TSN (Time-Sensitive Networking) – IEEE 802 Ethernet becomes real-time capable

Ethernet has become an indispensable part of industrial automation technology. This communication technology, which is standardized in IEEE 802, has earned wide acceptance due to its uniform technical basis, the associated interoperability, and its suitable scalability properties. However, there is one application area that standard Ethernet has been unable to penetrate so far: network communication with hard real-time requirements.

In order to cover this field of application in the future with a solution for real-time Ethernet that is standardized in IEEE 802 and accepted in the market, the Time-Sensitive Networking (TSN) task force was established at IEEE 802.1. The aim of this group is to extend existing Ethernet standards to achieve a degree of determinism that meets the hard real-time requirements of modern control networks in industrial automation and the automotive industry. This article offers a compact overview of the key components that are currently being developed within these TSN activities.

Key TSN components

The standards specified in the TSN task force can be roughly split up into three categories that are of primary importance for the overall TSN system:

- Time synchronization forms the indispensable foundation for the clocked end-to-end transmission of communication flows with hard real-time requirements.
- Scheduling and traffic shaping allow the joint transmission of data flows with hard or soft real-time requirements as well as traditional best-effort traffic in a convergent network infrastructure.
- Mechanisms for flow reservation and (redundant) path selection ensure that latency and reliability requirements are met for time-critical control flows.

The foundation: High-precision time synchronization

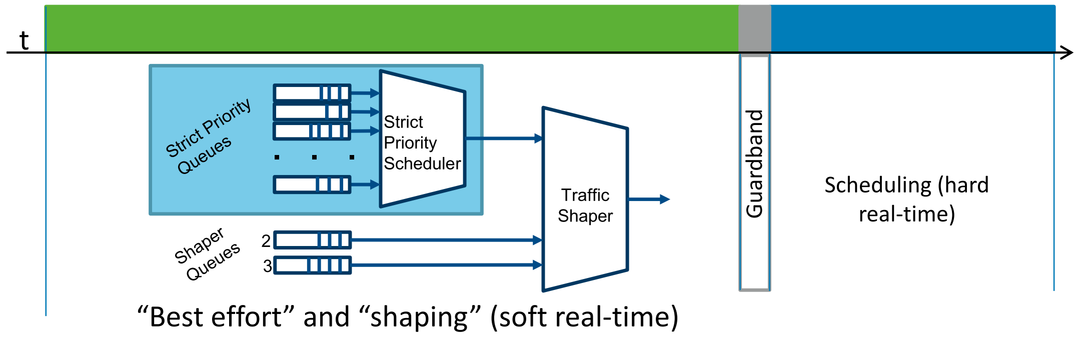
In order to transport data flows with hard real-time requirements in an Ethernet network with fixed cycles, high-precision time synchronization of all involved devices is essential. In TSN, this is achieved either through the use of the newly developed IEEE P802.1AS-Rev standard or through the use of the tried-and-tested IEEE 1588-2008 technology.

Real-time capable scheduling for soft and hard real-time

In addition to time synchronization, TSN offers mechanisms for scheduling and shaping network traffic. This enables the coexistence of different traffic categories within a single network infrastructure. For best-effort data traffic, the familiar, strict priorities in accordance with IEEE 802.1Q are used. However, one of the problems with this type of prioritization is that the sequence for data packets of equal priority cannot be influenced. Additionally, a data flow with high priority can block all other priorities on a permanent basis. Therefore, further prioritization mechanisms are required for time-critical data flows.

In TSN, shaping caters to network traffic with predictable transmission characteristics and soft real-time requirements. The related standard, IEEE 802.1Qav, defines a credit-based shaper (CBS), which prioritizes soft real-time flows over best-effort traffic in compliance with certain fairness criteria. Thus, CBS and strict priorities can already fulfill the requirements of many applications.

However, there are areas of application, particularly in the area of industrial automation and the automotive industry, that require even smaller as well as guaranteed worst-case latencies and jitter. Therefore, with TSN, cyclic transmission time windows (IEEE 802.1Qbv) are installed along the data path for time-critical data flows. During these windows, the time-critical data flows can be transmitted without hindrance (see picture 1). In addition, a guard band is set up that ensures that no data is allowed on the transmission path immediately prior to the time-critical transmission. The resulting bandwidth reduction induced by this guard band can be reduced to a minimum through the use of frame preemption (IEEE P802.1Qbu and IEEE 802.3br), i.e., the interruption of a data packet in favor of a more highly prioritized packet.



Picture 1: Connection between scheduler, CBS and "best effort"

Exceeding the baseline: Stream management and fault tolerance

Compliance with the requirements of individual applications regarding timing behavior and reliability constitutes the core of TSN. In order to ensure these characteristics, applications must register the corresponding data flows prior to their transmission. The identification, registration, and management of suitable paths can be a challenge, especially in larger networks and in conjunction with fixed transmission windows for different streams. To support the identification, registration, and management of suitable paths, TSN defines a set of mechanisms and interfaces in IEEE P802.1Qcc.

The reliability of data flows, especially in the event of errors, is also of great importance for many TSN application scenarios. For this reason, mechanisms are defined in IEEE P802.1CB and IEEE P802.1Qca that allow replication and redundant transmission of data over several disjunctive paths. Importantly, the redundancy properties achieved by these mechanisms are transparent for the communicating applications.

Timeline of the IEEE 802.1 standards and conclusion

TSN incorporates a series of standards that, combined, fulfill the requirements with respect to hard real-time data transmission. Due to the different time lines of the individual standards, the full functional scope of TSN will only be available in the course of the next few years. However, with IEEE 802.1Qbv-2015, the first standard of the TSN series is already available. Along with IEEE 802.1Qav for soft real-time requirements and IEEE 1588 for high-precision time synchronization, this TSN standard concerning transmission scheduling already allows performing the core tasks of TSN, even today.

Hirschmann Automation and Control GmbH is actively engaged in the TSN standardization process and works on supplying its customers with industrial networking equipment offering TSN functionality in the near future.

Authors

Brief vita: Dr. Oliver Kleineberg

Dr. Oliver Kleineberg has worked for Belden, Inc., since 2007 and has been head of the Advance Development unit of Hirschmann Automation & Control GmbH – which is part of Belden's industrial IT platform – since 2015. In 2012 and 2013, he was responsible for the integration of the Tofino Security technology into Belden's Industrial Communication Portfolio. Furthermore, he has been part of various IEEE 802, IEC and ODVA task forces for many years and has made a significant contribution to industrial communication protocol specifications such as HSR and TSN. He studied Computer Engineering at the Esslingen University of Applied Sciences in Germany and received his PhD in Computer Engineering from the University of Limerick, Limerick, Ireland.

Brief vita: Stephan Kehrer

Stephan Kehrer has worked for Belden, Inc., since 2007. Since 2012, he has worked in the Future Technologies unit of Hirschmann Automation & Control GmbH, which is part of Belden's industrial IT platform. He has devoted himself mainly to the analysis and evaluation of new and future technologies in the area of industrial communication. He is involved in several research projects and is a member of various task forces of the IEEE 802 and IEC. His focus within the IEEE 802 is on the topic of time-sensitive networking (TSN). He completed his studies in computer sciences at Eberhard Karls University Tübingen, Tübingen, Germany.