Improve Reliability and Redundancy of Automotive Ethernet Through Open Standards

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Ethernet technology is key to enabling advanced driver assistance system (ADAS) applications and autonomous driving because it offers low cost, low weight, and high data rate, plus is non-proprietary. To meet the safety and deterministic latency requirements for controlling a car, a new set of open standards is being developed that improve reliability, timing, redundancy, and failure detection of Ethernet-based applications so that this technology can be applied throughout an automobile.

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Making More Sophisticated Automotive Applications Possible

The automobile industry has a shared vision for Ethernet—using its advanced network architecture to enable progression of increasingly sophisticated applications, from infotainment to ADAS to control of mission-critical systems. Currently, Ethernet is being used for on-board diagnostics (OBD), firmware updates, and delivering video from surround-view cameras. The next stage is to use Ethernet to connect sensors to embedded CPUs, enabling sensor fusion for ADAS applications such as adaptive cruise control, lane assist, traffic sign recognition, pedestrian detection, and collision avoidance.

In the future, Ethernet will be used to directly control the powertrain and chassis for mission-critical functions such as braking, steering, transmission, and engine control—and eventually bring everything together for autonomous driving, as shown in Figure 1.

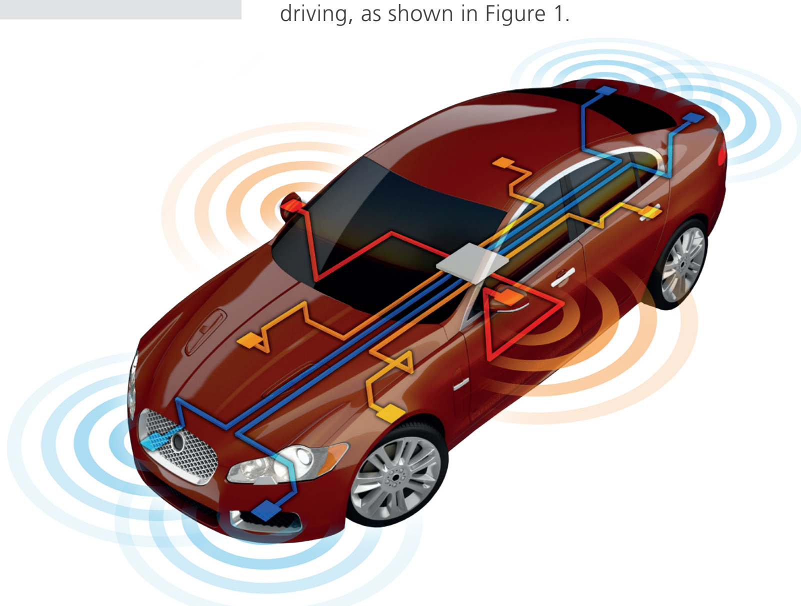

Figure 1: ADAS connecting systems for autonomous driving

Communication Protocol Requirements

More functionality means more requirements for connecting all the components in a car—particularly for bandwidth, safety and reliability, and latency.

Increasing the number of components—processors, cameras, and sensors such as radar—increases not only the bandwidth required, but also the need for reliable transfer of time-critical data. This requires provisions for deterministic and low latency, especially for mission-critical controls. For instance, dropping a packet in an application such as collision avoidance, leading to failure of timely braking, could be catastrophic. Similarly, autonomous driving will not be possible without system bandwidth sufficient to support data aggregation from multiple cameras and sensors.

From an Ethernet perspective, bandwidth primarily applies to the PHY layer. Reliability and latency primarily apply to the MAC layer.

Meeting Safety and Low-Latency Requirements

Open standards are being developed to meet safety, reliability, and latency requirements of future ADAS functions and autonomous systems. These standards ensure reliable and timely interoperation between all automobile components. To meet the safety and low-latency requirements for controlling automobiles, IEEE 802.1—the official standards body for Ethernet switching and data transmission control—is developing a new set of open standards, collectively referred to as time-sensitive networking (TSN) (Table 1). TSN enables low-latency, deterministic, and reliable transmission of synchronized packets. TSN is a superset of the audio-video bridging (AVB) standard, which describes how to guarantee bandwidth and enable data synchronization over Ethernet to ensure a high quality of service (QoS). It specifies precision of less than a microsecond and implementation that more than exceeds the requirements for many mission-critical functions.

Table 1: Main TSN Standards

Standard	Description
IEEE 802.1AS-Rev	Timing and Synchronization for Time-Sensitive Applications
IEEE 802.1Qbv	Enhancements for Scheduled Traffic
IEEE 802.1Qbu/ IEEE 802.3br	Frame Preemption
IEEE 802.1Qci	Per-Stream Filtering and Policing
IEEE 802.1CB	Frame Replication and Elimination for Reliability
IEEE 802.1Qcc	Stream Reservation Protocol (SRP) Enhancements and Performance Improvements (implemented in software)

IEEE 802.1AS-Rev—Timing and Synchronization for Time-Sensitive Applications

By introducing redundancy in the grand master clock and failure detection, standard IEEE 802.1AS-Rev makes setting the real-time clocks in the ECUs more reliable and addresses ISO 26262 functional safety requirements.

IEEE 802.1Qbv—Enhancements for Scheduled Traffic

The IEEE 802.1Qbv standard adds time-aware queue-draining procedures based on timing derived from the IEEE 802.1AS standard, allowing simultaneous support of scheduled traffic, credit-based shaper traffic, and other bridged traffic.

The standard adds transmission gates to the eight priority queues, which allow low-priority queues to be shut down to give higher priority queues immediate access to the network at specific times. This allows guaranteed access for high-priority, low-latency control frames, similar to time-triggered Ethernet previously specified by the SAE in 2011- AS6802, and enables periodic AV traffic transmission such as IEEE 1722 talker class A streams, which need frames to be transmitted every 125 microseconds.

IEEE 802.1Qbv introduces the concept of a guard band, which is a time period during which traffic cannot start transmitting to ensure control frames can be sent at their scheduled time. To support scheduled traffic, a time-aware shaper is needed to minimize communication latency and jitter. The higher priority class A data TA1-TA3, which is time-aware, is inserted between the two O1 frame fragments to minimize the latency. During the length of the guard band, the transmission of non-time-critical data is blocked to ensure that no new incoming time-aware (high-priority) data packets are delayed by other data O. Transmitted data is not just prioritized, but is now also deterministic—which is key for control systems.

IEEE 802.1Qbu and IEEE 802.3br—Frame Preemption

Preemption, as defined in IEEE 802.1Qbu and IEEE 802.3br, enables this guard band to be minimized, and a frame to be fragmented after its transmission has started. In other words, a higher priority frame can interrupt the transmission of a lower priority frame. The IEEE 802.3br standard defines the necessary encapsulation and checksums for the frame fragments, which have a minimum size of 64 bytes. Preemption and control of transmit queues concern traffic being transmitted on the egress port. Figure 2 illustrates an implementation of IEEE 802.1Qbu/IEEE 802.3br frame preemption by TA1, TA2, and TA3.

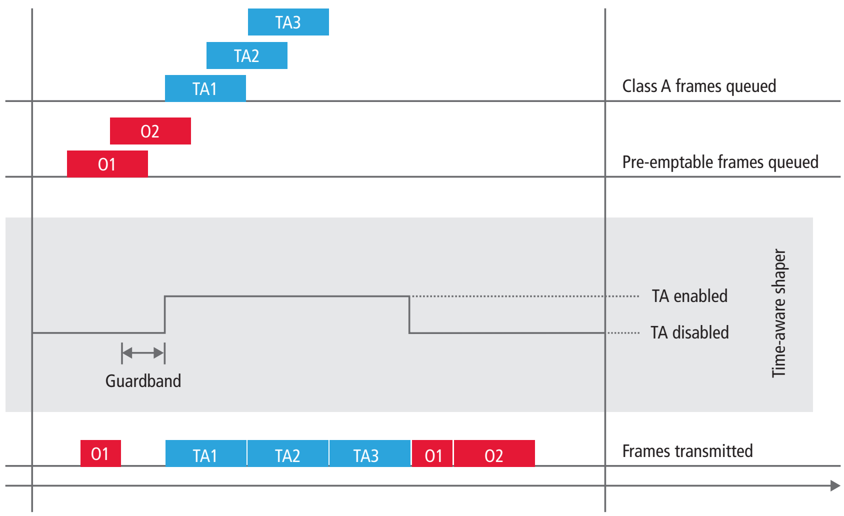

Figure 2: Sample timing diagram

IEEE 802.1Qci—Per-Stream Filtering and Policing

The IEEE 802.1Qci standard is at an early stage and concerns traffic being received at the ingress port. Its purpose is to mitigate the effects of nodes that operate incorrectly. It defines "policing and filtering functions that include the detection and mitigation of disruptive transmissions by other systems in a network, improving the robustness of that network."

IEEE 802.1CB—Frame Replication and Elimination for Reliability

The IEEE 802.1CB standard is also at an early stage and introduces seamless redundancy and failure detection, which is important for functional safety, as well as frame replication and elimination. For example, network nodes might be connected in a ring, with traffic being sent in both directions, requiring two separate paths to reach the destination. At the receiving node, the IEEE 802.1CB standard defines how the duplicate frames are eliminated. For functional safety, high-availability, redundant fault-tolerant design, and rapid failure detection are important. A ring topology is a way of introducing redundancy in the network. The IEEE 802.1CB and IEEE 802.1AS-Rev standards introduce methods for failure detection.

Using Cadence Ethernet MAC for Automotive Applications

For many years, Cadence has been offering Ethernet MAC products targeting automotive applications using AVB standards and more recently TSN standards. The Ethernet MAC supports transmit queues, with recently added support for the IEEE 802.1AS-Rev and IEEE 802.1Qbv standards by implementing a gate-on timer and a gate-off timer for each transmit queue.

Cadence has implemented a MAC merge sublayer (MMSL) module with two Ethernet MAC instances, one for the preemptable MAC (pMAC) and the other for the express MAC (eMAC), as shown in Figure 3. The eMAC is only required to support a single transmit queue. When preemption is disabled, the MMSL arbitrates between eMAC and pMAC on a frame-by-frame basis. The eMAC still has highest priority, but the frames transmitted from the pMAC will go out unmodified.

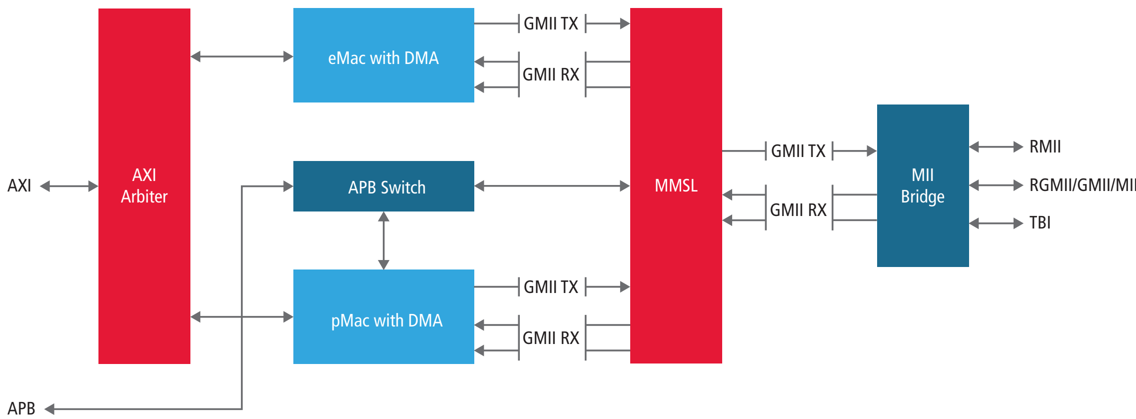

Figure 3: MAC merge sublayer

Cadence also offers a solution that supports the hardware requirements of preemption with IEEE 802.1Qbu. Cadence plans to add support for IEEE 802.1CB and IEEE 802.1Qci once the standards are more defined.

Conclusion

The new TSN standards as the next-generation AVB transport protocol provide the features required to fully address ISO 26262 requirements and expand the deployment of automotive Ethernet to safety-critical systems. TSN standards aim to improve the robustness, reliability, redundancy, and failure detection ability of Ethernet so that it can be used for real-time control and for safety-critical applications. As automotive Ethernet technology evolves, Cadence will continue to develop the Ethernet MAC product family to support the automotive industry.