Use Case – Network Reliability from the Perspective of Autonomous Driving

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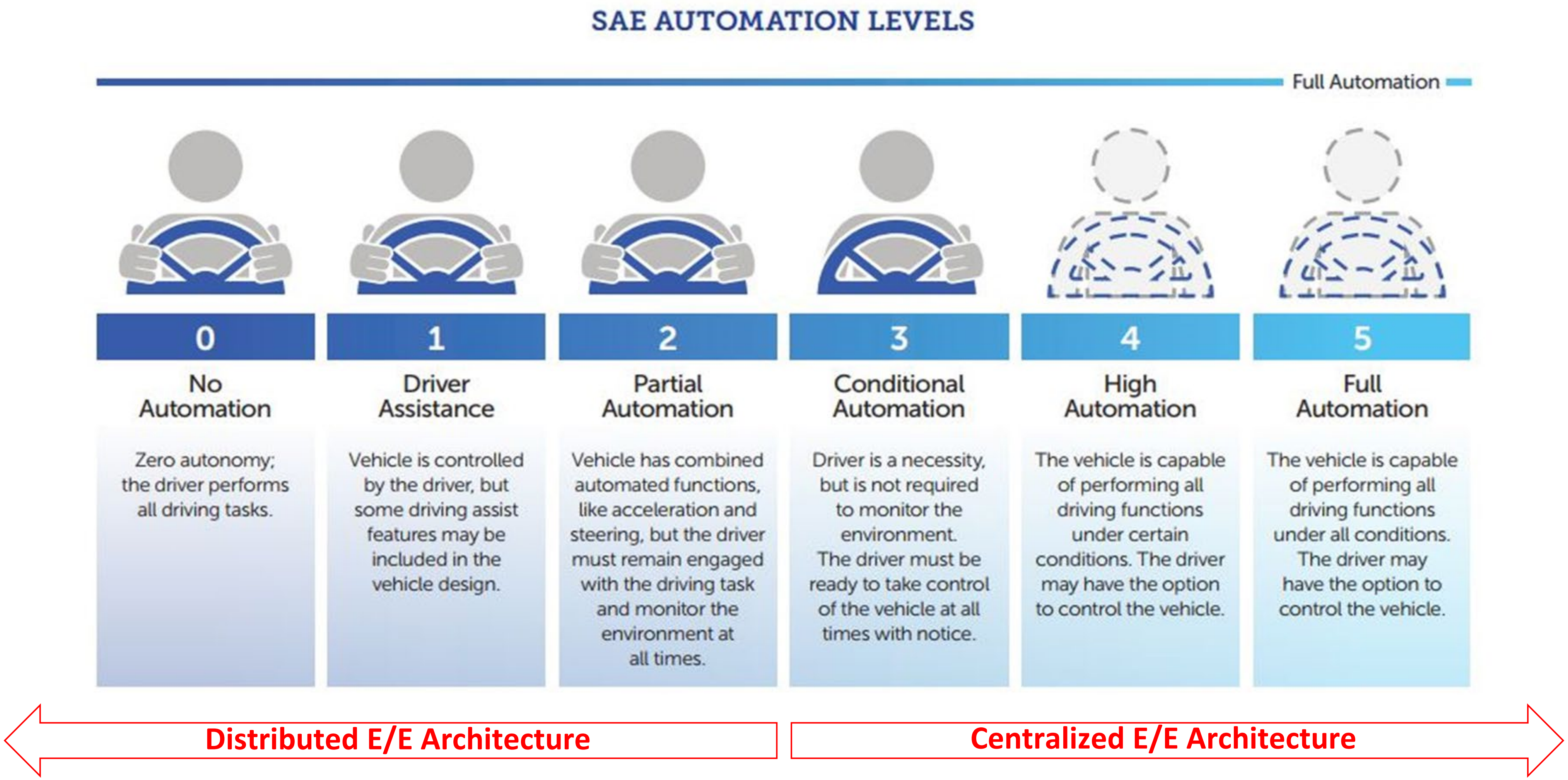
The Impact of Autonomous Driving on E/E Architecture



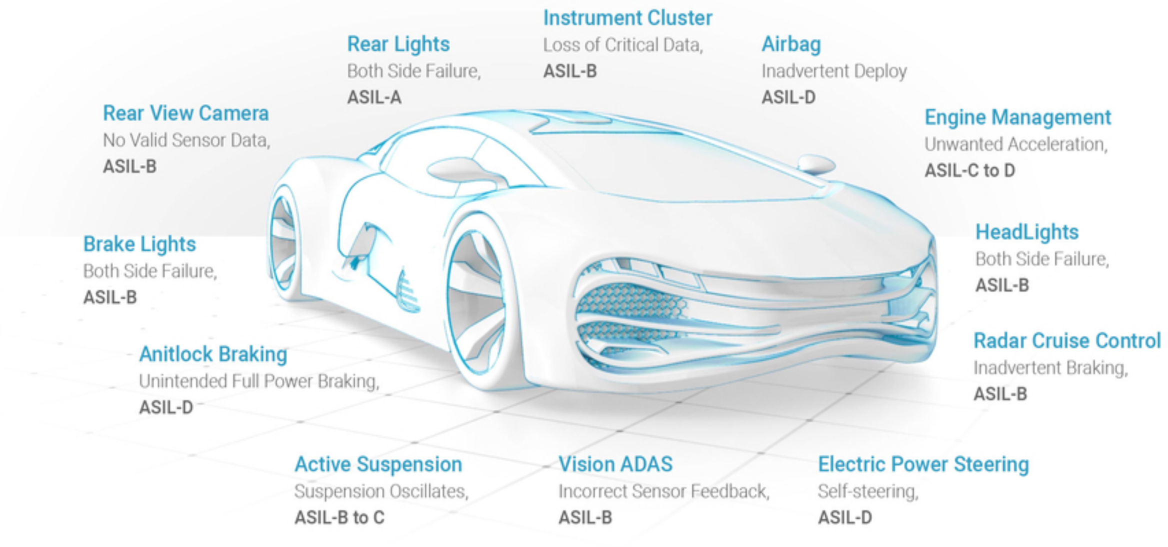
Source: SAE International, J3016_201806: Taxonomy and Definitions for Terms Related to Driving Automation Systems for On-Road Motor Vehicles

Reliability is the Key Requirement for the IVNs

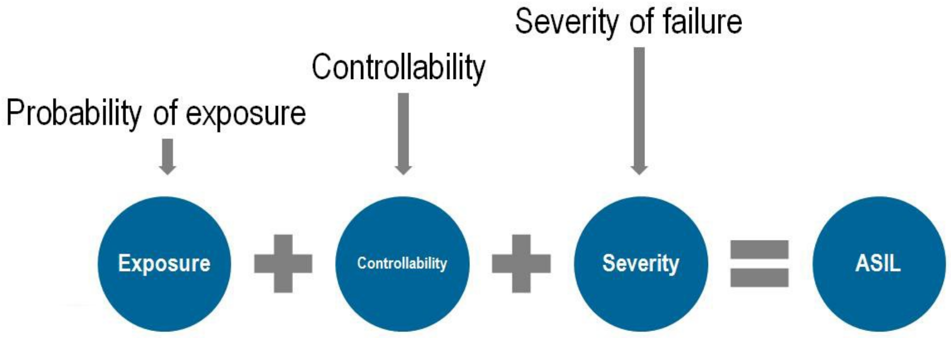
- **The safety of an autonomous driving system relies on network reliability, besides others…**
- **Two Levels of Network Reliability**
  - Reliability of Network Elements:
    - Sensors/actuators, gateways/switches, interfaces/links, ECUs/central computers
    - Reliability mainly determined by the 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.



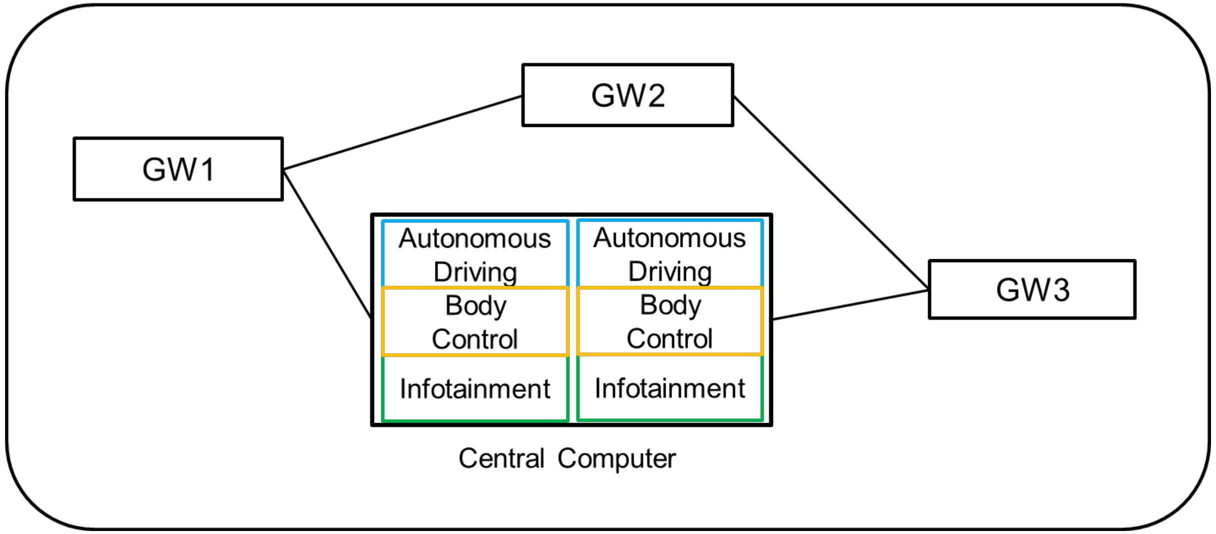
Source: Synopsys



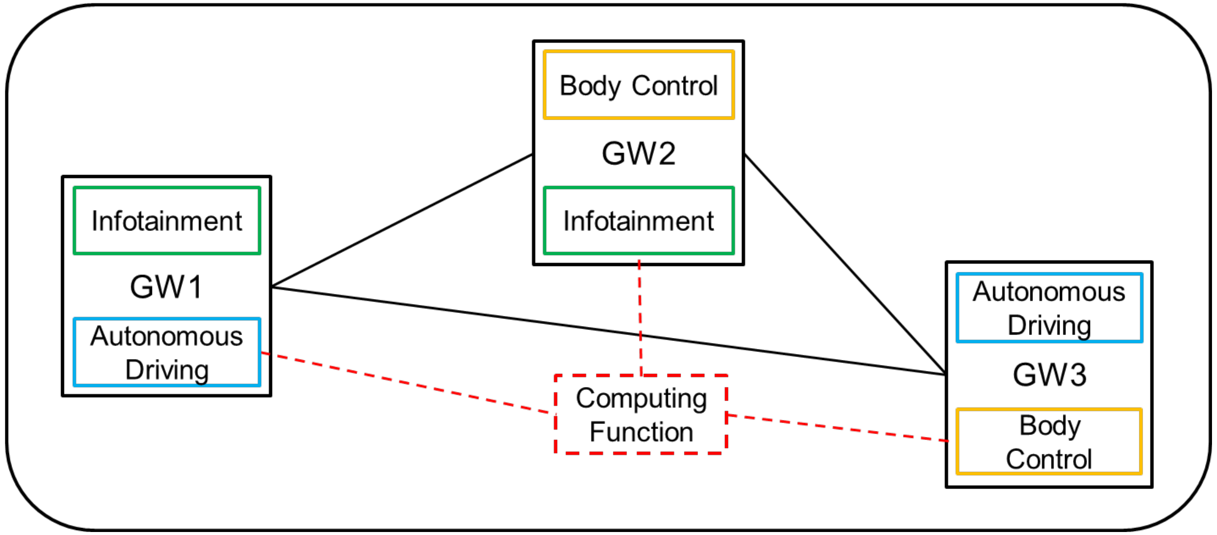
Source: National Instruments

Redundancy is Needed at Different Levels, for Different E/E Architectures

- **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

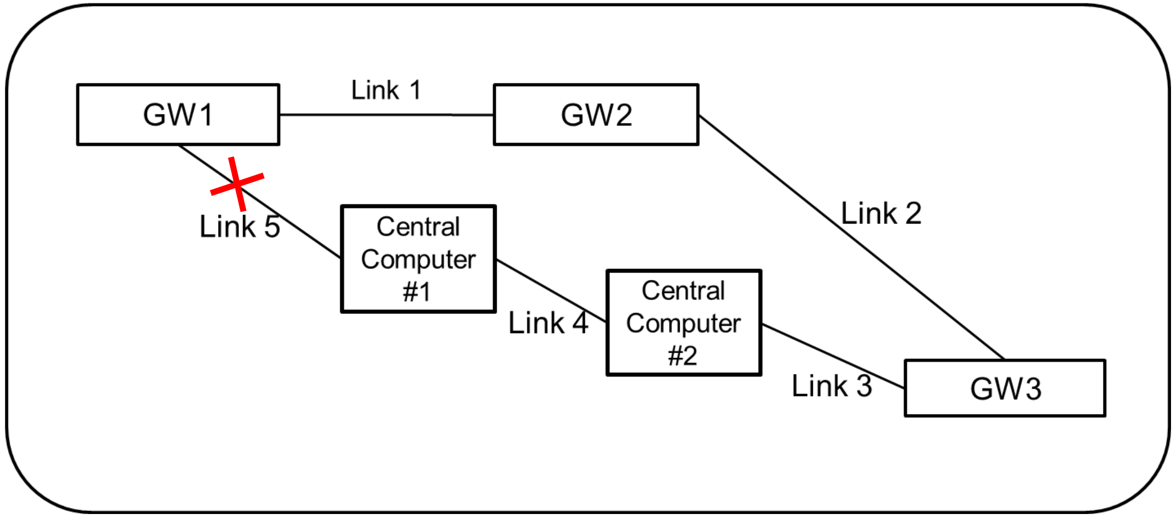


Scenario #1: All computational work is done at the central computer, with redundancy inside the central computer; Ring topology provides link level redundancy.



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.

Sensing Frequency

Device	Data Frequency
Cameras	30/60/…/FPS
Ultrasonic Radar	100Hz
mmWave Radar	50Hz
Lidar	20Hz

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

FPS 30	Hres	Vres	Fps	16bit 96dB	20bit 120dB	24bit 140dB	32bit 180dB
720p	1280	720	30	0.55	0.6875	0.825	1.1
1080p	1920	1080	30	1.25	1.55	1.8625	2.4875
2k	2560	1440	30	2.2125	2.7625	3.3125	4.425
4k	3840	2160	30	4.975	6.225	7.4625	9.95
8k	7680	4320	30	19.913	24.888	29.863	39.813

FPS 60	Hres	Vres	Fps	16bit 96dB	20bit 120dB	24bit 140dB	32bit 180dB
720p	1280	720	30	1.1	1.375	1.65	2.2
1080p	1920	1080	30	2.5	3.1	3.725	4.975
2k	2560	1440	30	4.425	5.525	6.625	8.85
4k	3840	2160	30	9.95	12.45	14.925	19.9
8k	7680	4320	30	39.826	49.776	59.726	79.626

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!