Use Case – Network Reliability from the Perspective of Autonomous Driving

Allan Zhu, July 2019
The Impact of Autonomous Driving on E/E Architecture

Source: SAE International, J3016_201806: Taxonomy and Definitions for Terms Related to Driving Automation Systems for On-Road Motor Vehicles
Reliability is the Key Requirement for the IVNs

- The safety of an autonomous driving system relies on network reliability, besides others...

- **Two Levels of Network Reliability**
  - Reliability of Network Elements:
    - Sensors/actuators, gateways/switches, interfaces/links, ECUs/central computers
    - Reliability mainly determined by the manufacturers who build them
  - Reliability of Networks:
    - Redundancy of key network elements and communication links, fast failure detection and switch over
    - Reliability mainly determined by the design of the in-vehicle network

- **These two levels of reliability compensate each other, to some degrees**
  - A well designed, highly reliable network will improve the level of system reliability.

- **In this contribution, we focus on the network-level reliability.**
Redundancy Improves Network Reliability

- **Defining reliability/risk**
  - **Automotive Safety Integrity Level (ASIL)** – a risk classification scheme defined by the ISO 26262 - Functional Safety for Road Vehicles standard.
  - The ASIL to be achieved should be considered at the beginning of the system design.
  - There are four ASILs identified by the standard: ASIL-A, ASIL-B, ASIL-C, and ASIL-D.
    - ASIL-D dictates the highest integrity requirements on the product and ASIL A the lowest.

- **Redundancy improves reliability**
  - ASIL-D = ASIL-B + ASIL-B
  - The reliability of two redundant ASIL-B network can provide the same reliability of a ASIL-D network.

Source: [Synopsys](#)  
Source: [National Instruments](#)
Dealing with Varieties of Redundancy

- Architecture could be domain-based or zone-based;
- Communication functions and computing functions could be co-located in same physical devices, or could be separated in different entities;
- Network may have 2 to 4 gateways/controllers

Scenario #1: All computational work is done at the central computer, with redundancy inside the central computer; Ring topology provides link level redundancy.

Scenario #2: Computational work is distributed in different GWs; Further, same function is deployed in different GWs to provide computational redundancy.
Use Case: A 3-Gateway Network

- **Network Description**
  - 2 central computers with 3 gateways;
  - 2 central computers connect to each other;
  - 3 gateways are interconnected by a ring;
  - Each central computer has at least one direct connection to one of the gateways.

- **Redundancy Requirements**
  - **Computer Redundancy**: 2 central computers back up each other in real time; when one fails, the other will take over all the computation work within pre-determined time limit;
  - **Communication Redundancy**: when any one link fails, there is one or more links to connect a gateway to a central computer. This new link needs to have enough bandwidth to handle traffic that could have been doubled.
    - Example: when Link 5 breaks, traffic from GW1 has to go through Link 1 → Link 2 → Link 3 to Central Computer #2;
    - Further, traffic from GW2, which used to have two options to reach central computers, now has only the Link 2 → Link 3 option.
      - In this case, Link 2 and Link 3 have to carry overflowed traffic from GW1;
    - Extra bandwidth needs to be considered and reserved for these links at the system design phase.
Failure Detection and Switching Time – the Key for Redundant Approach

- Different sensors have different sensing frequencies.

- How much sensory data can we afford to lose?
  - Assume:
    - A camera’s frame rate is 30FPS;
    - The car runs at 120km/hr (~75miles/hr);
    - Failure detection and switching over cause 1 frame lost at the central computer.
  - Result:
    - The car will run for 1.11m at this duration (inter-frame time is 33.3ms)

- How to ensure non-Ethernet traffic’s latency requirement over Ethernet?
  - Assume we encapsulate CAN frames and carry them using Ethernet;
  - CAN has a typical transmit period of 10ms (min 5ms).
  - How many CAN frames can we afford to lose?
    - Example: consider these CAN signals are braking signals to be sent to the brakes.

<table>
<thead>
<tr>
<th>Device</th>
<th>Data Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cameras</td>
<td>30/60/…/FPS</td>
</tr>
<tr>
<td>Ultrasonic Radar</td>
<td>100Hz</td>
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<tr>
<td>mmWave Radar</td>
<td>50Hz</td>
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<tr>
<td>Lidar</td>
<td>20Hz</td>
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</table>
Bandwidth Requirements

- Autonomous driving relies on various types of sensors;
- Sensor fusion accumulates data at gateways and send to central computers;
- Some sensory data requires high bandwidth
  - Example: at 1Gbps, we cannot even transmit one single uncompressed 1080p video stream with 16bit dynamic range at 30FPS.
- When any of the backbone links fail, alternate links will need to take over the traffic;
  - This imposes additional bandwidth requirements for backbone links.
- To prepare for the future, the TSN Automotive Profile shall determine a backbone link speed that is high enough to support autonomous driving.
  - We suggest minimum backbone link speed at 1Gbps.
  - For the standard to be future-proved, the link speed should be > 1Gbps.

### Image Quality vs Bandwidth

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<thead>
<tr>
<th>FPS</th>
<th>Hres</th>
<th>Vres</th>
<th>Fps</th>
<th>16bit 96dB</th>
<th>20bit 120dB</th>
<th>24bit 140dB</th>
<th>32bit 180dB</th>
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<tr>
<td>30</td>
<td>1280</td>
<td>720</td>
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Note: the data rates are in the unit of Gbps, and include 20% protocol overhead.

Image quality is determined by three key parameters, resolution, dynamic range and frame rate.
Summary

- Redundancy is one of the major approaches to achieve high reliability for IVNs;

- Fast failure detection and switching over to backup devices/links are the keys for this approach to be meaningful;
  - Failure detection and switching is suggested to be done within **10ms**, better within 1ms.
  - Transmitting the same frames over multiple paths will be able to provide zero-delay switch over; e.g., using frame replication and elimination for reliability;
    - Need to balance performance and cost when this approach is used.

- Backbone links need to be designed with extra bandwidth in order to handle overflowed traffic from failure devices/links;
  - Backbone link speed is suggested to be at least **1Gbps**, better higher than 1Gbps, to support autonomous driving.
Thank You!