Time Sensitive Networks - Update from the IIC Testbed for Flexible Manufacturing

Paul Didier
Manufacturing Solution Architect
Cisco Systems

Rick Blair
Principal Network System Architect
Schneider Electric

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Abstract

The IIC's TSN for Flexible Manufacturing testbed looks to enable Industrial IoT and Industrie 4.0 through deployment of open, standard, deterministic networks within production facilities. The goal is to display the value and readiness of Time-Sensitive Networks (new IEEE standards) supporting real-time control & synchronization of high performance machines.

The testbed is over 2 years old. There are over 25 companies participating, with 12 plugfests conducted, 2 testbed instances established, 2 demonstrators developed, an OPC UA Pub/Sub data exchange outlined and a whitepaper on industrial traffic type characterization and mapping produced. This paper will give an update on the testbed's activities, an outlook on the readiness of TSN as a technology and indication where further work is required from the testbed perspective. In addition, we will review the Industrial Automation traffic type characterization and TSN function mapping coming from the Testbed.

As a point, the IIC invites all ODVA members to participate in the activities – without the need to be an IIC member.

Introduction: Industrial Internet Consortium TSN for Flexible Manufacturing Testbed

The Testbed's vision is to enable Flexible Manufacturing for Industrial IoT and Industrie 4.0 through deployment of open, standard deterministic networks within production facilities. Its goal is to display the value and readiness of Time-Sensitive Networks (new IEEE standards) supporting real-time control & synchronization of high performance machines. Testbed activity is driving accelerated market adoption of this critical IIOT/Industrie 4.0 technology

The TSN Testbed is enabling the early phase usage of enhancements to Ethernet standards IEEE 802.1 and IEEE 802.3. All TSN Testbed work is communicated to IEEE and Avnu, a standards organization developing the interoperability and certification based on the IEEE's TSN. It is used to display OPC UA enabled vendor independent interoperability of real-time data and other industrial automation protocols (e.g. ODVA's EtherNet/IP) on the same network with typical IT voice/video data.

Participation in IIC's testbeds does not require IIC membership, but does require some basic approvals (e.g. NDAs). Therefore any ODVA member can participate without being an IIC member or giving financial contributions.

Key activities of the Testbed include:

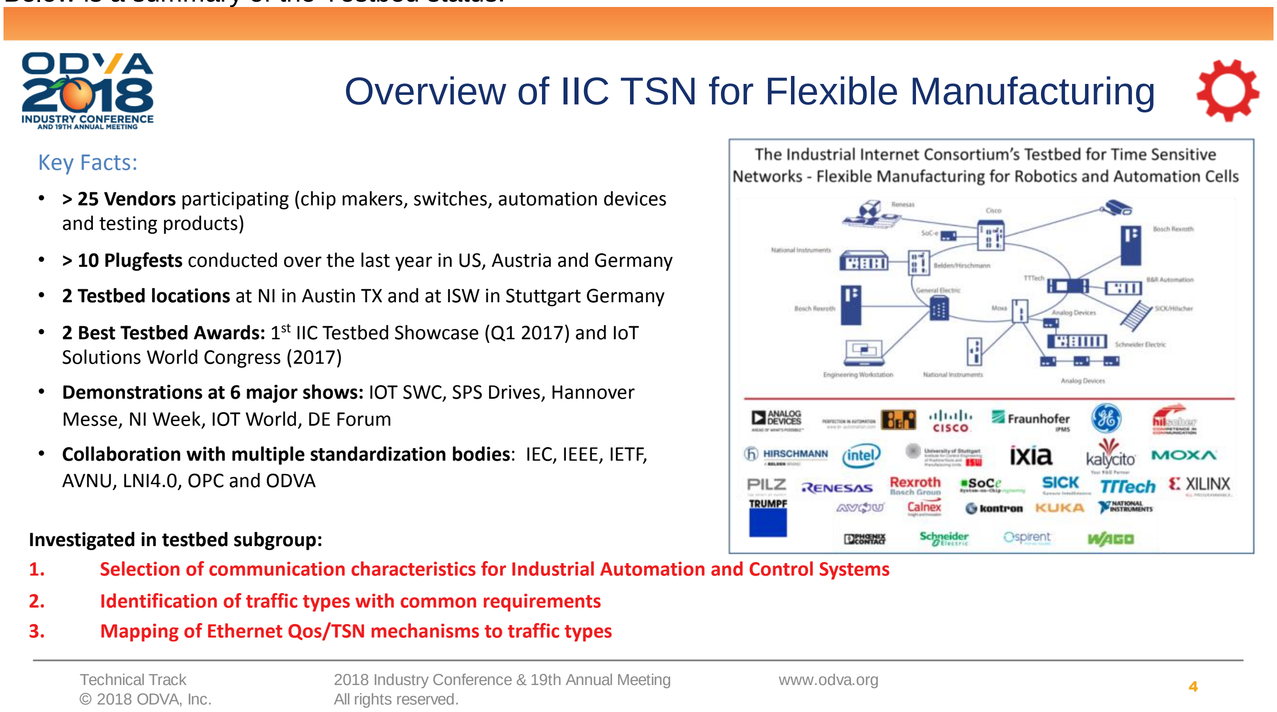
- Conducting Plugfests where participants can learn about TSN and conduct tests of in-development or available product with a variety of other companies, including chip, end-device, network and testing vendors. The plugfests focus on a range of TSN features including but not limited to:
    - Time synchronization
    - Communicating scheduled traffic (IEEE 802.1Qbv)
    - TSN Configuration and Management
    - Frame Preemption (IEEE 802.1Qbu and IEEE 802.3br)

  Plugfests are conducted in either the US-instance (NI Headquarters, Austin TX) or ISW (University of Stuttgart, Stuttgart Germany).
- Developing TSN Demonstrators that are used to display the capabilities of TSN and the results of the Testbed activities at major shows (e.g. SPS IPC Drives, Hannover Messe, IMTS, IoT Solutions World Congress, etc.)
- Developing an Interoperability Rack in each testbed location for the permanent installation of a TSN system for ongoing and long-term testing. The interoperability racks are internet accessible via established Firewalls/VPN.
- Conducting updates and discussions on a variety of TSN and relevant standards development activities. In this way, companies participating do not need to join all the relevant standards groups to stay abreast of developments and to provide feedback to those efforts.
- Collaborating with relevant standards and consortia including: IEEE, IEC, AVNU, OPC Foundation, LNI4.0, and ODVA
- Develop marketing and technical material to assist with the above, including press releases, a Marketing Brochure, arranging Press/Analyst interviews, articles (e.g. Journal of Innovation) and whitepapers.

The testbed currently has over 25 regular participants.

Testbed Status

Below is a summary of the Testbed status.



Traffic Types in Converged Industrial Network Whitepaper

A key output of the TSN Testbed activity relevant to the ODVA is the testbed's whitepaper on Description of Converged Traffic Types. The document describes application traffic types that are found in industrial and process control systems and therefore are supported in the Industrial Internet Consortium's Time Sensitive Networks for Flexible Manufacturing testbed, including different types of critical control traffic and other traffic that may be in a manufacturing network. The IEEE 802.1Q specification, Annex I lists traffic types as a means to structure network transmission priority and packet drop preference. This paper enhances those traffic types by adding types found in typical manufacturing Industrial Automation and Control Systems (IACS), with a list of characteristics to describe them precisely. In a draft enhancement, it then identifies IEEE 802.1 TSN mechanisms to support these traffic types in a converged network.

Traffic Type Characteristics are depicted below:

Traffic Type Characteristics

Application-derived communication requirements

Traffic Type	Description
Data Transmission Periodicity	• Cyclic/periodic • Acyclic/sporadic - also periodic frames with large periods (1-2 seconds)
Period	Planned data transmission interval ("cycle"), range in orders of magnitude of time
Synchronized to network	Indication whether application is synchronized to network time (yes or no)
Data delivery guarantee	• *Deadline*: data delivery of each packet in a stream is guaranteed to occur at all registered receivers at or before a specified time (within a communication cycle) • *Latency*: data delivery of each packet in a stream is guaranteed to occur at all registered receivers within a predictable timespan starting when the packet is transmitted by the sender and ending when the packet is received • *Bandwidth*: data delivery of each packet in a stream is guaranteed to occur at all registered receivers if the bandwidth utilization is within the resources reserved by the sender
Tolerance to interference	Application's tolerance of a certain amount of latency variation of the packet's transmission (i.e. jitter)
Tolerance to loss	Application's tolerance to a certain amount of consecutive packet loss in network transmission
Data size	Application payload size to be transmitted (fixed or variable)
Criticality	Criticality of the application data for the operation of the critical parts of the system (high, medium, low)

A summary of the Traffic Types and their characteristics is depicted below:

Traffic Types for Industrial Automation and Control Systems

Types	Periodicity	Typical Period	Synchronized to network	Data delivery guarantee	Tolerance to interference	Tolerance to loss	Typical application data size	Criticality
Isochronous	Periodic	< 2ms	Yes	Deadline	0	None	Fixed: 30 - 100 Bytes	High
Cyclic	Periodic	2 - 20ms	No	Latency	<= latency	1 - 4 Frames	Fixed: 50 - 1000 Bytes	High
Events	Sporadic	n.a.	No	Latency	<= latency	Yes	Variable: 100 - 1500 Bytes	High
Network Control	Periodic	50ms - 1s	No	Bandwidth	Yes	Yes	Variable: 50 - 500 Bytes	High
Config & Diagnostics	Sporadic	n.a.	No	Bandwidth	n.a.	Yes	Variable: 500 - 1500 bytes	Medium
Best Effort	Sporadic	n.a.	No	None	n.a.	Yes	Variable: 30 - 1500 Bytes	Low
Video	Periodic	Frame Rate	No	Latency	n.a.	Yes	Variable: 1000 - 1500 Bytes	Low
Audio/Voice	Periodic	n.a.	No	Latency	n.a.	Yes	Variable: 1000 - 1500 Bytes	Low

Table of applied TSN Mechanisms

Mechanism	Description and Comment
IEEE 802.1Q	**Strict Priority Forwarding** Strict Priority Forwarding suggests that packets are assigned to outbound queues identified by a Traffic Class. The traffic classes are all prioritized in this way.
IEEE 802.1Qav	**Forwarding and Queuing Enhancements for Time-Sensitive Streams – Credit Based Shaping** This mechanism ensures traffic types receive requested bandwidth over other lower priority traffic types, but does not meet other Data Delivery Guarantees outlined. It was particularly designed for Audio/Video traffic types. Credit-based Shaping queues can also be used to limit a traffic type's use of bandwidth as the credit is only replenished over a certain amount of time. When Scheduled Traffic is introduced, these bandwidth guarantees are not achievable to the same degree as independently.
IEEE 802.1AS-Rev	**Timing and Synchronization for Time-Sensitive Applications** Clock synchronization is required to support scheduled traffic (IEEE 802.1Qbv) and Credit-based shaping ensuring that the network infrastructure and end devices can transmit on a schedule based on a common sense of time. Therefore in the mapping considerations, it receives the same recommendation type as Scheduled Traffic. It should be noted that the IACS applications often require time synchronization, but that consideration is not reflected in the mappings.
IEEE 802.1Qbv	**Enhancements for Scheduled Traffic** This enhancement enables traffic streams to be communicated in the network without interference and with little or no jitter. This feature can be used to meet all the data delivery guarantees: deadline, latency and bandwidth.
IEEE 802.1Qbu & IEEE 802.3br	**Frame preemption** Frame preemption has two key capabilities. First, in the absence of traffic scheduling (802.1Qbv), frame preemption can be used to reduce latency and jitter of packet transmission to help meet deadline and latency data delivery guarantees for express frames in the presence of potentially interfering preemptible frames. Second, in the presence of traffic scheduling, frame preemption is beneficial to lower priority preemptible traffic by freeing utilizable bandwidth for transmission.
IEEE 802.1Qcc	**Stream Reservation Protocol (SRP) Enhancements and Performance Improvements** SRP contains multiple signaling protocols. This enhancement adds the Multiple Stream Registration Protocol (MSRP) as a signaling protocol that enables the ability to reserve network resources for devices that will guarantee the transmission and reception of data streams across a network with the requested QoS capability. These end stations are referred to as Talkers (devices that produce data streams) and Listeners (devices that consume data streams). This mechanism is used to provide consistent QoS behavior across the network.
IEEE 802.1CB	**Frame Replication & Elimination for Reliability** This mechanism supplies a critical function for industrial networking systems – seamless redundancy from connection or network infrastructure outage. It is considered an optional mechanism for critical applications where the network topology supports redundant, non-congruent paths. Additionally, this protocol contains specifications for Stream Identification. For ingress policing (Rate or Time-based) on Stream ID is mandatory, this part of the specification is also required.

Mechanism	Description and Comment
IEEE 802.1Qci	**Per-Stream Filtering and Policing (a.k.a. Ingress Policing)** This mechanism referred to as *per stream filtering and policing* (PSFP), is used to filter/police ingress frames that do not meet the specified policies as configured on the relevant managed objects. PSFP is supported by the following policing actions: • Time-based policing. This is supported by the *Stream Gate Instance*. This identifies the details of the of the time gate parameters. This allows detection of incoming frames during time periods when the stream gate is in the closed state to result in the stream gate being permanently set to a closed state, until such a time as management action is taken to reset the condition. The intent is to support applications where the transmission and reception of frames across the network is coordinated such that frames are received only when the stream gate is open, and hence, a frame received by the stream gate when it is in the closed state represents an invalid receive condition [IEEE 802.1Q §8.6.5.1.2]. The Stream Gate Instance applies to one or more Streams • Rate-based policing. This is supported by the *Flow meter instances*. This allows to specify the Committed Information Rate, and Excess Information Rate. These meters apply to specific one or more streams, and allow policing of streams that exceed the configured rate. This mechanism is used to protect queues from unwarranted traffic and maintain the established quality of service for specified traffic and streams. The recommendations below include a type of policing to be applied.

Below is a summary table of the Traffic Types mapped to TSN Mechanisms

Summary of Mappings

Types	802.1Q Strict Priority	Traffic Class	802.1Qbv (exclusive gating)	802.1AS-Rev Clock Synch	Cut-Through	802.1CB – Frame Replication	802.1Qbu – Frame Preemption	802.1Qci – Time-based Ingress Policing	802.1Qav – Credit Based Shaping	Reservation/Scheduling
Isochronous	M	6	M	M	O	O		M^T		M
Cyclic - Option: Strict priority	M	5				O	R	M^R		M
Cyclic – Option: Scheduled Traffic	M	5	M	M		O		M^R		M
Events - Control	M	4				O	O	M^R		M
Events - Alarms & Operator Commands	M	3		M			O	M^R	O*	M
Config & Diag.	M	2					O	M^R		M
Network Control	M	7			C		C			
Video, Audio, Voice	M	1					O	M^R	R	M
Best Effort	M	0					O			

Legend:
- M - Mandatory
- O - Optional
- C – Conditional
- R –Recommended
- ^{T} – Time-based
- ^{R} – Rate-based
- * - End devices

Technical Track

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15

References (optional)

IIC's TSN Testbed for Flexible Manufacturing whitepaper Description of Converged Traffic Types: https://www.iiconsortium.org/pdf/IIC_TSN_Testbed_Traffic_Whitepaper_20180418.pdf

IIC's Journal of Innovation, January 2017: https://www.iiconsortium.org/news/joi-articles/2017-Jan-Results-Insights-Best-Practices-from-TSN-Testbed-I.pdf

IIC's Testbed: TSN for Flexible Manufacturing: https://www.iiconsortium.org/time-sensitive-networks.htm

IIC's TSN Testbed Brochure: https://www.iiconsortium.org/pdf/TSN-brochure-8-22-18.pdf