TOSHIBA

Ethernet-based high-speed communication for Zonal Architectures and Telematics systems

Expanding SoC Connectivity in Automotive Domain Controllers

Introduction

The past decades have seen the slow demise of the role of mechanical engineers in the automotive industry as software programmers displace them. Vehicles have gone from being mechanical marvels to software-defined transportation solutions. And, if you believe that the quantity of software and the electronics that implement that code's functionality has peaked, you're going to be disappointed. The reality is that the automotive industry is still largely at the beginning of its journey to reshape how the electrical and electronic (E/E) architecture of vehicles will be implemented.

Electronic control units (ECU) handling individual functions within the vehicle have long been the approach to electrifying previously mechanical functions, such as window lifters, and adding new functionality, such as rain sensors. As a result, even a basic vehicle model contains around 70 ECUs, with premium models featuring well over 100. However, as vehicle original equipment manufacturers (OEM) look to differentiate their products and regulators place pressure on OEMs to add advanced safety features (ADAS), it is clear the old one-feature-per-box approach is no longer tenable.

Instead, the in-vehicle networks are being upgraded to support simpler connectivity with sufficient bandwidth to allow a small number of zonal controllers and performance computers to handle multiple functions, coupled with a reduced number of classic ECUs. With the use of multicore system-on-chip (SoC) processors well established, the challenge is to ensure that these devices have the connectivity needed by these new zonal controller-based E/E architectures.

From Decentralized to Zonal Control

ECUs have steadily replaced purely mechanical functionality in automotive for decades. The list is endless: window lifters, door and sunroof openers, rear-view mirrors. With the introduction of connectivity such as Controller Area Network (CAN), Local Interconnect Network (LIN), Media Oriented Systems Transport (MOST), and FlexRay, to name but a few, each domain, from infotainment and chassis to powertrain and body and comfort, were provided with an appropriately dimensioned automotive networking technology. Each ensured enough bandwidth and sufficient functional safety at an acceptable price point, linked together in a decentralized architecture (Figure 1). However, as a result, the cable loom has become the third heaviest and third most expensive component in the modern vehicle. And although there are plenty of wires available, the addition of new, differentiating features often demands yet another connectivity technology.

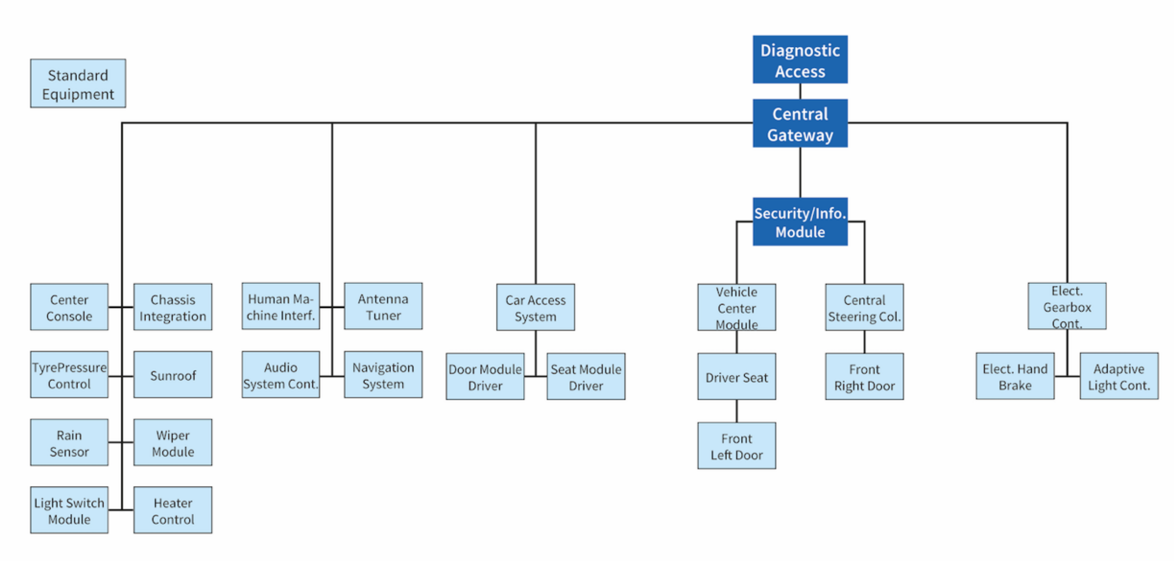

Figure 1 - The classic decentralized approach to the automotive E/E architecture no longer meets the needs of today's, increasing electrification of vehicles.

The reversing camera is a good example. A rear-mounted camera is engaged when the driver reverses, providing an image of the blind spot behind the vehicle. The natural output is the in-vehicle infotainment unit with its large colour display. However, in order to provide the higher bandwidth required for video transmission, most reversing cameras typically utilize low-voltage differential signalling (LVDS) technology, requiring the use of additional cables and connectors. Since the camera is at the vehicle's rear and the IVI unit is near the front, yet another long cable length must be accommodated. And this example is not an exception. New features often circumvent available networking pathways by using extra wiring.

As consumers have also become more accustomed to software updates and feature improvements over the life of products, such as with their smartphones, they have started to expect it for their vehicles too. Some OEMs, such as Tesla, are already addressing this need, selling software upgrades that enable additional features to a purchased vehicle without needing to visit the dealer. Processors, with their multicore capabilities, have also penetrated the automotive industry. Thus, thanks partly to vehicle electrification, the window is open for a complete overhaul of the E/E architecture.

The approach being taken is toward a zonal architecture (Figure 2). Each vehicle is equipped with one or two (for backup reasons) high-performance computers (HPC) and several powerful zone ECUs. These connect to a high-speed network tuned to the needs of automotive and based upon the well-established and understood Ethernet technology. Functionality, such as the control of Matrix-LED Headlights, is implemented in software. The inputs required, from cameras to steering wheel angle, are fed from sensors around the vehicle to the zone controller handling the Adaptive Driving Beam (ADB) function in software. From here, commands are issued to each headlamp cluster ECU. Should the software algorithm be improved, or a bug be found, this software function can be updated via an over-the-air (OTA) update.

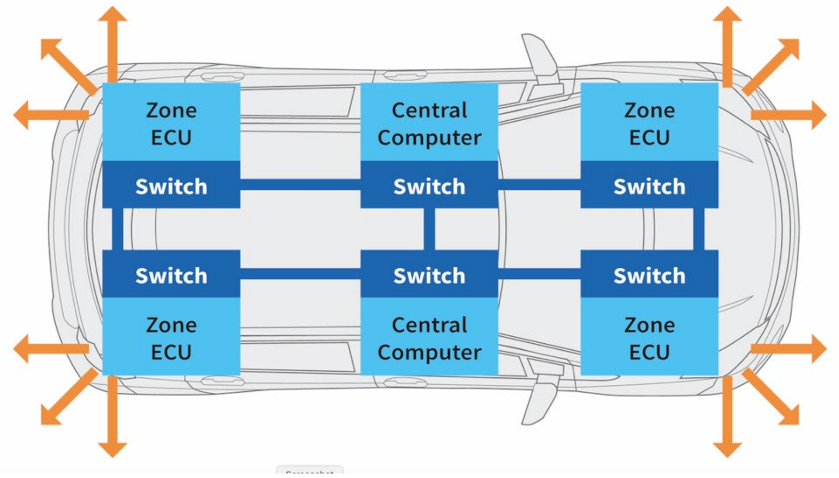

Figure 2 - In a zonal architecture, the bulk of the work is undertaken by central computers, or HPCs, linked via multi-gigabit automotive Ethernet with zone ECUs. Sensor and actuator ECUs are accessible via this high-speed, robust backbone.

Thus, the distance between sensors and zonal ECUs, and that between ECUs and actuators, becomes optimized. Reviewing our previous camera example, reversing or surround-view cameras are connected to their nearest zonal controllers. When the vehicle reverses, the IVI can acquire the camera's video data via the automotive Ethernet network with which all HPCs and ECUs are connected.

Ethernet Tuned to the Needs of Automotive

Ethernet is a well-established networking technology that has continuously been updated and revised to meet the demands of IT systems and Internet connectivity. However, this IEEE standard technology is primarily focused on reliable data delivery and less on end-to-end delivery timing requirements. But, because the necessary building blocks are commonly available on most microcontrollers (MCU) and SoCs, and there is a wealth of understanding for the technology amongst the engineering community, it made sense to build upon it to fulfil the needs of, amongst others, the automotive industry.

While classic Ethernet cables are required to transport data over tens to hundreds of meters and need protection for the environments where they are installed, the domain of the vehicle has other requirements. Maximum cable lengths of 15m are expected and, to save weight, four twisted pairs of shielded conductors are unnecessary. Thus, a single unshielded twisted pair (UTP) cable (T1) using point-to-point network topology is specified for automotive Ethernet implementations within the IEEE802.3ch MultiGBASE-T1 standard. To support this, a new specification for the physical layer has been developed to meet the demands of electromagnetic compatibility. Despite using unshielded UTP, data rates of up to 10GBits/s are supported.

New extensions to the Ethernet standard have been developed to ensure bandwidth can be reserved for video and audio data and to guarantee that connected nodes can operate synchronously. These fall into two groups: Audio Video Bridging (AVB) and Time Sensitive Networking (TSN).

AVB is primarily focused on features that ensure audio and video data arrive at their destination in time to be output correctly to speakers or a screen. This requires reserving bandwidth between nodes and the switches that connect them. IEEE 802.1Qav handles queuing and forwarding, which guarantees that bursts of other data do not overwhelm the network and disrupt time-sensitive data. IEEE 802.1Qat performs stream reservation to ensure that the end-to-end resources are in place in layer 2 to guarantee Quality of Service (QoS). Then there is IEEE 802.1AS, a subset of IEEE 1588. This provides a mechanism to share synchronization data from a grandmaster network node and all other nodes, thus implementing a common time base for sampling and outputting signals. Finally, IEEE 1722 packets help compensate for worst-time transport delays.

TSN also supports applications, such as closed-loop control systems, that have even tighter latency requirements and must offer high availability. These are implemented by IEEE 802.1Qbv, which blocks low latency traffic during defined time windows, and IEEE 802.3br, which targets latency reduction in mixed traffic environments. IEEE 802.1Qbu offers pre-emption methodologies in layer 2 to support this.

Finally, IEEE802.3az supports Energy Efficient Ethernet (EEE), allowing nodes to be placed into power-saving standby when there is no need to transfer traffic across the network.

The SoC Connectivity Bottleneck

As Ethernet started to establish itself in the automotive industry, few of the available SoCs included a suitable automotive Ethernet interface. Solutions such as Toshiba's TC9562XBG filled the gap, adding TSN- and AVB-capable automotive Ethernet via a PCIe interface. Today's SoCs increasingly support automotive Ethernet natively. However, as the responsibilities of HPCs and zonal controllers continue to grow, there is often a need for additional automotive Ethernet interfaces and PCIe connectivity. Driving this requirement are the use of PCIe modules, such as Car2Car or V2X, WiFi, cellular modems, NVMe flash storage, or additional computing power from an SoC, and the lack of a second Ethernet port on the SoC.

Toshiba has developed an advanced automotive interface bridge to resolve this connectivity shortage, the TC9563XBG (Figure 3). Thanks to its combination of PCIe Gen 3 interface and switch, coupled with dual TSN MAC Ethernet interfaces, it is the ideal complement to the powerful SoCs selected for HPCs and zone controllers. Provided in an automotive-qualified PBGA, this interface bridge is available in a 10mm ×10mm package with a 0.65mm ball pitch.

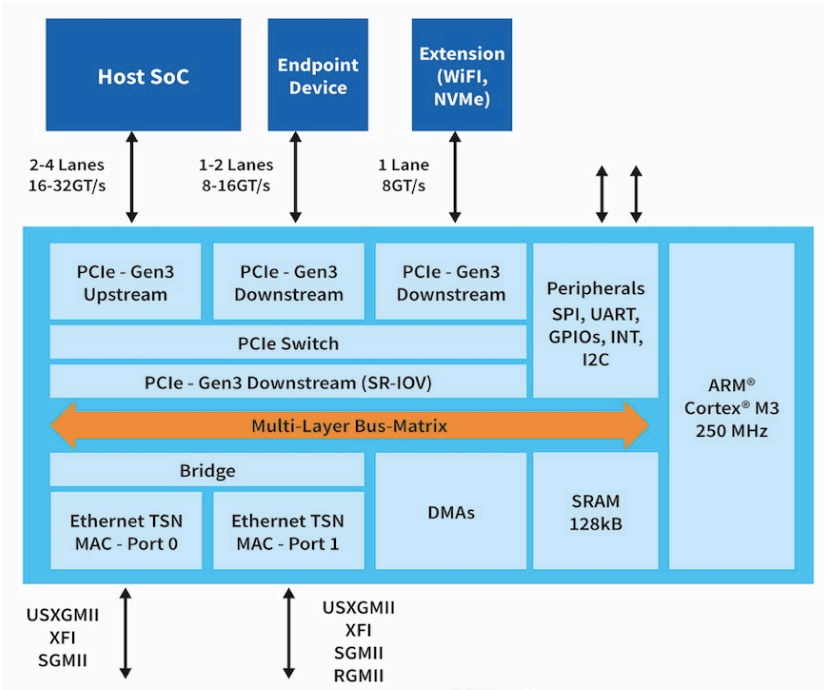

Figure 3 - The TC9563XBG automotive bridge interface offers a four-port PCIe switch with three external PCIe ports and two AVB/TSN capable Ethernet interfaces to extend the connectivity of powerful SoCs.

There are three external PCIe ports and one internal port. Of the three external ports, one is an upstream port that can get configured with up to 4-lanes (32GT/sec) to the host SoC. The external ports can be set up in a 4/1/1 (upstream/downstream/downstream) lane configuration, offering 32/8/8GT/sec, or a 2/2/1 lane configuration, supporting 16/16/8GT/sec (Figure 4). The switch integrates a reference clock for its downstream ports and provides support for power management.

PCI port setting	Upstream port	Downstream port0	Downstream port1
Setting A	4 lane (32GT/sec)	1 lane (8GT/sec)	1 lane (8GT/sec)
Setting B	2 lane (16GT/sec)	2 lane (16GT/sec)	1 lane (8GT/sec)

Figure 4 - Two setting options are available for the PCIe switch, enabling the upstream/downstream ports to support the demanded link speeds.

The internal PCIe downstream port functions as an endpoint for the two Ethernet ports. This port supports SR-IOV (single root I/O virtualization) with two physical functions (PF) and six virtual functions (VF), three for each Ethernet port. For application developers, this means that networking using virtualized operating systems (OS) can be easily supported.

Automotive Ethernet connectivity is provided via two AVB/TSN-capable ports that can be connected to the development team's chosen media-independent interface (MII) PHY solution. Each supports network speeds of 10Mb/sec to 10Gb/sec, but the MIIs supported by each port differ slightly as follows:

- Port A: USXGMII/XFI/SGMII
- Port B: USXGMII/XFI/SGMII/RGMII

The ports are full-duplex, offering eight queues for both transmit and receive with 46KB shared across the queues in each direction. By appropriately configuring an input pin on the TC9563XBG, the current gPTP timestamp can be captured. Furthermore, up to two outputs can be configured to generate a pulse train on this same timestamp.

The precise AVB and TSN support is as follows:

- IEEE 802.1AS - gPTP and synchronization, supported by the application processor software.
- IEEE 802.1Qav - forwarding and queuing for time-sensitive AVB streams.
- IEEE 1722 - transport protocol for audio/video streams in various formats.
- IEEE 802.3az - energy efficient Ethernet support (EEE).
- IEEE 802.1Qbv - enhancements to TSN traffic scheduling.
- IEEE 802.3br - traffic interspersing for TSN (planning).
- IEEE 802.1Qbu - frame preemption for TSN (planning).
- IEEE 802.1.Qbb - flow control to avoid packet loss during network congestion.

Configuration for the TC9563XBG is downloaded into memory mapped registers, while the firmware is downloaded via the PCIe interface by the SoC host at startup to the available 128kB of SRAM. The automotive interface bridge also features an Arm® Cortex®-M3 processor that can operate at up to 250MHz. It handles the configuration of the system but isn't involved in the transfer of data between PCIe lanes and the Ethernet ports. If required, it can provide additional functionality for the target application via its SPI, I^2C, and UART serial interfaces and its GPIO pins.

TC9563XBG Integration in Zonal HPCs and Telematics

To support the HPCs forming the central computing platform of modern vehicles, the TC9563XBG simply extends the PCIe interface of the chosen SoC. After the selection of suitable PHYs, this automotive interface bridge ensures reliable connectivity as part of the automotive Ethernet network. The additional PCIe interfaces then provide connections for NVMe flash storage and any additional processing power, such as a further SoC (Figure 5).

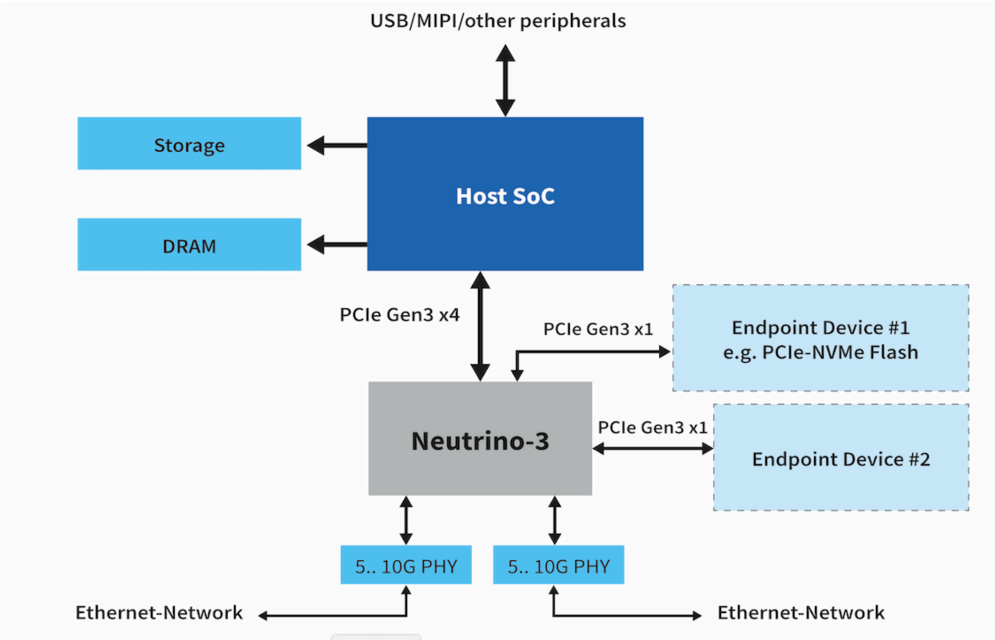

Figure 5 - TC9563XBG within (HPC) zonal ECUs provides the necessary high-speed link to the Ethernet car network

The challenges for telematics units, in-vehicle infotainment (IVI), and zone controllers typically differ slightly from HPCs. With the increased availability of PCIe for wireless modules, such as integrated WiFi and Bluetooth devices, 5G modems, or even V2X communication, the host SoC is often short of PCIe ports. The TC9563XBG's PCIe switch can accommodate PCIe devices while also providing one or two automotive Ethernet ports (Figure 6).

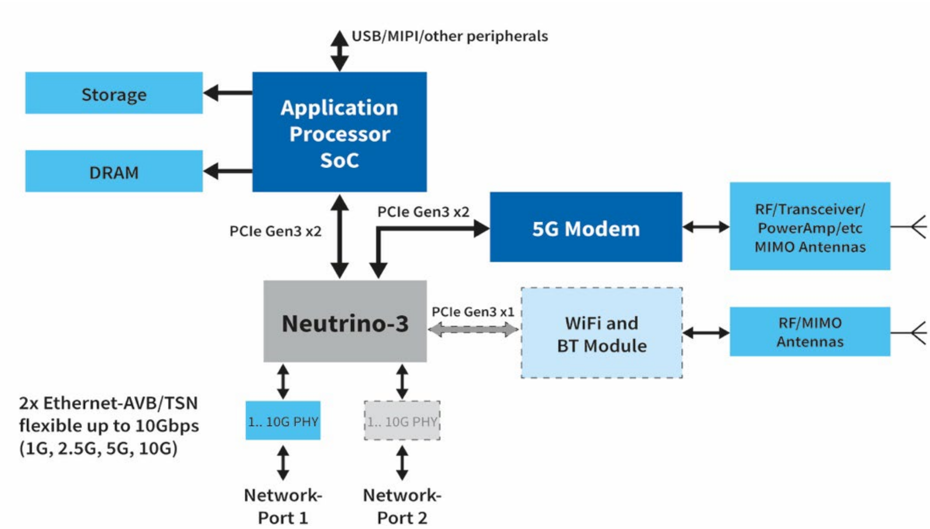

Figure 6 - In telematics applications, the automotive bridge interface offers PCIe connectivity to wireless modules. One or two automotive Ethernet ports are available according to the needs dictated by the application.

On the software side, drivers and sample applications for Linux and firmware can be provided on request. Additionally, along with the TC9563 Reference Board (Figure 7), Toshiba provides comprehensive engineering support for both hardware and software.

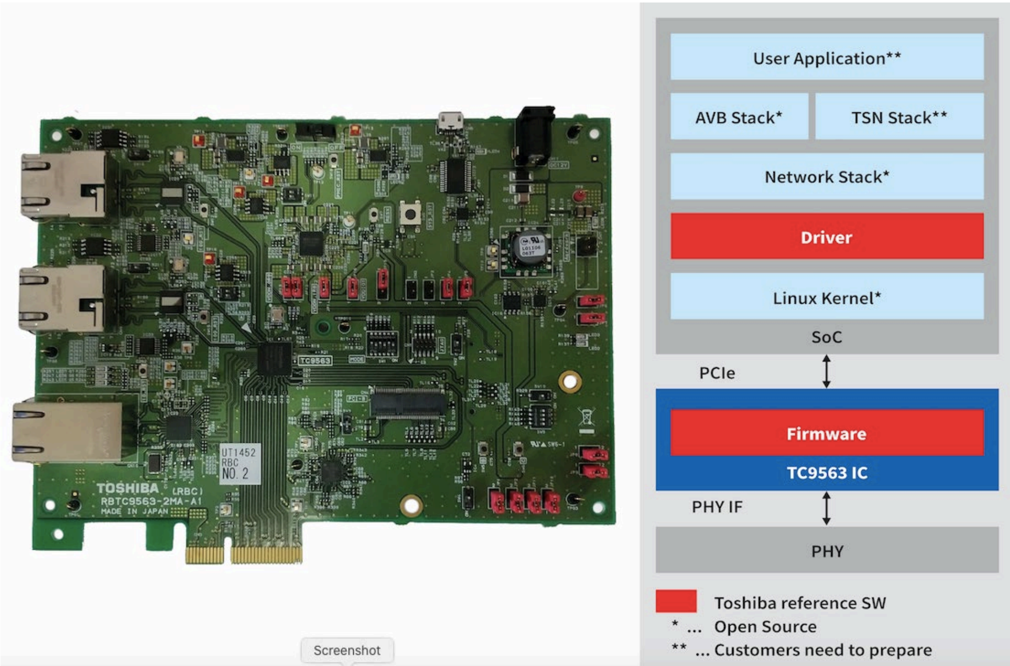

Figure 7: TC9563XBG Reference Board

Summary

The world of automotive is changing, and not just in the powertrain. With the vehicle's functionality increasingly being defined by its software, not just the mechanical hardware, new E/E architectures are required. A version of Ethernet, suited to the needs of automotive and operating at multi-gigabit data rates, is rapidly establishing itself, enabling these new architectures to be implemented. Constructed of powerful HPCs and zone ECUs, functionality will be distributed across them rather than having one function per ECU like the decentralized approach of the past. However, the SoCs available for these new types of ECU often lack the required connectivity, with a limit on the available Ethernet and PCIe interfaces. Toshiba's automotive interface bridge, the TC9563XBG, resolves this challenge thanks to its PCIe switch and two AVB/TSN Ethernet ports. Together with its compact PBGA automotive package and comprehensive software and development support, it is well suited to the needs of today's telematics, IVI, HPCs, and zone ECUs.

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