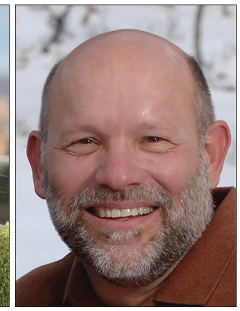
Time-Sensitive Networking Standards



János Farkas Lucia Lo Bello Craig Gunther

IEEE 802.1 Time-Sensitive Networking (TSN) makes it possible to carry data traffic of time-critical and/or mission-critical applications over a bridged Ethernet network shared by various kinds of applications having different Quality of Service (QoS) requirements, i.e., time and/or mission critical TSN traffic and non-TSN best effort traffic. TSN provides guaranteed data transport with bounded low latency, low delay variation, and extremely low data loss for time and/or mission critical traffic.

By reserving resources for critical traffic, and applying various queuing and shaping techniques, TSN achieves zero congestion loss for critical data traffic. This, in turn, allows TSN to guarantee a worst-case end-to-end latency for critical data. TSN also provides ultra-reliability for data traffic via a data packet level reliability mechanism as well as protection against bandwidth violation, malfunctioning, malicious attacks, etc. TSN includes reliable time synchronization, a profile of IEEE 1588, which provides the basis for many other TSN functions.

These features make TSN applicable and economical for various use cases. TSN can be used in various verticals, e.g., in industrial automation networks being developed for Industry 4.0, in mobile networks for 5G, in networks for critical machine-to-machine communication, for new networking approaches in vehicles including support for autonomous driving, and many more, with a constantly expanding list.

Standardization of this work was started as IEEE 802.1 Audio Video Bridging (AVB), which is successfully deployed for various applications today, e.g., professional audio and video studios, and automotive infotainment. AVB then evolved into IEEE 802.1 TSN to reflect the expanded scope of the work. The standardization of TSN is an ongoing effort in IEEE 802.1; new TSN features are being developed as the application of TSN is expanding, and further standardization contributions are expected.

This special issue of the *IEEE Communications Standards Magazine* provides an introduction and overview to TSN; furthermore, it explains the applicability of TSN in some use cases, e.g., industrial automation, automotive networks and mobile fronthaul.

The first article, "Introduction to Time-Sensitive Networking" authored by Norman Finn, provides an introduction to TSN. It explains how TSN differs from other types of packet services and describes in detail the essential features of TSN. The article also lists use cases for TSN and collects the relevant standards.

The second article, "Time-Sensitive Networking: An Introduction" authored by John L. Messenger, describes the tools in the TSN toolset and explains in detail the TSN standards to provide bounded low latency and zero congestion loss. Furthermore, the article looks out to gaps and next steps in TSN standardization.

The third article, "Distributing Deterministic, Accurate Time for Tightly Coordinated Network and Software Applications: IEEE 802.1AS, the TSN profile of PTP: Concepts and Applications" authored by Kevin B. Stanton, provides a description of time synchronization, which is one of the essential features of TSN. In particular, the article describes the TSN time synchronization standard: the generalized Precision Time Protocol (gPTP) specified by IEEE 802.1AS, which is a profile of the IEEE 1588 Precision Time Protocol. Furthermore, the article provides details on time transfer on IEEE 802.3 Ethernet links and on IEEE 802.11 Wireless LANs, i.e., both over wired and wireless links. The article also describes further considerations, e.g., application of gPTP, security aspects, possible enhancements, and interoperability.

The fourth article, "Traffic Planning for Time-Sensitive Communication" co-authored by Wilfried Steiner, Silviu S. Craciunas, and Ramon Serna Oliver, provides detailed description of network planning when IEEE 802.1 Qbv Enhancements for Scheduled Traffic, one of the key TSN tools to provide controlled latency, is used in a network. The article describes 802.1Qbv and its relationship to other time-based transmission and queuing techniques. All these techniques require time synchronization, e.g., 802.1AS. The article also describes how to provide a schedule for a given traffic pattern supported by a particular network. Both industrial automation and automotive applications are considered by the authors of the paper.

The fifth article, "Design Aspects of Low Latency Services with Time-Sensitive Networking" co-authored by Csaba Simon, Markosz Maliosz, and Miklós Máté, describes the details, benefits, and applicability of two TSN tools to provide bounded latency: IEEE 802.1 Qbv Enhancements for

Scheduled Traffic and frame preemption specified by IEEE 802.3br and IEEE 802.1Qbu. The article describes the application of these two tools to two use cases: industrial automation and mobile fronthaul.

The sixth article, "Enabling Fog Computing for Industrial Automation through Time-Sensitive Networking (TSN)" co-authored by Paul Pop, Michael Lander Raagaard, Marina Gutiérrez, and Wilfried Steiner, involves higher-layer aspects such as network configuration and fog computing to leverage TSN for industrial automation. The article explains the TSN configuration architecture specified by IEEE 802.1Qcc and how fog computing can be applied together with TSN. The article provides details of configuration and reconfiguration of IEEE 802.1 Qbv Enhancements for Scheduled Traffic via a case study.

The seventh article, "Level 5 by Layer 2: Time-Sensitive Networking for Autonomous Vehicles" co-authored by Soheil Samii and Helge Zinner, provides a view of the application of the TSN standards to automotive networks, which fosters the evolution of autonomous vehicles. The article describes the essential TSN features for automotive networks. The article also describes the application details of key TSN standards to the automotive use case in light of the needs of autonomous driving.

Clearly, there is real interest in TSN from various industries. The work on providing the details for the application of the TSN standards to various verticals is ongoing. For instance, the work has been recently finished on the IEEE 802.1 CM TSN profile for fronthaul to connect a cellular network's radio equipment to their remote controller. Another recent initiative is a joint project of the IEC and IEEE 802 to specify TSN Profile for Industrial Automation (IEC/IEEE 60802). TSN has a key role as a common denominator to provide converged networks for Industry 4.0, where the convergence of operations technology and information technology is a necessity, especially in light of the introduction of cloud to industrial automation. Furthermore, new TSN techniques can be specified if needed for a particular use case. We are still in an early phase; there is more to come and the application of TSN will get wider.

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Biographies

János Farkas (janos.farkas@ericsson.com) is senior specialist of deterministic networking at Ericsson Research. He is the Chair of the IEEE 802.1 Time-Sensitive Networking (TSN) Task Group, has been the Editor of IEEE P802.1CM TSN for Fronthaul and IEEE 802.1Qca Path Control and Reservation, one of the main contributors to IEEE 802.1aq Shortest Path Bridging, and an active contributor to various IEEE 802.1 standards. He is a Co-Chair of the IETF Deterministic Networking (DetNet) Working Group and co-author of multiple drafts. His recent focus is deterministic packet networking. He has also been working on carrier networks. His former research activities include IP QoS solutions for radio access networks and network traffic management. He has a number of patents and research papers in the area of telecommunications networks. He has Ph.D. and M.Sc. degrees in electrical engineering from Budapest University of Technology and Economics.

Lucia Lo Bello (lobello@unict.it) is a tenured Associate Professor with the Department of Electrical, Electronic and Computer Engineering, University of Catania, Italy. She received the M.S. degree in electronic engineering and the Ph.D. degree in computer engineering from the University of Catania, Catania, Italy, in 1994 and 1998, respectively. She was also a Guest Professor at the University of Malardalen, Sweden, in 2014. During the academic year 2000 to 2001, she was a Visiting Researcher with the Department of Computer Engineering, Seoul National University, Korea. She has authored or coauthored more than 140 technical papers in the area of automotive communications, industrial networks, real-time embedded systems, and wireless sensor networks. She is responsible for several international and national projects in the area of real-time embedded systems and networks. She is a Senior Member of the IEEE and was the Chair of the IEEE Industrial Electronic Society Technical Committee on Factory Automation for two terms (2014–2015 and 2016–2017). She is the current IES representative within IEEE Women in Engineering.

Craig Gunther (craiggunther@yahoo.com) is a consultant focused on helping companies integrate TSN into their products and offerings. Previously, Craig was a Distinguished Engineer with Harman International's Corporate Technology Group, responsible for research and development of new technologies. He was the editor of the IEEE 802.1 Stream Reservation Protocol (SRP), one of the core standards in the Audio-Video Bridging (AVB) Systems profile, the predecessor of today's TSN standards. As an IEEE Senior Member and secretary of the IEEE 802.1 TSN Task Group, he continues to be involved in TSN development. His participation in the Avnu Alliance was instrumental in creating their Conformance and Interoperability program for AVB systems, resulting in Harman International's Crown DCi 8|600ND Amplifier becoming the first Avnu certified endpoint. Prior to his work at Harman International, he was a Distinguished Member of Technical Staff with Lucent Technologies, and earlier with Ascend Communications, where he worked on high density remote access servers that were critical to the Internet's growth during the late 1990s.