Highlights

- Automotive Ethernet complexities
- Realistic workloads for in-vehicle networks
- How to validate the network at the system level
- Experiments and observations
  - Running 802.1AS and time shaped traffic together
  - Running CBS and TAS together

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SYSTEM LEVEL VALIDATION OF ECU

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AGENDA

• Automotive Ethernet network Layer – complexities

• How to plan a network system test?

• Experiments & Observations

• Conclusion
AUTOMOTIVE ETHERNET NETWORK LAYER - CHALLENGES
AUTOMOTIVE ETHERNET ECOSYSTEM

Additional complexity at the network layer
FIRST LEVEL VALIDATION STRATEGY

- Functional validation of each protocol
- Adhering to industry acceptance criterion
What happens when you put everything together?
REALISTIC WORKLOAD FOR IN-VEHICULAR NETWORKS

<table>
<thead>
<tr>
<th>Time Aware Shaper</th>
<th>Control Signal Frame</th>
</tr>
</thead>
<tbody>
<tr>
<td>Credit Based Shaper</td>
<td>Large A/V Frame</td>
</tr>
<tr>
<td>Best Effort Priority</td>
<td>Lower Priority Data Frame</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Traffic Type</th>
<th>Priority Class</th>
</tr>
</thead>
<tbody>
<tr>
<td>ADAS Video Stream</td>
<td>Class A AVB Traffic</td>
</tr>
<tr>
<td>Infotainment Audio / Video Stream</td>
<td>Class B AVB Traffic</td>
</tr>
<tr>
<td>Command and Control (C&amp;C) signals</td>
<td>Time Aware traffic</td>
</tr>
<tr>
<td>Diagnostics / file / data transfer</td>
<td>Best Effort Priority Traffic</td>
</tr>
</tbody>
</table>
COST OF FAILURE IS HUGE

Critical failures can happen at system level and under malicious traffic condition.

Chrysler’s recall of 1.4M vehicles for a software bug in ECU costed them $1.1 Billion
HOW TO VALIDATE THE NETWORK AT SYSTEM LEVEL?
FACTORS CONTRIBUTING AT A SYSTEM LEVEL

Variable Line-rate

Variable Frame size

Variable Scheduling

Effects

• Elevated latency

• Packet loss

• Poor scheduling accuracy.
MAJOR TESTING CAPABILITIES THAT CAN HELP?

• Emulation of realistic workload for an In vehicular network
  • Mix of shaped and unshaped traffic

• Control over triggering negative scenarios that can impact network performance.

• Ability to measure traffic characteristics and timing accuracy in high precision at line rate
EXAMPLE AUTOMOTIVE TOPOLOGY WITH TSN TRAFFIC

Data Transmission Rate

<table>
<thead>
<tr>
<th>Traffic Type</th>
<th>Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unscheduled Ethernet Traffic</td>
<td>Line Rate</td>
</tr>
<tr>
<td>ADAS Sensor Traffic</td>
<td>2000 fps</td>
</tr>
</tbody>
</table>

Protocols Deployed

- 802.1 AS – gPTP for Time Synchronization
- 802.1 Qbv – Time Aware Shaper
- 802.1Qav – Credit Based Shaper
EMULATION OF IN VEHICULAR NETWORKING USING TEST TOOL

Frame Rate

<table>
<thead>
<tr>
<th>Traffic Item</th>
<th>Tx Frame Rate</th>
<th>Rx Frame Rate</th>
<th>Tx L1 Rate (bps)</th>
<th>Rx L1 Rate (bps)</th>
<th>Tx Rate (Bps)</th>
<th>Rx Rate (Bps)</th>
<th>Tx Rate (kbps)</th>
<th>Rx Rate (kbps)</th>
<th>Tx Rate (Mbps)</th>
<th>Rx Rate (Mbps)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Qcv_Infolternent_Talker</td>
<td>497,000,000</td>
<td>485,000,000</td>
<td>400,126,000,000</td>
<td>400,126,000,000</td>
<td>497,000,000</td>
<td>485,000,000</td>
<td>392,448,000</td>
<td>392,448,000</td>
<td>392,448</td>
<td>392,448</td>
</tr>
<tr>
<td>Qcv_Diagnostic_Source</td>
<td>81,957,500</td>
<td>61,464,500</td>
<td>599,892,000,000</td>
<td>599,892,000,000</td>
<td>599,892,000</td>
<td>599,892,000</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>QCV_ADAS_Sensor_DATA_VLAN_PTD</td>
<td>1,000,000</td>
<td>1,000,000</td>
<td>960,000,000</td>
<td>960,000,000</td>
<td>1,000,000</td>
<td>1,000,000</td>
<td>800,000</td>
<td>800,000</td>
<td>800,000</td>
<td>800,000</td>
</tr>
<tr>
<td>QCV_ADAS_Sensor_DATA_VLAN_PTD</td>
<td>1,000,000</td>
<td>1,000,000</td>
<td>960,000,000</td>
<td>960,000,000</td>
<td>1,000,000</td>
<td>1,000,000</td>
<td>800,000</td>
<td>800,000</td>
<td>800,000</td>
<td>800,000</td>
</tr>
</tbody>
</table>

Latency

<table>
<thead>
<tr>
<th>Traffic Item</th>
<th>Store-Forward Avg Latency (ms)</th>
<th>Store-Forward Min Latency (ms)</th>
<th>Store-Forward Max Latency (ms)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Qcv_Infolternent_Talker</td>
<td>6,428</td>
<td>1,440</td>
<td>13,340</td>
</tr>
<tr>
<td>Qcv_Diagnostic_Source</td>
<td>291,500</td>
<td>2,500</td>
<td>309,300</td>
</tr>
<tr>
<td>QCV_ADAS_Sensor_DATA_VLAN_PTD</td>
<td>1,304</td>
<td>2,200</td>
<td>2,300</td>
</tr>
<tr>
<td>QCV_ADAS_Sensor_DATA_VLAN_PTD</td>
<td>1,304</td>
<td>2,200</td>
<td>2,440</td>
</tr>
</tbody>
</table>

Loss

<table>
<thead>
<tr>
<th>Traffic Item</th>
<th>Tx Frames</th>
<th>Rx Frames</th>
<th>Frames Delta</th>
<th>Loss %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Qcv_Infolternent_Talker</td>
<td>5,157,778</td>
<td>5,157,776</td>
<td>0</td>
<td>0.000</td>
</tr>
<tr>
<td>Qcv_Diagnostic_Source</td>
<td>9,973,305</td>
<td>7,770,173</td>
<td>2,203,132</td>
<td>22.090</td>
</tr>
<tr>
<td>QCV_ADAS_Sensor_DATA_VLAN_PTD</td>
<td>177,816</td>
<td>177,816</td>
<td>0</td>
<td>0.000</td>
</tr>
<tr>
<td>QCV_ADAS_Sensor_DATA_VLAN_PTD</td>
<td>141,217</td>
<td>141,217</td>
<td>0</td>
<td>0.000</td>
</tr>
</tbody>
</table>
EXPERIMENTS & OBSERVATIONS
**SCENARIO 1: RUNNING 802.1AS + TIME SHAPED TRAFFIC TOGETHER**

Talker sending
- Periodic 802.1AS Messages
- Scheduled time critical application workloads

Device forwarding
- Scheduled time critical application workloads as per the schedule configured.
- Generated 802.1AS messages.

Listener analysing
- The time critical traffic from the Device Under Test.
- Reporting anomalies like loss/latency/jitter.
RESULT: IMPACT OF GPTP ON SCHEDULED TRAFFIC

Running 802.1AS & Time Aware Shaper Together

Variation of Latency for Scheduled Traffic

- Scheduled Traffic at 10% line rate
- Scheduled Traffic at 50% line rate
- Scheduled Traffic at 80% line rate

Approach 1: gPTP traffic is assigned to priority 0 and gate is always open
RESULT : IMPACT OF SCHEDULED TRAFFIC ON GPTP

Approach 2: gPTP traffic is best effort

When 50% cycle time is allowed for best effort traffic

<table>
<thead>
<tr>
<th>802.1AS Sync Interval</th>
<th>8/sec</th>
<th>64/sec</th>
<th>128/sec</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slave Offset measured at Ixia (ns)</td>
<td>880ns</td>
<td>280ns</td>
<td>260ns</td>
</tr>
<tr>
<td>Sync Msg Rx Interval at Ixia Slave (/sec)</td>
<td>8/sec</td>
<td>61/sec</td>
<td>118/sec</td>
</tr>
</tbody>
</table>

When 25% cycle time is allowed for best effort traffic

<table>
<thead>
<tr>
<th>802.1AS Sync Interval</th>
<th>8/sec</th>
<th>64/sec</th>
<th>128/sec</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slave Offset measured at Ixia (ns)</td>
<td>940ns</td>
<td>300ns</td>
<td>280ns</td>
</tr>
<tr>
<td>Sync Msg Rx Interval at Ixia Slave (/sec)</td>
<td>8/sec</td>
<td>60/sec</td>
<td>118/sec</td>
</tr>
</tbody>
</table>
WHAT HAPPENS WHEN A GPTP INTERFERES WITH DATA TRAFFIC?
WHAT HAPPENS WHEN A GPTP INTERFERES WITH DATA TRAFFIC?
SCENARIO 1: OBSERVATIONS

• Allowing 802.1AS packets as part of unscheduled or best effort traffic can cause drift in timing accuracy.

• SYNC packets issued by DUT during Gate-Close state will get buffered and forwarded in next Gate-Open event.

• An ideal solution would be to provision for 802.1AS packets as part of scheduled traffic.
SCENARIO 2: RUNNING CBS AND TAS TOGETHER

Talker sending
- Talker sending scheduled SR Class B traffic

Device forwarding
- Apply CBS inside the transmit interval

Listener analysing
- Inter packet Gap of Rx Traffic
- Reporting anomalies like loss/latency/jitter.
WHAT HAPPENS WHEN A TALKER MISBEHAVES?

Cycle Time = 1 sec

Scheduled Traffic in Burst

Infotainment System

Protocols Supported
1. 802.1 Qbv

Infotainment Speaker

Qbv Talker

ECU

Qbv Listener
WHAT HAPPENS WHEN A TALKER MISBEHAVES?

Scheduled Traffic in Burst

scheduled traffic uniformly spaced

Infotainment System

Qbv Talker

ECU

Protocols Supported

1. 802.1 Qbv
2. 802.1 Qav

Infotainment Speaker

Qbv Listener
Scheduled bursty traffic at DUTs Ingress.
Not spaced out per SR Class.

Scheduled traffic is shaped at DUTs Egress by CBS.
Packets spaced out per SR Class.

### RESULTS: CBS OF BURSTY TRAFFIC

#### Scheduled SR class B traffic at 10% line rate

<table>
<thead>
<tr>
<th>Inter Packet Gap of Traffic at DUT Ingress</th>
<th>Expected IPG of Traffic at DUT Egress (usec)</th>
<th>Rx IPG of Traffic from DUT Egress (usec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>12 Bytes</td>
<td>250</td>
<td>243.3</td>
</tr>
<tr>
<td>24 Bytes</td>
<td>250</td>
<td>242</td>
</tr>
<tr>
<td>36 Bytes</td>
<td>250</td>
<td>245</td>
</tr>
</tbody>
</table>

#### Scheduled SR class B traffic at 30% line rate

<table>
<thead>
<tr>
<th>Inter Packet Gap of Traffic at DUT Ingress</th>
<th>Expected IPG of Traffic at DUT Egress (usec)</th>
<th>Rx IPG of Traffic from DUT Egress (usec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>12 Bytes</td>
<td>250</td>
<td>243.3</td>
</tr>
<tr>
<td>24 Bytes</td>
<td>250</td>
<td>242</td>
</tr>
<tr>
<td>36 Bytes</td>
<td>250</td>
<td>245</td>
</tr>
</tbody>
</table>
SCENARIO 2: OBSERVATIONS

• If an automotive talker starts sending un-expected packets in bursts during its scheduled interval, then it needs to be handled in an ECU.

• An ideal solution will be to have credit based shaper run hand in hand with time aware shaper.

• Credit based shaper would shape the bursty nature of frames based on “rate of credit accumulation” and Inter-Frame-Gap defined by the SR Class.
SETUP INFORMATION

Test Tool Used

ECU under test

- 4 port automotive switch with TSN capability
- No of Queues - 8
- Link speed – 1 Gbps
CONCLUSION
EFFECTIVE VALIDATION FOR AUTOMOTIVE NETWORK

• Functionality testing in isolation is an IMPORTANT first step – but not COMPLETE.

• Benchmarking the interplay of different functions at system level is the CRITICAL step for being production ready.

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