White Paper

Time Sensitive Networking for Aerospace

Contents

The integration of Time Sensitive Networking (TSN) into the aerospace industry promises valuable developments in terms of determinism, real-time transmission, network convergence, and reliability. The IEEE is currently writing various industry profiles that will enable its use in the different fields of application. The first draft of the profile for aerospace (IEEE P802.1DP standard) was presented at the end of 2023, with the release of the final profile planned for the end of 2024.

This white paper highlights the integration of Time-Sensitive Networking (TSN) in the aerospace industry. It provides an overview of TSN standards and profiles and the IEEE P802.1DP standard relevant to aerospace applications. It also discusses key topics such as time synchronization, latency, resource management, and reliability in the context of TSN. Finally, the TSN IP cores from Fraunhofer IPMS and CAST are presented, which offer robust implementation and scalability for aerospace.

An overview of TSN

TSN consists of a set of standards that extend Ethernet network communication with determinism and real-time transmission. The standards enable real-time synchronization and deterministic data transmission with low latency and optimized jitter in a converged Ethernet network. They enable the use of standard Ethernet components for specialized solutions and central network control.

In addition to individual standards that serve different performance and functional requirements, work is currently ongoing to create profiles that describe how TSN should be used in individual industries. Each profile defines specific configurations and parameter sets for optimal use. These include topics such as time constraints, priority levels, network topology, and communication requirements. Six different profiles are currently being worked on:

- IEEE P802.1DP: TSN Profile for Aerospace Onboard Ethernet Communication
- IEEE/IEC 60802: TSN Profile for Industrial Automation
- IEEE P802.1DG: TSN Profile for Automotive In-Vehicle Communications
- IEEE P802.1CM: TSN Profile for Fronthaul
- IEEE P8021.DF: TSN Profile for Service Provider Networks
- IEEE P802.1BA: TSN Profile for Audio Video Bridging (AVB) Systems

In addition to the profiles, there are extensive TSN features that are not necessarily used in all TSN networks.

It depends on the network requirements for the individual areas of time synchronization, reliability, resource management, and latency.

Time synchronization

The time synchronization functions ensure a common time perception of all devices in the network. In general, it is based on the IEEE 1588 standard, which describes how nodes can synchronize their local time and maintain accurate clock synchronization with an accuracy of only a few nanoseconds. The 802.1AS standard includes selected options of 1588 and eliminates several variants to improve interoperability. Since 802.1AS-2020, it has also included support for multiple clocks and redundant clocks. For aerospace, in particular, the focus is on 802.1AS-2020 and extensions in 802.1DP to increase resilience through multiple time domains.

Latency

Latency is another key issue with TSN. Several features ensure low latency in the network for high-priority traffic versus low-priority, best-effort traffic.

The 802.1Qbv time-aware shaper uses different traffic classes assigned to time slots, helping to avoid bottlenecks in data transmission by minimizing the queuing effect in Ethernet switch transmission. To do this, the switch must be able to recognize frames with different priorities, a capability that is integrated in the Ethernet standard (VLAN Ethernet Frame Format).

In certain cases, the scheduler uses a protection band that prevents frames that are too large from passing through the time window. These are transmitted in the next permitted time window, which can lead to inefficient bandwidth utilization as it blocks the transmission of low-priority frames in the queues. For this reason, 802.1Qbu specifies how higher-priority frames can interrupt the transmission of lower-priority frames. This means that the lower-priority frames are fragmented into pieces and reassembled at the receiving end. This can improve the latency in the data transmission of high-priority frames, as high-priority traffic passes through the network preferentially.

The 802.1Qav – Credit-Based Shaper defines an algorithm that prioritizes data streams with real-time requirements over best-effort traffic. The shaper assigns a credit or send credit to data streams. As long as the send credit is in the positive range, data packets with reserved bandwidth are transmitted preferentially. The send credit decreases with each preferred transmission until it finally becomes negative. As soon as a negative value is reached, the best-effort data packets in the queues are transmitted. If this delays the forwarding of data packets with reserved bandwidth, the send credit increases accordingly. In this way, the delivery of frames with high priority is ensured via the best-effort traffic, which in turn reduces the latency for frames with high priority.

Resource management

The resource management area includes functions that can be used to manage the TSN network. The 802.1Qat stream reservation protocol enables devices to request and reserve network bandwidth to ensure sufficient capacity for real-time or critical data streams. The 802.1Qcc standard defines management interfaces and protocols for TSN networks to set up switches and other devices in the network. The standard covers centralized, decentralized, and hybrid models that can be used depending on the network administrator's preferences. The 802.1AB standard describes a protocol that can be used to determine the topology of the network. This means a device can use this protocol to find out which other devices are in the network. This is known as the link layer discovery protocol.

Reliability

This area includes functions that increase the reliability of the network and reduce the risk of communication errors. The 802.1CB- Frame Replication and Elimination helps to ensure delivery even in the event of a defective network path. The standard describes how packets are duplicated at the sender and how it is ensured that the copies follow separate paths through the network. This increases the probability that a packet will get through the network, even if one of the paths is defective. This minimizes problems with broken or loose cable connections, for example. This function is bandwidth-intensive, as multiple copies are sent over the network for transmission. 802.1Qci, therefore, prevents data traffic overload and improves the robustness of the network. This is ensured by securing that the data traffic complies with certain rules before it is distributed in the network, thus protecting the network from incorrect or faulty data traffic. Redundant transmission is typically generated by TSN switches or redundant TSN endpoints with multiple ports.

TSN for aerospace applications

Low latency times and time synchronization have always been decisive factors in the aerospace industry due to safety requirements, which is why TSN has great potential in these sectors. The communication protocols currently in use, such as Spacewire, MIL-STD-1553, or ARINC-664, do not offer the same advantages as TSN in comparison. Some of them have yet to evolve to meet the increasing demand for more bandwidth due to the higher volumes of data generated. The increasing amount of data is partly due to the fact that more sensors and devices are being used, but also because every sensor and every device in the network today requires more bandwidth for data acquisition and processing. The ARINC 664 protocol is based on Ethernet and supports high bandwidth but does not contain a common time concept and, therefore, cannot be used for time-critical messages without further effort.

The 802.1DP profile defines the configuration and functional options for the aerospace sector to ensure interoperability. It is currently being developed as a joint project between IEEE and AE Avionics Network, with many other partners from the aerospace industry participating. Aerospace includes many different application areas such as commercial aircraft, but also military aircraft and satellites. The profile consists of both a synchronous and an asynchronous profile. The synchronous profile must be used for time-critical data. The asynchronous profile is intended for non-time-critical data traffic and does not support time synchronization. These applications are currently covered by Ethernet networks in the aerospace industry. Work on this profile focuses on the safety-critical features of aerospace. The first draft is currently under review, and the profile is expected to be published in 2024.

TSN offers benefits to the aerospace industry. One of the most important is lower equipment costs, as less expensive Ethernet components can be used for the networks. The convergence of networks also plays a major role. This will reduce the number of isolated network islands within an aircraft and facilitate data access across devices. As in other industries, TSN can save cabling, which can lead to lower weight.

Aerospace networks and requirements

In current aerospace network architectures, the main focus is on safety features. As a rule, these networks are based on communication domains with different requirements in terms of determinism and bandwidth (see Table 1). Accordingly, these domains are currently served by different communication protocols that can meet the respective requirements. Each of these domains usually requires a connection to ground-based computer networks, which can be shared if necessary.

A complicating factor in the industry is that while certain domains can be assumed to be present in every aircraft, there is a wide variety of systems and network architectures in use. This means that the characteristics within the domain can only be described in general terms.

Passenger aircraft

Aircraft Domain Control (ACD) consists of systems and networks that ensure the flight is safe. This includes all flight control systems such as instruments, engine control, autopilot, warning systems for the crew, and much more. This domain has high demands on determinism, as many of these systems require strict synchronization via the network. The bandwidth requirement, on the other hand, is rather low.

The second domain is the Airline Information Service Domain (AISD), which covers data that is not directly necessary for the safe monitoring and control of the aircraft. This domain has medium requirements regarding determinism, as although no safety-critical data is processed, safety-relevant information must still be provided. This includes, for example, safety instructions for passengers, but also functions such as aircraft monitoring and diagnostics and communication with the ground station to transmit weather information and other flight data.

The third domain is the Passenger Entertainment and Network Services Domain (PIESD), which basically handles network and entertainment services for passenger services. This includes audio and video transmission, passenger WiFi, light and temperature control, and much more. This domain is characterized by a low requirement for determinism and higher bandwidth requirements.

Military aircraft

Aircraft used for military purposes are usually divided into two domains. The designations can vary depending on the type of aircraft. The domain that covers the data areas necessary for the safe control and monitoring of the aircraft, similar to the ACD for passenger aircraft, is often referred to as the Air Vehicle System for unmanned aircraft, for example.

The second domain, which is often called the Mission System, can be used for different applications depending on the type of aircraft. This can include, for example, weapon systems, video radar, and various other sensor systems through to mission planning. This domain also places high demands on determinism and bandwidth.

Satellites

The last type of vehicle is the satellite, which also contains a flight control system, called a platform control system, with high determinism requirements. There is also the payload network, which includes communications, transponders, cameras, scientific research instruments, and more. These instruments can, in turn, require a high bandwidth, and determinism is generally not very relevant.

Fraunhofer IPMS TSN-IP Cores

Figure 1 shows the TSN IP cores developed at Fraunhofer IPMS and available for licensing through our partner CAST. The TSN-IP family consists of three different IP cores. The TSN core function for timing synchronization (IEEE 802.1AS-2020), traffic shaping (IEEE 802.1Qav and IEEE 802.1Qbv), and frame preemption (IEEE 802.1Qbu and IEEE 802.3br) are implemented in hardware to ensure precision and reliability. All IP cores implement a real-time Ethernet MAC with low latency (LLEMAC).

- TSN-EP: TSN Endpoint
- TSN-SE: TSN Switched Endpoint
- TSN-SW: TSN Multiport Switch

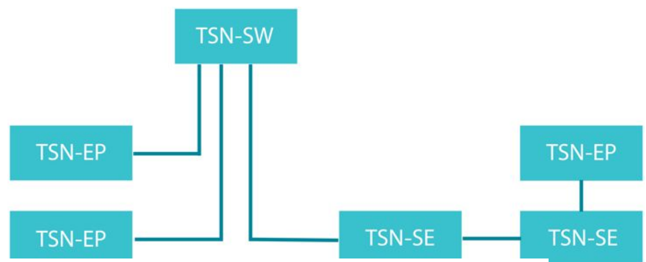

Figure 1 - Fraunhofer IPMS TSN IP Cores

Aircraft Domain	Function	Determinism Latency	Bandwith
Passenger Aircraft			
Aircraft Domain Control (ACD)	Flight Control	high	low
Airline Information Services Domain (AISD)	Flight and aircraft information services	medium	medium
Passenger Entertainment and Network Services Domain (PIESD)	Passenger entertainment and services	low	high
Military Aircraft			
Air Vehicle System	Flight Control	high	high
Mission System	Mission Control	high	high
Satellites			
Platform Control	Flight Control	high	low
Payload Network	Scientificor technological equipment	low	high

Table 1 - Aircraft Domain Requirements

The TSN-EP adds TSN functionalities to devices that act as endpoints in a network. This component can also be regarded as a TSN MAC.

The TSN-SE extends two endpoints with switching functionality and thus enables the integration of switched endpoint devices into TSN networks. This enables daisy-chaining of devices or ring architectures, as well as functionally secure operation using redundant links in accordance with IEEE 802.1CB (redundant endpoint). The design implements a 1GbE switch bar with cut-through architecture and is characterized by very low deterministic input and output latencies.

The TSN-SW is suitable for multi-port switch devices that are to be integrated into a TSN Ethernet network. The ports can be scaled up to 24 external ports. The switch supports Ethernet bridging functions according to IEEE 802.1Q-2018 and has a configurable number of ports, operates in cut-through mode at line speed, and can offer a port-to-port latency of one microsecond. The core is, therefore, suitable for applications with demanding real-time requirements.

All these TSN IP cores are available through our partner CAST in RTL source code or netlists optimized for FPGA devices. The scope of delivery includes everything required for a successful implementation, including example synthesis and simulation scripts, an extensive testbench, and comprehensive documentation.

The extension of the IP cores to 10G to meet the increasing data throughput requirements is currently in progress. The TSN-EP and the integrated Low-Latency Ethernet MAC (LLEMAC) are already available in the 10G version.

About Fraunhofer IPMS

The Fraunhofer-Gesellschaft, based in Germany, is the world’s leading organization for application-oriented research. With its focus on future-relevant key technologies and the utilization of the results in business and industry, it plays a central role in the innovation process.
The Data Communication and Computing (DCC) division has been developing and licensing IP cores for licensees worldwide for more than two decades. Its expertise ranges from the provision of IP core modules for licensing to individual customization, as well as support during implementation. IPMS offers comprehensive Ethernet solutions for various applications.

About CAST

Computer Aided Software Technologies, Inc. (CAST) is a silicon IP provider founded in 1993. The company’s ASIC and FPGA IP product line includes microcontrollers and processors; compression engines for data, images, and video; interfaces for automotive, aerospace, and other applications; various common peripheral devices; and comprehensive SoC security modules.

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