Technical Article

How Ethernet accelerates the move to software-defined vehicles

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A zone architecture and Ethernet represent the future of networking in vehicles. New features in vehicles, as well as the shift to aggregating sensors and actuators into zonal control modules, require a high-bandwidth and low latency in-vehicle communication network. A zone architecture implementing Ethernet enables the growing trend of the software-defined vehicle.

Most vehicles today are built using a type of wiring and electronic control unit (ECU) architecture called a domain architecture. A domain architecture categorizes ECUs into domains based on specific functions, regardless of their physical location in the vehicle.

A zone architecture, in contrast to a domain architecture, organizes communication, power distribution and load control by location rather than by function, as shown in Figure 1. A zonal control module behaves as a network data bridge between the vehicle's computing system and local edge nodes such as smart sensors and ECUs. To reduce cabling in the vehicle, a zonal control module will also distribute power to different edge nodes (by implementing semiconductor smart fuse capabilities), handle low-level computing, and drive local loads such as motors and lighting.

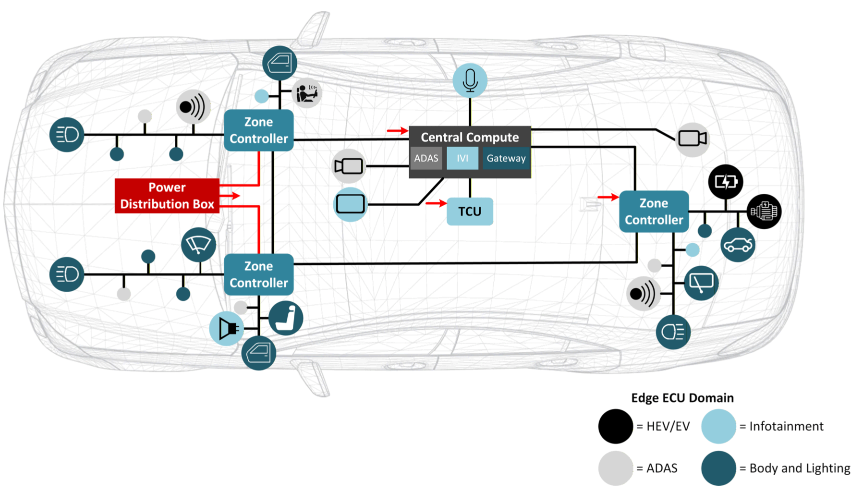

Figure 1. Example of a zone architecture

Zonal control modules transfer data from various sensors and ECUs through an edge-node communication network, and forward the combined sensor data to the central computing system through backbone communication. Similarly, the zonal control modules transfer data received from the central computing system to various actuators, again through backbone communication, again through an edge-node communication network. This two-way communication between the central computing system and the zonal control modules requires a high-bandwidth and low-latency communication backbone in order to handle the large amount of data generated by functions such as multiple advanced driver assistance system (ADAS) sensors, vehicle motion control and adaptive driving beams.

Bandwidth requirements in a zone architecture

To understand the value in using Ethernet in vehicles, let's break down Ethernet use by application. The newly defined Single-Pair Ethernet supports speeds from 10Mbps to 10Gbps, defined through Institute of Electrical and Electronics Engineers (IEEE) 802.3cg (10Mbps), IEEE 802.3bw (100 Mbps), IEEE 802.bu (1Gbps) and IEEE 802.3ch (10Gbps). All of these new Ethernet technologies work over a single-pair cable and can communicate at distances as far as 15m, which is long enough to cover the longest link in a vehicle. Ethernet can also enable the time synchronization of sensor data using IEEE 802.1AS timestamping to achieve low latency.

While Ethernet is capable of extremely fast speeds, these speeds are not necessary in every context. For example, communicating with the door control module or the heating, ventilation and air-conditioning system does not require a 100Mbps data rate. A 10Mbps Ethernet PHY such as the DP83TD555J-Q1 or alternative network protocol such as Controller Area Network (CAN) is better for lower-speed and less bandwidth-intensive use cases, while reserving higher speeds for sending aggregated camera and autonomous driving sensor data from the zonal control modules to the central computing system. Figure 2 shows where to use different speeds of Ethernet in a zone architecture.

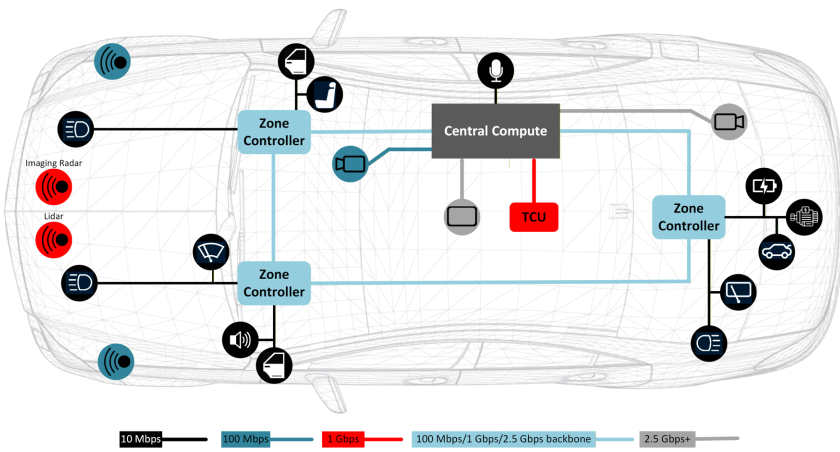

Figure 2. Ethernet in a zone architecture

Using Figure 2, let's take a closer look at the communication speeds used for radar, lidar, camera and body applications. When the radar or lidar system-on-a-chip (SoC) processes the data, typically CAN, 10Mbps Ethernet or 100Mbps Ethernet communicates lidar or radar data to the zonal control module When only first- or second-level data processing occurs, 100Mbps to 1Gbps Ethernet communicates radar and lidar data to the zonal module or central computer. Sending raw lidar or radar data to the central computing system for processing will extract more information through sensor fusion of various sensors. The transmission of such a large amount of raw data requires a higher bandwidth, typically a serial/deserializer (SerDes) protocol or 2.5Gbps plus Ethernet.

For cameras, SerDes such as Flat Panel Display (FPD)-Link is the most appropriate protocol when a level of increased ADAS data requires all of the raw data from the front camera for post-processing.

If it is possible to compress the data from the front camera and you don't need this increased level of ADAS data, 100Mbps Ethernet is an alternative.

Body domain modules such as door handle sensors, window-lift control modules and side mirror control modules traditionally use the CAN and Local Interconnect Network (LIN) protocols to communicate, as neither require a high bandwidth. While designers will continue to use CAN and LIN, the increased use of Ethernet in vehicles also creates a place for 10Mbps 10BASE-T1S multidrop Ethernet. Ethernet is traditionally a point-to-point topology, but 10BASE-T1S Ethernet is the first Ethernet standard enabling functionality over a bus topology.

Multigigabit Ethernet in a zone architecture

What is the potential evolution of the zone architecture? It begins with aggregating body domain data, incorporating power distribution, and centralizing computing. Over time, zone architectures will start aggregating data from other domains such as ADAS and infotainment. The end goal is to incorporate all domains into the zone architecture. Regardless of which domain the data belongs to, the zonal control module and central computing system will still use the same backbone communication network to transfer data. Audio is a prime target to move into zone control modules, since it’s possible to transmit audio data over Ethernet with Audio Video Bridging standards.

Body domain functions typically require 10Mbps or less. But as ADAS or in-vehicle infotainment functions such as radar, lidar, audio and cameras become incorporated into the zone architecture, the speed and bandwidth requirements must increase and/or the Ethernet backbone topology may change from star to ring to accommodate the amount of safety-critical and time-sensitive sensor data.

Audio generates about 1.5Mbps per channel; a radar sensor typically generates 0.1Mbps to 15Mbps. Lidar generates 20Mbps to 100Mbps. Cameras generate the most 500Mbps to 3.5Gbps. Today’s vehicles typically have four to six radar sensors, one to five lidar sensors, 12 to 20 audio speakers, 12 to 16 audio microphones and six to 12 cameras. Table 1 shows the range of data generated by each type.

Table 1. Data generated in a zone architecture

Type	Data Generated	Quantity of Sensors	Low	Mid	High
Audio speaker	1.5Mbps	12 to 20	3.2Mbps	24Mbps	30Mbps
Audio microphone	1.5Mbps	12 to 16	3.2Mbps	21Mbps	24Mbps
Radar	0.1 - 15Mbps	4 to 6	0.4Mbps	35Mbps	90Mbps
Lidar	20 - 100Mbps	1 to 5	20Mbps	100Mbps	500Mbps
Camera	500Mbps - 3.5Gbps	6 to 12	3Gbps	9Gbps	42Gbps

It is the total data being generated that is causing the push for 2.5Gbps, 5Gbps and 10Gbps Ethernet among original equipment manufacturers (OEMs). The zone architecture needs a backbone communication network capable of transmitting the enormous amount of data produced by ADAS sensors to the central computing system. Uncompressed camera data already goes beyond current Ethernet capabilities, and cameras continue increasing in resolution and pixel count. As vehicles continue toward autonomy, the number of sensors will increase. Thus, the bandwidth required to support increased camera resolution and sensors will grow correspondingly.

The Ethernet speeds that OEMs are requesting most likely differ because of the transition schedules for incorporating different functions into the zonal control module. Audio playback on interior speakers is one of the first cross-domain data types adopted for use on the Ethernet backbone. This is likely caused by lower data generation in comparison, since 20 audio speaker channels generate about 30 Mbps. An existing 100Mbps or 1Gbps Ethernet backbone can easily accommodate the addition of audio playback data. Overall, the more high data functions in zonal control modules, the higher the bandwidth requirements.

Using Ethernet as the backbone for a zone architecture allows vehicles to transfer more data over the in-vehicle network when connecting to the internet or remote OEM servers. This enables subscription-based services and vehicle diagnostics through remotely performed firmware-over-the-air (FOTA) updates. FOTA updates allow for different hardware and software update cycles, which can be asynchronous as a result of the independence of sensors and actuators from the central computing node. A FOTA update can also push additional features and safety improvements, instead of waiting for a new model or having to bring the vehicle in to be worked on. Both the OEM and the customer benefit, as the OEM has control over updating the vehicle with additional features after launch, and the consumer is less inconvenienced by trips to a dealer to update firmware.

PHYs in a zone architecture

Ethernet requires the use of PHYs to transmit and receive high-speed data. Automotive Ethernet PHYs eliminate many of the concerns with Ethernet as the backbone of the wiring in vehicles, such as poor signal quality in such a volatile environment. Ethernet PHYs from Texas Instruments (TI) are capable of operating at a range of temperatures from –40°C to 125°C, in compliance with Automotive Electronics Council-Q100 Grade 1 standards.

Ethernet PHYs also have to pass Ethernet compliance standards, ensuring that they meet certain interoperability and reliability standards regarding electromagnetic compatibility and electromagnetic interference, as well as IEEE conformance as specified by Open Alliance TC1 and TC12 standards, to work in a vehicular environment. With advanced diagnostic features such as signal quality indication, time domain reflectometry and electrostatic discharge sensors, PHYs are capable of detecting when errors occur and can identify these faults and enable the host system to respond proactively. For example, in the event of electrostatic discharge (ESD), the PHY sends an interrupt signal to the SoC and Media Access Control to alert it of the event and then checks other parts in the system.

Ethernet PHYs can also wake up remote ECUs over the Single-Pair Ethernet cable using the Open Alliance TC10 specification's wake and sleep technology, which eliminates the need for a separate wire to wake the ECUs from sleep. IEEE 802.1AE Media Access Control Security (MACsec) could also be an important technology to enable the authentication of networking ECUs and to encrypt/decrypt data to avoid cyberattacks, as cyberattacks represent the biggest threat to automotive networking.

Additional Ethernet PHYs include:

- TI's DP83TC812-Q1, DP83TC815-Q1, and DP83TC814-Q1 100BASE-T1 PHYs have next-generation features suitable for luxury vehicles, while the smaller DP83TC813-Q1 100BASE-T1 PHY may be appealing in situations where printed circuit board space is at a premium. The DP83TG720-Q1 and DP83TG721-Q1 can connect zonal modules to data-intensive features such as the central computing system and telematics control unit, leaving headroom for the inclusion of additional features in later models without making intensive changes to the wiring harness. Combined, these PHYs open the door for more advanced and capable vehicles on the road.
- TI's portfolio of Single-Pair Ethernet PHYs is designed to be footprint or pin-to-pin compatible with both TI's 100BASE-T1 and 1000BASE-T1 PHYs. A single board design enables upgrades to the feature set or bandwidth in future developments with no hardware changes. This approach helps accelerate development cycles, meet requirements of different OEMs, and reduce time to market, thus saving R&D costs.
- The DP83TD555J-Q1 10BASE-T1S Serial Peripheral Interface MAC PHY integrates seamlessly into existing Ethernet backbone networks, eliminating protocol conversion gateways and their associated latency and processing overhead when connecting traditional CAN/LIN edge nodes. Supporting Power over Data Line, the device delivers both power and 10Mbps data over a single twisted-pair cable, reducing cable weight and system cost. Built-in PHY Collision Avoidance provides deterministic scheduling with guaranteed transmit opportunities for each network node, ensuring predictable communication timing. The larger Ethernet frame payloads enable extraction of higher data volumes and more diverse data types from ECUs at the vehicle's edge, facilitating advanced diagnostics and over-the-air updates while maintaining real-time performance.

Conclusion

Advancements in automotive Ethernet technology will enable automakers to deliver more features and capabilities to new vehicles. A zone architecture implementing Ethernet will help accelerate the shift to software-defined vehicles by providing the data capacity that will support the next wave of autonomous features – leading to safer and smarter vehicles on the road.

Additional resources

- Read the white paper, "TSN in Automotive Zone Architectures: Enabling Ethernet Ring Architectures and AVB-Distributed Audio" to learn how Time-Sensitive Networking increases reliability of a vehicle's network.
- For an additional overview on zone architectures, see the white paper, "How a Zone Architecture Paves the Way to a Fully Software-Defined Vehicle."
- For more information on the Open Alliance TC10 specification, check out the application note, "DP83TC812-Q1 TC10 System Timing Measurements."