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

Giancarlo Vasta, Magneti Marelli, giancarlo.vasta@magnetimarelli.com
Lucia Lo Bello, University of Catania, lobello@unict.it

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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…
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
### Traffic type

<table>
<thead>
<tr>
<th>Traffic type</th>
<th>Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Scheduled traffic</strong></td>
<td>High priority real-time traffic transmitted according to a time schedule (time-driven) with no interference from other traffic.</td>
</tr>
<tr>
<td><strong>Stream Reservation</strong></td>
<td>Periodic, guaranteed</td>
</tr>
<tr>
<td><strong>Event-driven traffic</strong></td>
<td>Aperiodic bursts, generated by events, with real-time constraints</td>
</tr>
<tr>
<td><strong>Best-effort traffic</strong></td>
<td>No guarantees, performance is statistical</td>
</tr>
</tbody>
</table>
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).
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**

![Diagram showing priority queues for ED Traffic]
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.
## Scenarios

### Case A: 100 Mbps Scenario – ADAS

<table>
<thead>
<tr>
<th>Flow</th>
<th>Number of flows</th>
<th>Total MAC Bandwidth</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lidar</td>
<td>4</td>
<td>0.93 Mbps</td>
</tr>
<tr>
<td>Ultrasonic</td>
<td>4</td>
<td>0.23 Mbps</td>
</tr>
<tr>
<td>ADAS Sensors</td>
<td>4</td>
<td>Max 34 Mbps</td>
</tr>
<tr>
<td>30 fps compressed Video</td>
<td>4</td>
<td>~52 Mbps</td>
</tr>
</tbody>
</table>

### Case B: 1 Gbps Scenario – ADAS

<table>
<thead>
<tr>
<th>Flow</th>
<th>Number of flows</th>
<th>Total MAC Bandwidth</th>
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<td>4</td>
<td>0.23 Mbps</td>
</tr>
<tr>
<td>ADAS Sensors</td>
<td>4</td>
<td>Max 34 Mbps</td>
</tr>
<tr>
<td>60 fps compressed Video</td>
<td>4</td>
<td>~103 Mbps</td>
</tr>
</tbody>
</table>
## Case C: 10 Gbps Scenario – Automated Driving

<table>
<thead>
<tr>
<th>Flow</th>
<th>Number of flows</th>
<th>Total MAC Bandwidth</th>
</tr>
</thead>
<tbody>
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<tr>
<td>Ultrasonic</td>
<td>4</td>
<td>0.23 Mbps</td>
</tr>
<tr>
<td>ADAS Sensors</td>
<td>4</td>
<td>Max 34 Mbps</td>
</tr>
<tr>
<td>30 fps uncompressed Video</td>
<td>4</td>
<td>~7 Gbps</td>
</tr>
</tbody>
</table>
## Flow Parameters and Mapping

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

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)
Event-driven flows

ED Flows: Message latency

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

Proposed Approach

Alternative 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

Proposed Approach

Alternative 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

Proposed Approach

Alternative 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.

Proposed Approach

Alternative Approach
Other traffic classes – Case B: 1 Gbps scenario

- 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.
Other traffic classes – Case C: 10 Gbps scenario

- 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.
The proposed approach provides event-driven traffic with very low maximum latency values and 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

Understanding the context around the vehicle

Function / SW Layer

Perception

Think & Decision

Actuation

Environment Data Sensing / Receiving

Object Detection

Mapping

Sensor Fusion

Data Fusion / Environment Model

Decision

Actuation

Planning and executing motion

Sensor specific ECU (?)

Lidar

Radar

Camera

UltraSound

Automated Driving Domain Controller

Int and Ext. V2X Led Lights

PWT ECU

Steering ECU

Brakes ECU

Suspension ECU

V2X Contr. Unit

GNSS Receiver

Perception

Think & Decision

Actuation

Component / HW Layer

Understanding the context around the vehicle

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V2X Contr. Unit

GNSS Receiver

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