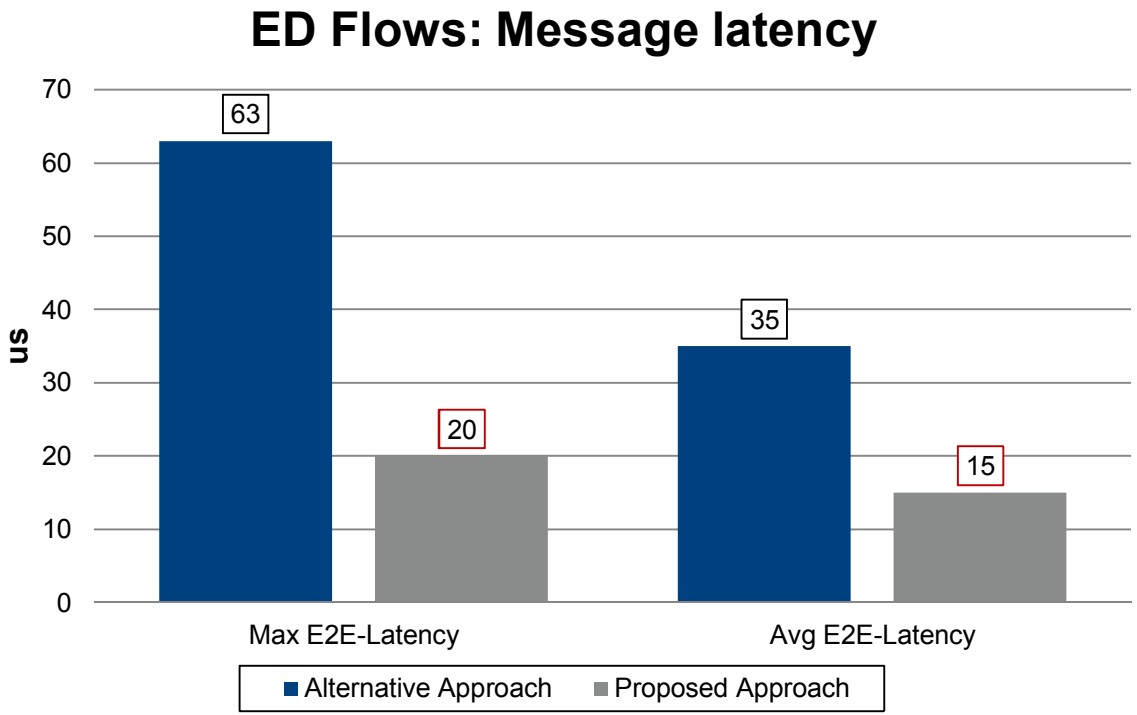


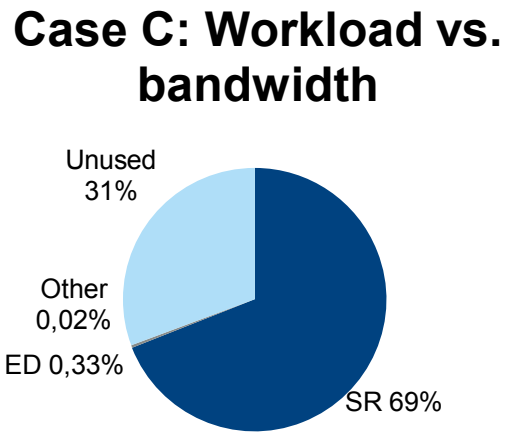
Proposed Approach



Simulation Results – Case C: 10 Gbps scenario

Event-driven flows





Under high SR workload (69% in this scenario) the proposed approach significantly reduces the latency of event-driven traffic.

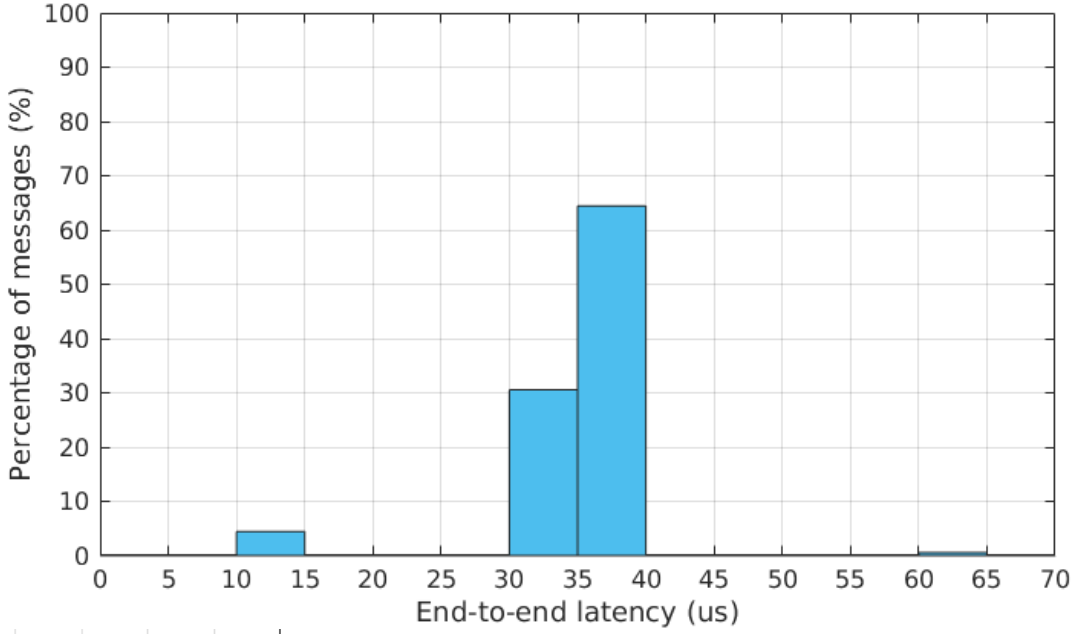
Simulation Results – Case C: 10 Gbps scenario

Event-driven flows – End-to-end latency distribution

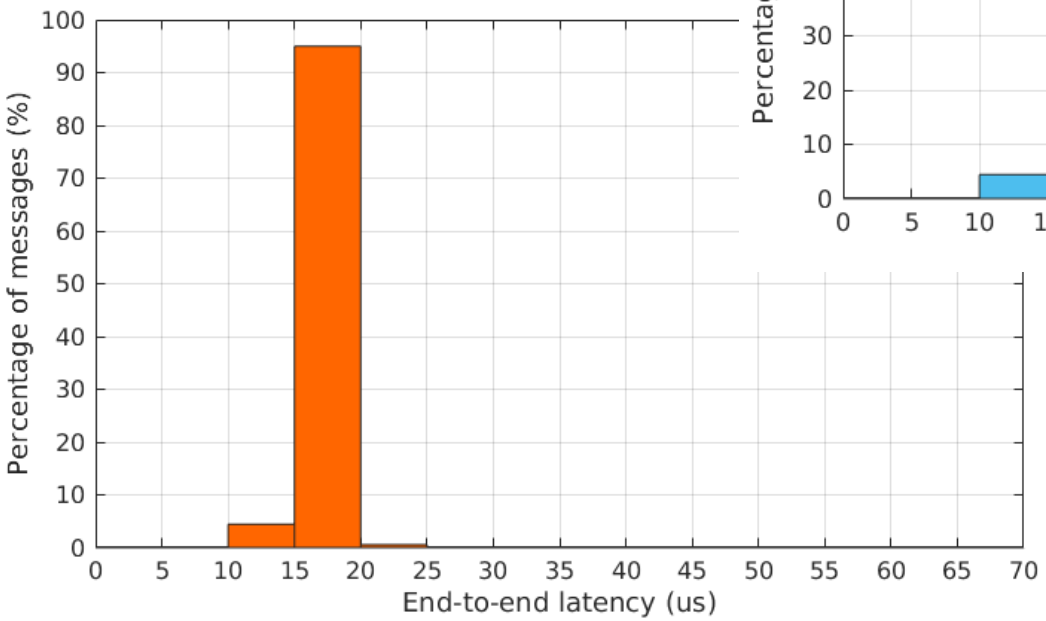
The ED traffic with the proposed approach obtains:

- lower latency values
- lower latency variability

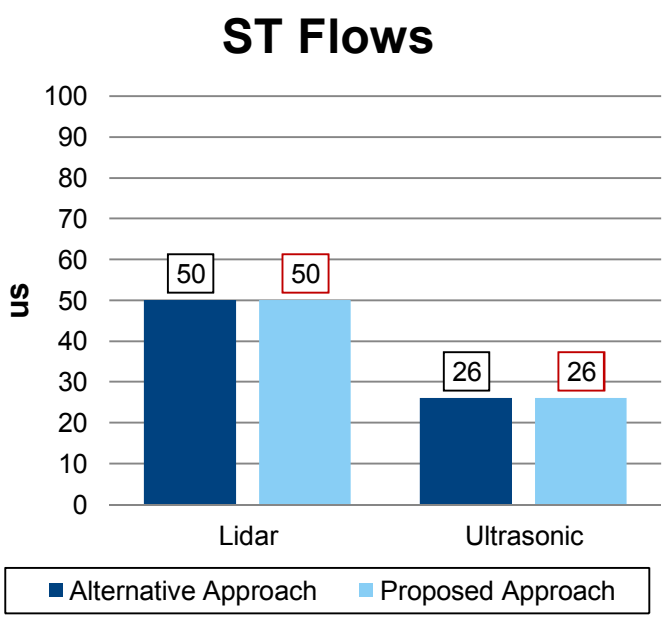
Alternative Approach

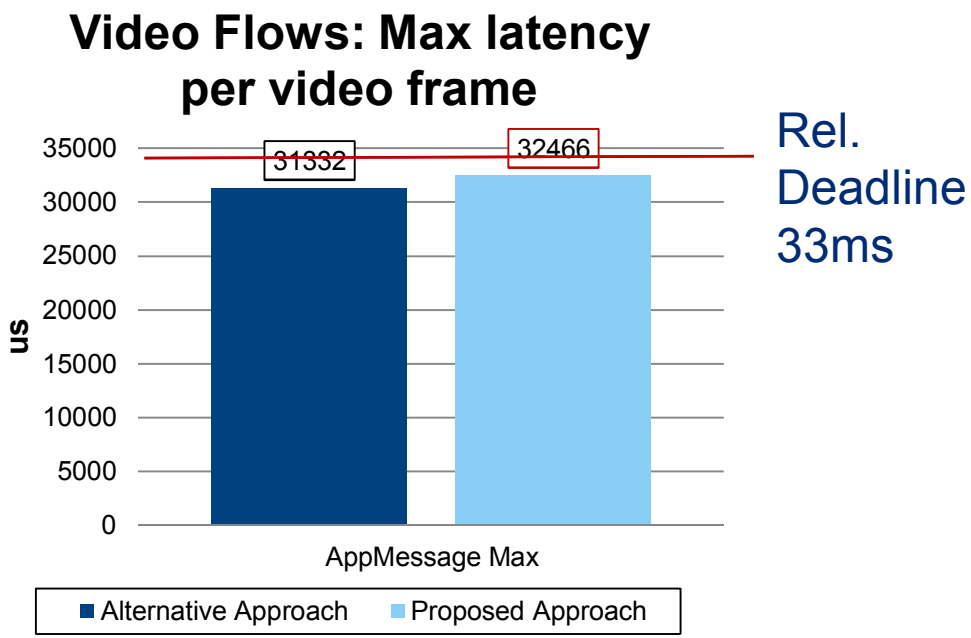


Proposed Approach



Other traffic classes – Case A: 100 Mbps scenario





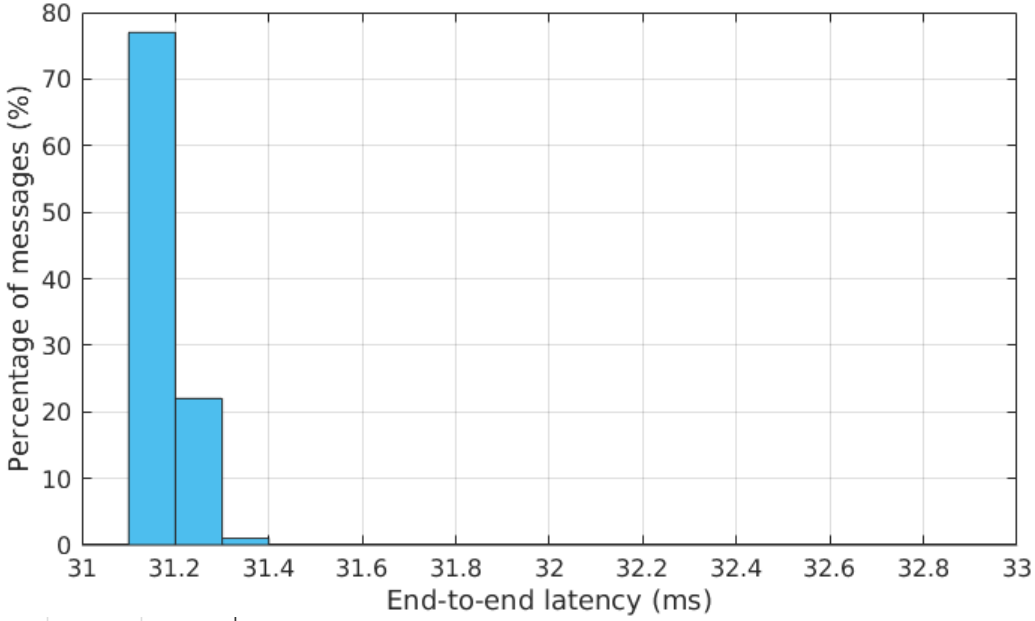
- Scheduled traffic is unaltered.
- SR Class A traffic (i.e., video streams) meets the relative deadline of 33ms per video frame with both approaches.

Other traffic classes – Case A: 100 Mbps scenario

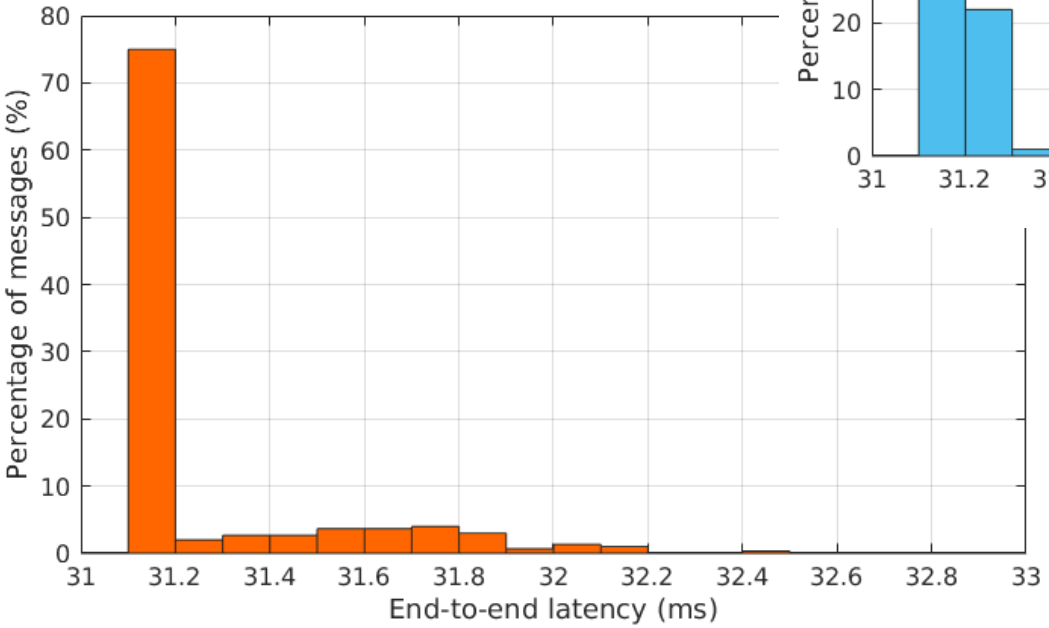
Video flows (SR_A) – End-to-end latency distribution

- The proposed approach obtains a longer tail, but the difference between the maximum values is around 3% and affects only 0.3% of the video frames.
- The relative deadline (33ms) is met in both cases.

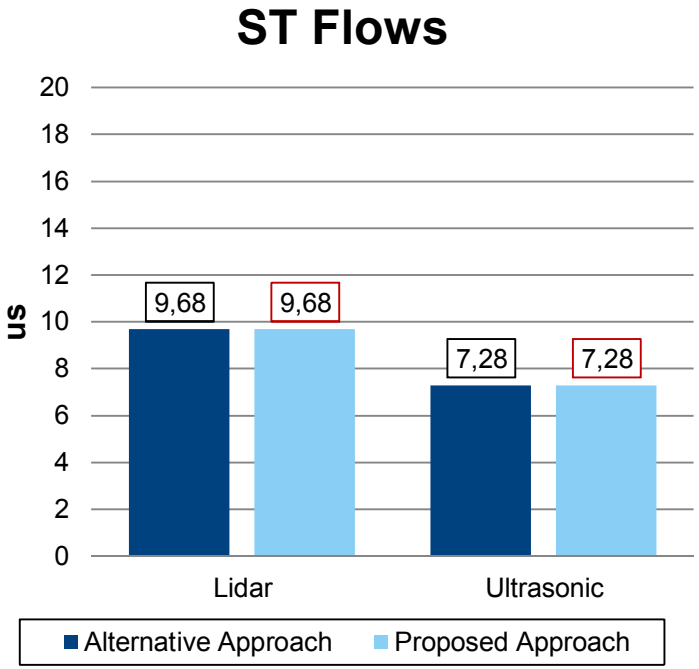
Alternative Approach

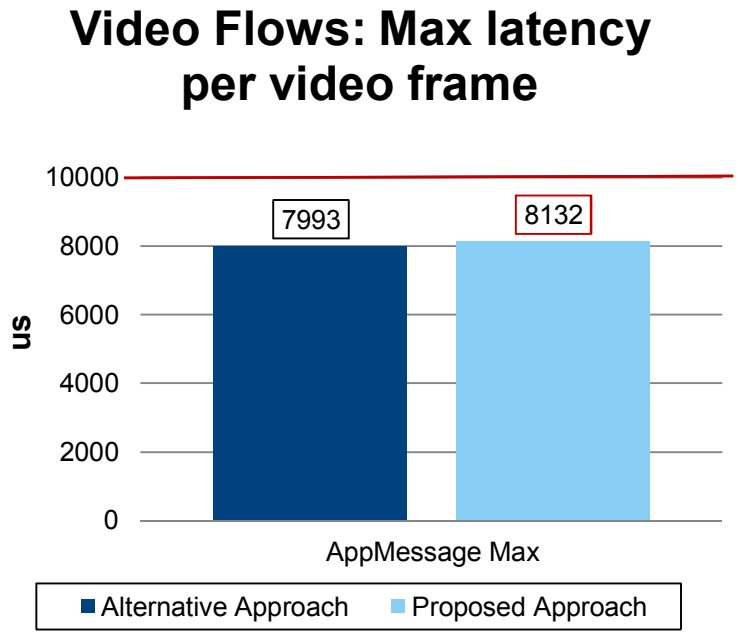


Proposed Approach



Other traffic classes – Case B: 1 Gbps scenario





Rel. Deadline 10 ms

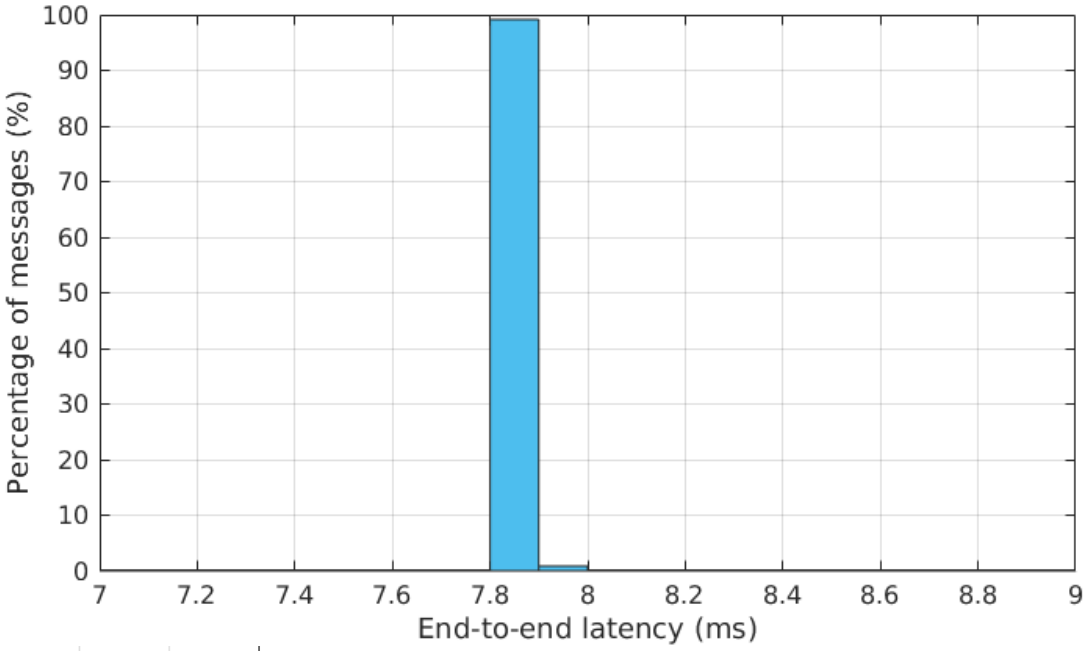
- Scheduled traffic is unaltered.
- SR Class A traffic (i.e., video streams) meets the relative deadline of 10ms per video frame in both approaches.

Other traffic classes – Case B: 1 Gbps scenario

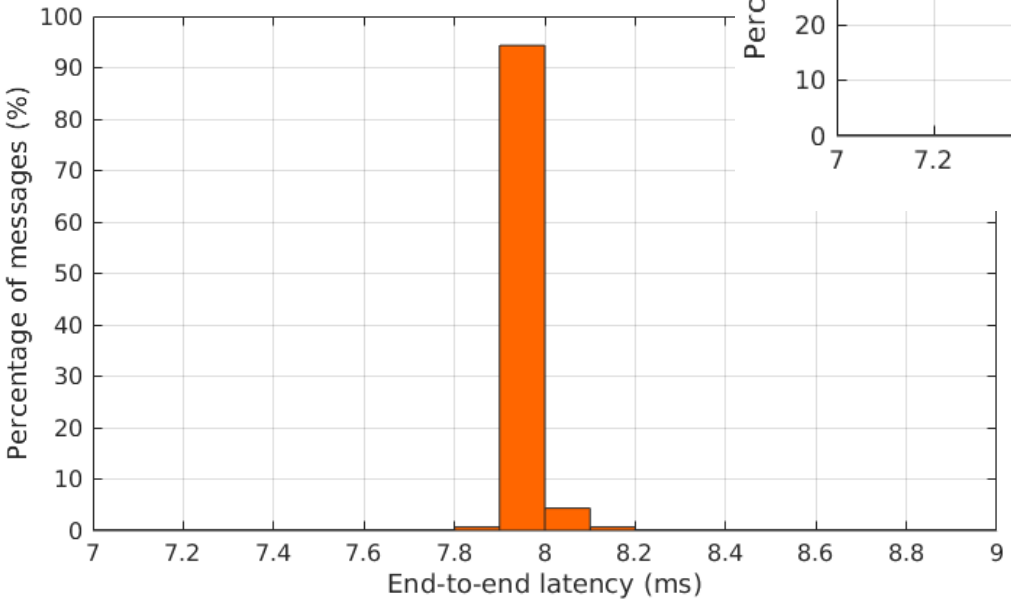
Video flows (SR_A) – End-to-end latency distribution

The proposed approach obtains slightly higher latency values and variability for SR flows, but the difference is minor.

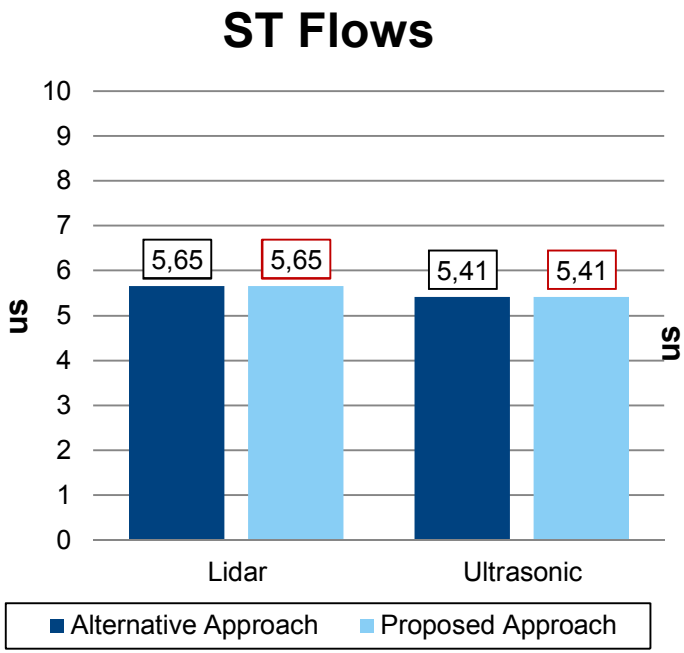
Alternative Approach

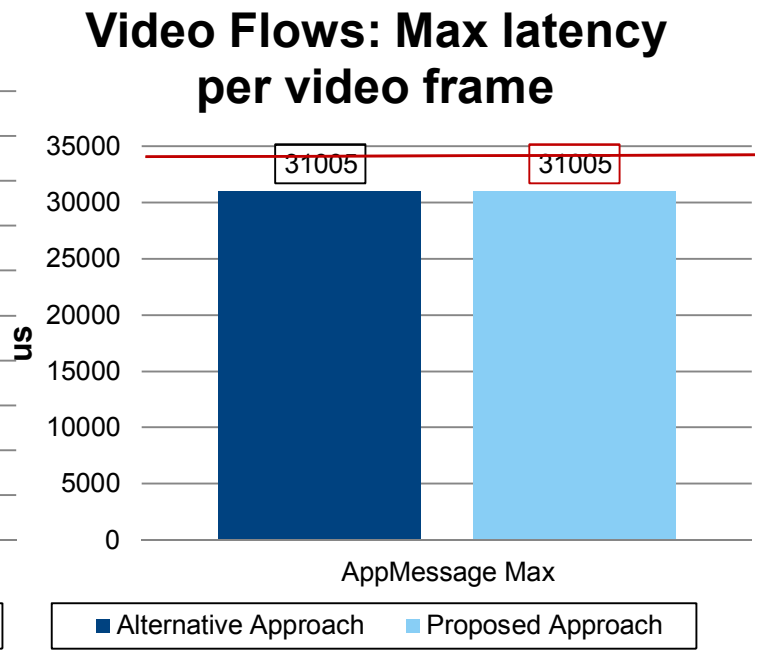


Proposed Approach



Other traffic classes – Case C: 10 Gbps scenario





Rel. Deadline 33 ms

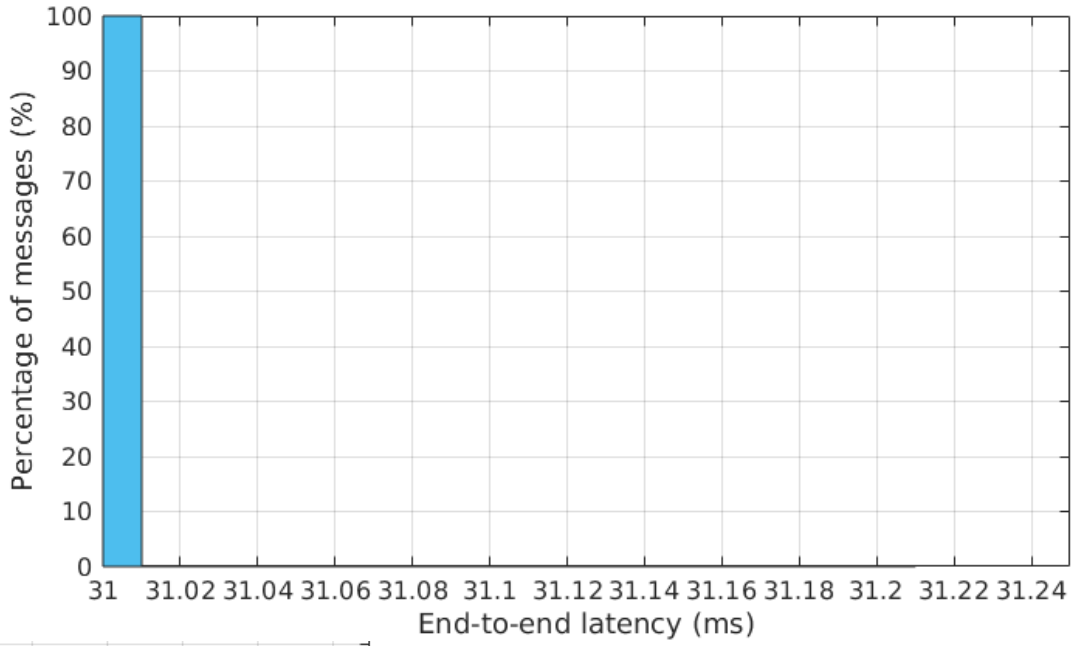
- Scheduled traffic is unaltered.
- SR Class A traffic (i.e., video streams) meets the relative deadline of 33ms per video frame in both approaches.

Other traffic classes – Case C: 10 Gbps scenario

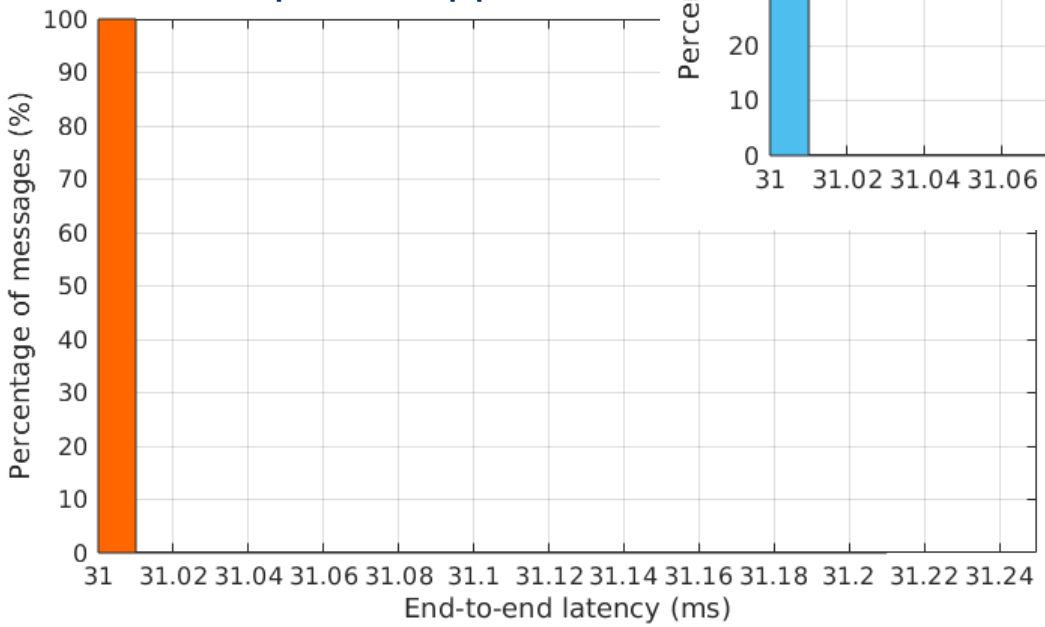
Video Flows (SR_A) – End-to-end latency distribution

Plenty of bandwidth, so no difference between the two approaches.

Alternative Approach



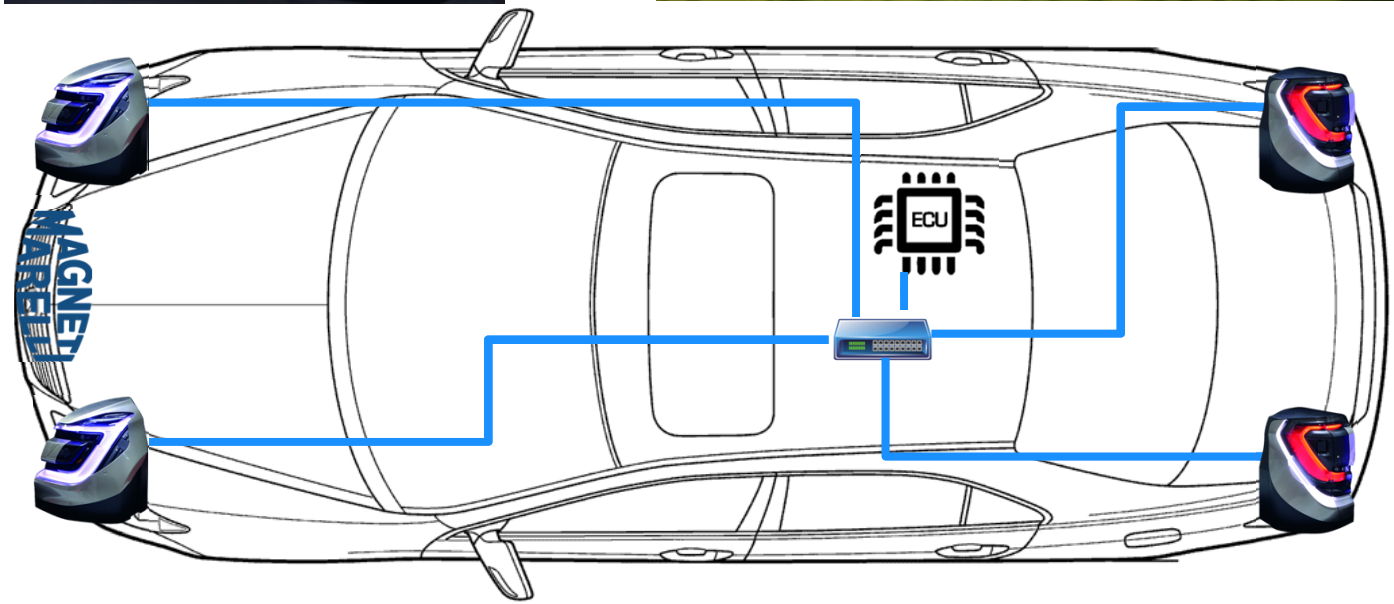
Proposed Approach



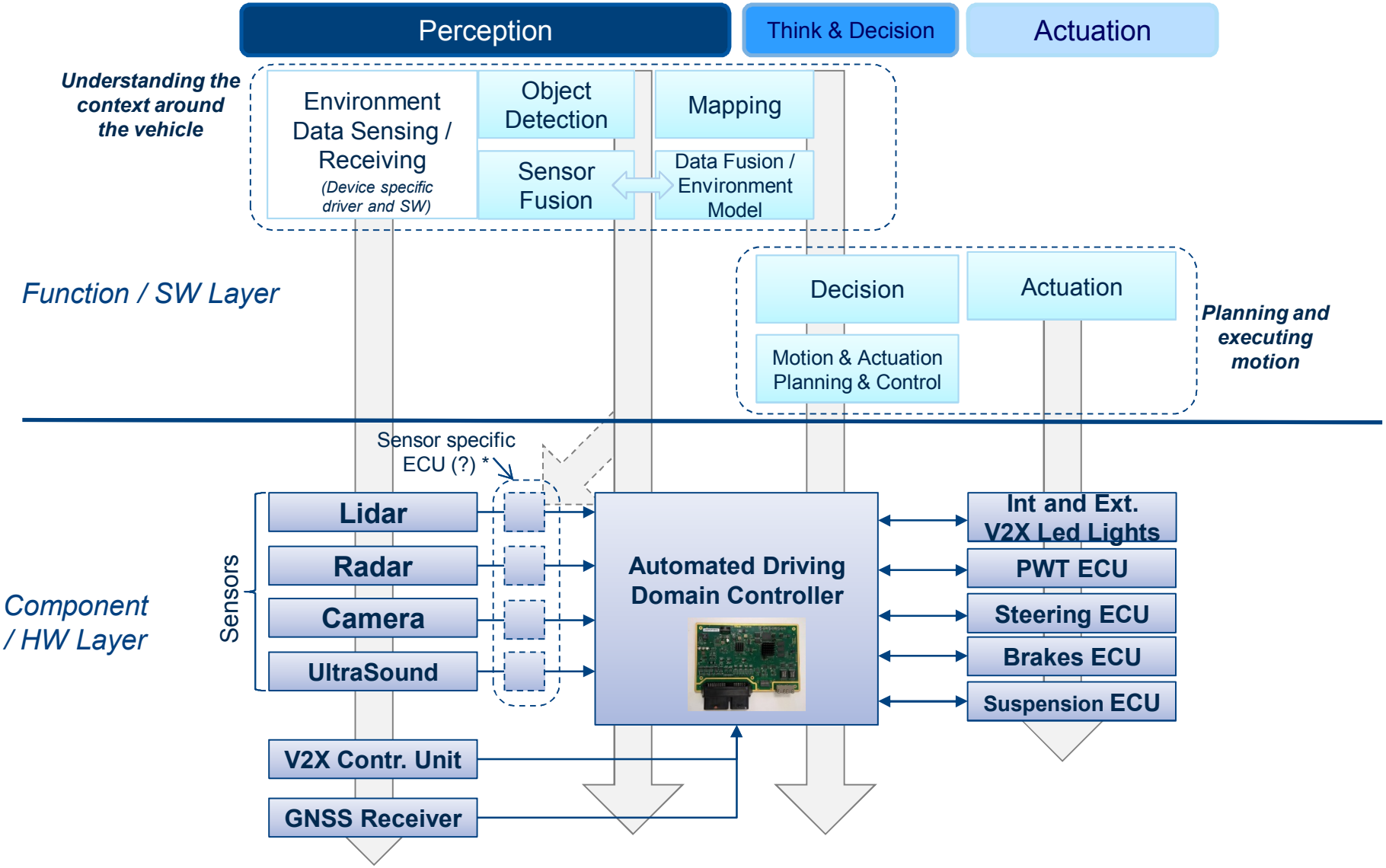
Summarizing

- The proposed approach provides event-driven traffic with
  - very low maximum latency values
  - very low latency variability.
- In addition, the proposed approach
  - does not affect Scheduled traffic
  - has a very limited impact on the E2E maximum latency for Stream Reservation traffic

Application on Autonomous Driving: Smart Corner™



Automated Driving architecture



* Sensor specific ECUs used instead of Automated Driving Domain Controller for Individual ADAS functions

Magneti Marelli Autonomous Vehicles

Autonomous Vehicle for
Highway scenario (level 3)

Autonomous Vehicle for
Parking scenario (level 4)

Autonomous Vehicle for
Urban scenario (level 4)