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3. Time-Sensitive Networking in Automotive Embedded Systems

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ABSTRACT

A set of standards created by the Time-Sensitive Networking (TSN) task group introduce novel features to Switched Ethernet. The most recent and best model-based development methodologies for automotive embedded systems should seamlessly incorporate TSN. Software architecture modelling, timing predictability verification, simulation, and hardware realisation and deployment are a few of the key stages in these processes.

Due to the fact that networks differ according to their domains, Ethernet in automotive could lessen the network cacophony. "A domain-based architecture makes up the networking setup inside a car. By switching to Ethernet's zonal architecture, all of the network systems' gateways become unnecessary.

KEYWORDS

Time-Sensitive Networking, TSN, Ethernet, Automotive, Embedded System, Automotive Industry, automotive scenarios.

Introduction:

The Time-Sensitive Networking Task Group of the IEEE 802.1TM Working Group is developing a set of IEEE Standards Association (IEEE SA) standards with a focus on TSN. The specifications outline the methods for time-sensitive data transmission over deterministic Ethernet networks.

There is no single standard that addresses TSN. Instead, a number of different IEEE standards govern and control its collection of capabilities. With the help of profiles, TSN determines the precise set of features, options, configurations, and protocols that are suitable for a given set of TSN applications. While some profiles are clearly defined, others are still under development. [1]

Time Sensitive Networking:

Low latency, determinism, and guaranteed bandwidth are all requirements for automotive Ethernet, whereas these characteristics are not necessary for home or office use. It is now possible to create a deterministic Ethernet that ensures messages arrive at their destination in real time, or at the very least, within a specified window of time. Real-time networking is necessary as ADAS (advanced driver assistance systems) in automobiles advance. For the TSN version of Ethernet, IEEE and the industry have created standards and are still working on them. [2]

Table 1: The TSN Working group has introduced multiple standards.

TSN Standard	Specification Description
IEEE 802.1Qbv-2015	Time-aware shaper
IEEE 802.1Qbu-2016 and IEEE 802.3br-2016	Preemption
IEEE 802.1Qch-2017	Cyclic queuing and forwarding
IEEE 802.1Qci-2017	Per stream filtering and policing
IEEE 802.1CB-2017	Frame replication and elimination
IEEE P802.1AS-REV	Enhanced generic precise timing protocol

Source: Synopsys article "Ethernet Time-Sensitive Networking for Automotive ADAS Applications," John Swanson, Sr. Product Marketing Manager, Synopsys, 2018.

ADAS has to often synchronize with multiple systems in the car, requiring a lot of data to be deployed over the network. [3]

TSN in the Automotive Industry:

Modern automotive systems require high-bandwidth and low-latency in-vehicle communications in order to support driver features and functional advancements. For an increasing number of applications, automotive technology innovation is concentrated on both hardware and software, such as adaptive cruise control with stop-and-go, lane departure warning, blind-spot warning, traffic sign recognition, night vision, active headlight system, parking automation, efficient dynamics, hybrid engines, internet access, telematics, online services, Bluetooth integration, local hazard warning, personalization, SW update, and a host of others.

With the rapid development of fresh, cutting-edge features and, of course, the introduction of autonomous vehicles, this list keeps going and expanding.

Automotive systems are becoming more complex and require more and more source code, and embedded software is a key enabler for advanced functionality and features. Additionally, software complexity creates additional difficulties, including, to name just two, the need for timing predictability and the distribution of software across electronic control units (ECUs). [4]

Review of Literature:

High bandwidth and low latency requirements are met by the TSN standard. TSN, like Ethernet, also takes into account the security and safety requirements that permit its use in safety-critical applications. In their article, Ashjaei et al. (2021) [5] discuss recent advancements in the field of automotive embedded systems that mandate the use of TSN and provide a summary of how it is currently applied in these applications.

The features that distinguish TSN from conventional Ethernet have been highlighted. These include the potential for reliable clock synchronisation support, the capacity to set aside resources for various traffic types, the use of traffic prioritisation and traffic shaping, and general effectiveness.

They both agreed that incorporating TSN into the new development processes for automotive embedded systems is the best way to thoroughly examine its potential in the automotive domain. Future work will concentrate on IEEE 802.1Qcr-2020, a TSN sub-standard that calls for robust, bounded latency asynchronous shaping.

In [6], Zhao et al. (2021) make an effort to offer details that will aid researchers in choosing the best TSN sub-standards for the use cases. Various traffic shapers, including TAS, ATS, CBS, and Strict Priority (SP), are introduced by these standards. Numerous experiments were conducted in order to evaluate the quantitative performance of traffic shapers used alone and in combination. One of the parameters was the upper bound of delay, backlog, and jitter. They performed the first such quantitative analysis, to their knowledge. They came to the conclusion that SP shaper is better than CBS at reducing high-priority traffic transmission delays. CBS specifies bandwidth reservations at the same time for each priority traffic. In contrast to SP and CBS, ATS has a favourable impact on low priority traffic. while it has some limitations when considering high-priority traffic.

Since TSN is still a new technology, there aren't as many hardware and software tools available to support its use. Due to this, Krumacker et al. (2021) [7] made the decision to create and implement their own TSN mechanism based on a framework for network simulation. The created solution is very adaptable and suitable for many use cases. Since the ns-3 simulator enables them to achieve an implementation that will fit into its modular framework, they chose to use it.

Methodology:

It is necessary to perform a different Quality of Service (QoS) for traffic with different characteristics in this study of automotive TSN communication. A different traffic priority assignment or shaping mechanism denotes a different quality of service (QoS).

To guarantee the real-time performance of traffic, automotive TSN networks are primarily used. The traffic of various car scenarios can be mapped to various traffic classes if meeting the time constraint of the traffic is taken to be the primary goal of the design for automotive TSN networks.

In this case, only the timing constraints for the traffic class need to be stated, and the design goals can then be formulated in accordance with the requirements. According to Table 1:

Table 1: Correspondence between traffic types and automotive scenarios.

Traffic Class	PCP	Priority	Automotive Scenarios
TC8	7	Highest	Safety-related control signals, such as engine signals, brake signals, turn signals, Advanced Driving Assistance System (ADAS) control signals, etc.
TC7	6		Safety-related media signals, such as environmental perception sensor signals: millimeter-wave radar, lidar, ultrasonic radar, cameras, ADAS fusion data, real-time map download, positioning signals, etc.
TC6	5		Reserved
TC5	4		Network management signals, such as Precision Time Protocol (PTP) synchronization messages, network redundancy signals, network diagnostic signals, etc.
TC4	3		Vehicle to Everything (V2X) related events, warnings, alarm signals, dynamic network configuration signals, etc.
TC3	2		Non-safety-related control signals, such as lighting control, air conditioning control, door and window control, infotainment system control, etc., and vehicle status sensor signals: fuel battery consumption, water temperature, tire pressure signal, etc.
TC2	1		Non-safety-related media signals, such as audio and video signals of audio-visual entertainment systems, low-speed camera signals: reversing cameras, 360-degree surround-view cameras, head-up display signals (HUD), etc.
TC1	0	Lowest	Firmware Over the air technology (OTA) and software OTA, including offline map download, etc., cloud logging, uploading, diagnostic and configuration signals, and other Internet data access

Result and Discussion:

The methodology for the design of automotive TSN networks is formed, as shown in Figure 1, while the time constraint of traffic is taken as the primary objective. This methodology takes into account the design of automotive E/E architecture, software architecture, application scenarios, and the traffic characteristics in this scenario.

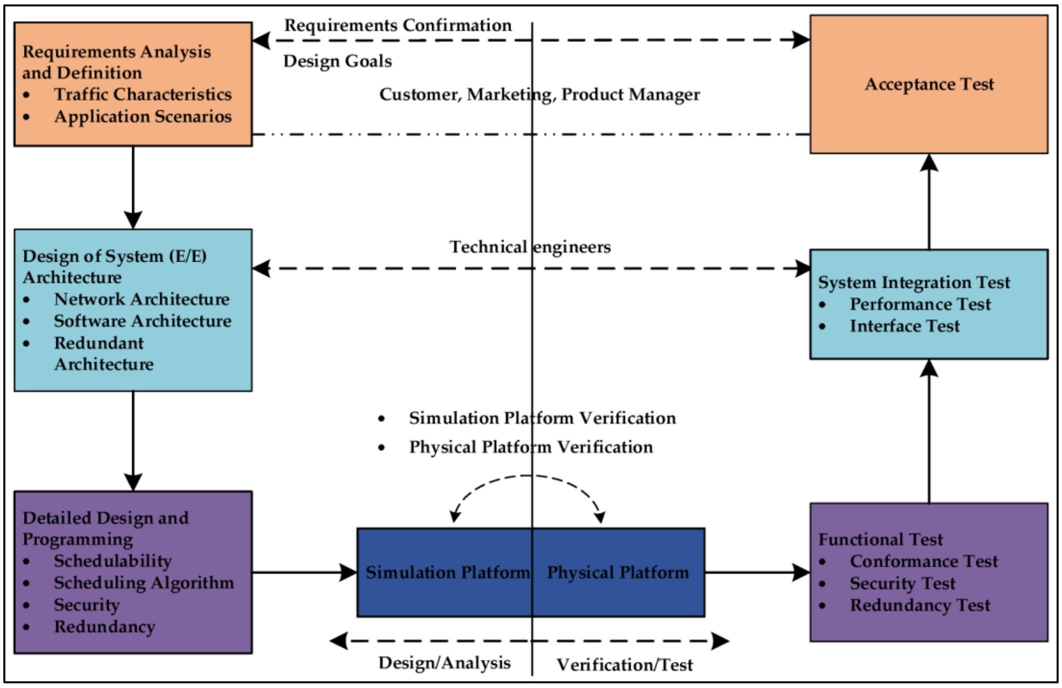

Figure 1: The methodology for the Design of Automotive TSN Networks

Figure 1 illustrates the main components of the design of automotive TSN networks. These components are: requirements analysis and definition; system design or E/E architecture; detailed design and programming; simulation platform verification; physical platform verification; functional test; system integration test; and acceptance test. [8-9]

Determining the application scenarios for the automotive TSN networks and all the traffic that needs to be transmitted with the necessary characteristics is the goal of requirement analysis and definition. Customers, market personnel, and product managers typically complete this portion of the work, while technical engineers are required for all other stages. Network architecture, software architecture, and redundant architecture make up the design of E/E architecture. The overall TSN system's structure is determined by the E/E architecture. The network in intelligent connected vehicles (ICVs) is a complex network that coexists with buses like Ethernet, CAN, and LIN as well as other networks. The E/E architecture also significantly affects how well the network performs. The star topology and the ring topology have different advantages and applicable scenarios.

Timing and synchronization for time sensitive applications:

An understanding of time that is shared by all devices in a network that expects deterministic packet transmission is necessary. All networked devices using the Best Master Clock Algorithm (BCMA) receive time distribution over Ethernet packets from the clock master or clock masters. A profile or closely defined subset of 1588v2 precision timing over packet is 802.1AS-Rev. Multiple time domains, two timescales (precision time protocol and arbitrary), and optional support for one-step in addition to two-step are all added by 802.1AS-Rev to 802.1AS. [10-11]

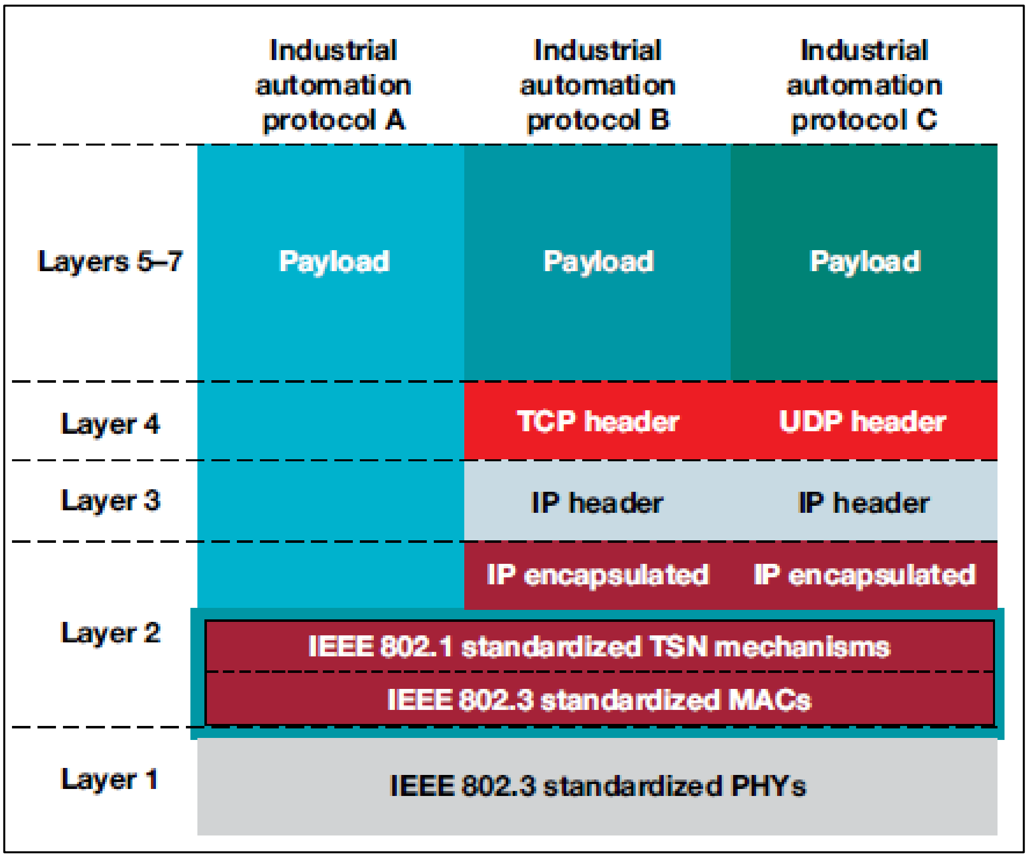

Figure 2: IEEE TSN and the Communications Stack

Time stamping of sent and received packets must be supported by the underlying hardware as closely as is practical. The hardware must also be able to add a time stamp to the packet as it is being transmitted in order for one step delay reporting to work. The transmit time stamp is included in a follow-up packet for two-step delay reporting, which can sometimes increase the packet load caused by time synchronisation over packet. [12]

Conclusion:

As TSN continues to gain interest and use across multiple industries, so too does the demand for an increasing number of profiles – the selection and use of TSN tools for specific applications. In this paper, how to design a perfect or optimal automotive TSN system has been discussed, and the automotive TSN design methodology is proposed from a global and holistic perspective. Different car manufacturers have different development models, and each model may also use different in-vehicle network systems. However, the design of any automotive TSN system can follow the methodology presented in this paper regardless of the differences existing in different companies or researchers. In the methodology, the correspondence between traffic types and traffic priorities is critical. The priority of the traffic determines the scheduling algorithm and different QoS. The core design goal of the automotive TSN system is meeting the timing constraints of each traffic.

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