The Integration of Time-Sensitive Networking into EtherNet/IP Technologies

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Level Setting

- *Time Sensitive Networking is a group of IEEE 802.1 standards enabling deterministic connectivity through IEEE 802 Networks.*

- *These standards enable communications that are in practice very similar to what EtherNet/IP has done for over a decade, but with scheduling of transmission and preemption to minimize worst case latency and jitter of high priority traffic at the cost of delaying less essential traffic.*

- *By moving these standards into IEEE 802.1, fieldbus implementations will have the opportunity to coexist while achieving their goals on a converged network.*

- *These standards diverge from the Ethernet that EtherNet/IP currently uses by implementing preemption, scheduling, and a different time sync protocol.*

- *Many introductory presentations for TSN exist, one such is:* https://1.ieee802.org/tsn-webinar_overview-of-tsn/

Time-Sensitive Networking (TSN) Profiles (Selection and Use of TSN tools)

Audio Video Bridging [802.1BA/Revision]	Fronthaul [802.1CM/de]	Industrial Automation [IEC/IEEE 60802]	Automotive In-Vehicle [P802.1DG]	Service Provider [P802.1DF]	Aerospace Onboard [IEEE P802.1DP / SAE AS6675]

TSN Components

(Tools of the TSN toolset)

Time synchronization:
Timing and Synchronization [802.1AS-2020]
(a profile of IEEE 1588)
Hot Standby [P802.1ASdm]
YANG [P802.1ASdn]
Inclusive Terminology [P802.1ASdr]

Synchronization

High availability / Ultra reliability:
Frame Replication and Elimination [802.1CB]
Path Control and Reservation [802.1Qca]
Per-Stream Filtering and Policing [802.1Qci]
Reliability for Time Sync [802.1AS-2020]

Reliability

Latency

Bounded low latency:
Credit Based Shaper [802.1Qav]
Frame Preemption [802.1Qbu & 802.3br]
Scheduled Traffic [802.1Qbv]
Cyclic Queuing and Forwarding [802.1Qch]
Asynchronous Traffic Shaping [802.1Qcr]
Shaper Parameter Settings [P802.1Qdq]
QoS Provisions [P802.1DC]

Resource Management

Zero congestion loss = Bounded latency

Dedicated resources & API:
Stream Reservation Protocol [802.1Qat]
Link-local Registration Protocol [802.1CS]
TSN Configuration [802.1Qcc]
Foundational Bridge YANG [802.1Qcp]
YANG for CFM [802.1Qcx]
YANG for LLDP [P802.1ABcu]
YANG for 802.1Qbv/Qbu/Qci [P802.1Qcw]
YANG & MIB for FRER [P802.1CBcv]
Extended Stream Identification [P802.1CBdb]
Resource Allocation Protocol [P802.1Qdd]
TSN Configuration Enhancements [P802.1Qdj]
LLDPv2 for Multiframe Data Units [P802.1ABdh]
Multicast and Local Address Assignment [P802.1CQ]

Note: A 'P' in front of '802.1' indicates an ongoing Project.

More on TSN standards and ongoing projects at: https://www.ieee802.org/1/tsn

Standards Update - IEC/IEEE 60802

Attribute	Classification	Full-Blown Devices Example Selection "Common"	Constraint Devices Example Selection "Common"
Gate Control List entries 802.1Q 8.6.8.4	Quantity	At least 3	At least 3
Tick granularity 802.1Q 8.6.8.4	Quantity	<= 10ns	<= 10ns
Admin Cycle Time range **802.1Q 8.6.8.4**	Quantity		
Application Cycle time (is a multiple of Admin Cycle Time / Network Cycle)	Information	---	---
100Mbps	Quantity	250 µs to 1 ms	250 µs to 1 ms
>=1Gbps	Quantity	31,25 µs to 1 ms	31,25 µs to 1 ms
Timing points for scheduled traffic 802.1Q 12.29.2[1]	Quantity	<= 10ns	<= 10ns
Maximum gap for transmission of consecutive frames[2] IPG := 96 bit times	Quantity	IPG	IPG
Preemption **802.1Q 6.7.2**			
First or non-final fragment size	Quantity	64	64
Number of Hold & Release events 802.1Q 12.30.1	Quantity	2	2
10Mbps	Feature	Mandatory	Optional
100Mbps	Feature	Mandatory	Optional
1Gbps	Feature	Mandatory	Optional
2,5Gbps	Feature	Optional	Optional
5Gbps	Feature	Optional	Optional
10Gbps	Feature	Optional	Optional

Conformance Class Examples

- IEC/IEEE 60802 is a Profile of TSN Standards for Industrial Automation.
- The project was started in May of 2018.
- General approach is set
  - Two Conformance Classes (A/B)
    - Conformance Class B: Time Sync, LLDP, Management Protocols, TSN Domains, Security (all other features optional)
    - Conformance Class A: Conformance Class B plus scheduling and preemption mandatory at 100Mbps and 1Gbps
- Members actively pushing specification forward are trying to drive to closure of first edition
- Fall 2023 is the currently anticipated date for Edition 1.

Standards Update - IEC/IEEE 60802

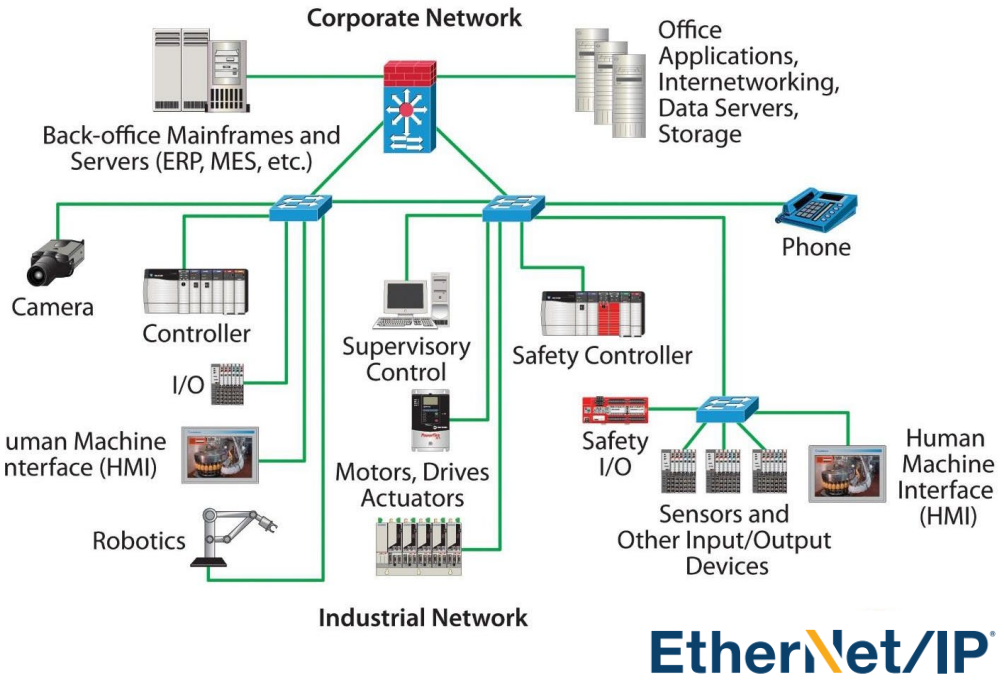
- Specification is on the 3rd task group ballot as of September 2021. There will be at least 4 task group ballots.
  - IEEE Specifications go through task group ballots, working group ballot(s), and sponsor ballot(s)
  - Over 1000 comments on this ballot, most of which have been resolved as of March 2022.
    - Comment resolution of the 2nd task group ballot having over 950 comments took 14 months

CATEGORY	All Respondents	
	TOTAL	%
Yes	9	42.86%
No	12	57.14%
Voting Yes or No	21	100.00%
Abs. Time	5	12.50%
Abs. Expertise	7	17.50%
Abs. Other	0	0.00%
Respondents	40	
Voting members	33	
Non-voting	7	
No. of commenters	22	55.00%
No. of comments	1010	

Responses to IEC/IEEE 60802 D1.3

Competitive Analysis of Fieldbus TSN Adoption

- Some fieldbuses have published a TSN profile that is not 60802 compliant, and have TSN devices currently in the field.
- At least one fieldbus has a published TSN profile but is waiting until 60802 is complete to release devices.
- Other fieldbuses are waiting for 60802 to release a TSN profile



Fieldbus Scope

ODVA 60802 Adoption

- ODVA's TRB convened an Ad-Hoc Group to evaluate the adoption of IEC/IEEE 60802.
- The ad-hoc group created a TDE for internal SIG use to guide the implementation throughout the Distributed Motion and Time Synchronization SIG, EtherNet/IP Infrastructure SIG and EtherNet/IP System SIG.
- The following slides highlight some of the recommendations from that group.

High Level Technical Requirements for EtherNet/IP

- The TSN data link layer for EtherNet/IP EtherNet/IP should be expanded to support new network standards including IEEE 802.1Q-2018 with amendments, IEEE 802.1AB-2016, IEEE 802.1AS-2020, IEEE 802.1CB and IEC/IEEE 60802.

- TSN standards should comprise an optionally applied new Application Profile for EtherNet/IP as defined in Volume 2 of the Common Industrial Protocol.
  - EtherNet/IP implementing systems and their devices may choose to natively implement the TSN Application Profile, or use one or multiple gateways, to enable reliable application operation in a TSN network.
  - Both native implementations and implementations through (a) gateway(s) must provide and allow fair network level access with other 60802-compliant devices.

- Existing EtherNet/IP devices may work with TSN networks without change, recognizing their relative Quality of Service on the wire may be degraded when compared to a non-TSN network.
  - The ability to converge non-TSN EtherNet/IP devices on a TSN network must be maintained.
  - Degradation of Quality of Service may result in non-operable applications

Applicative TSN Models for 60802

- Stream-Class Based Scheduling + Preemption
  - This model implements preemption for high priority streams and Qbv in bridges. Each traffic stream is assigned a traffic specification and bridge queues open/close based on the traffic specification of the streams.
- Class Based Scheduling + Preemption
  - This model implements preemption for high priority streams and Qbv in bridges. Each traffic stream is aggregated into a class of traffic (Isochronous, cyclic & other) and bridge queues open/close based on giving each class of traffic a prioritized access to the wire.
- End-Station Scheduling + Preemption
  - This model implements preemption for high priority traffic in bridges and Qbv in end-stations only. End-station scheduling works on the principle of evaluating and constraining ingress to a time sensitive network, taking worst-case latency of all traffic into account.

- EtherNet/IP should be able to support all of the above when used in a TSN network

Use Case 1 – Isochronous Control Loops with Guaranteed Low Latency

- The prime example of an ‘Isochronous’ Control Loop in the ODVA ecosystem is CIP Motion.
- CIP Motion can be adapted to 60802 by aligning the motion control pla time with the network schedule start time.
- Once CIP Motion and 60802 are aligned, the user may choose to config transport using:
  - End-Station Scheduling
  - Class Based Infrastructure Scheduling
  - Stream-class Based Scheduling
- Model selection should be chosen based on coexisting traffic.
  - User may need to make different selections dependent on the 'other’ fieldbuses.

Use Case 2 – Cyclic Control Loops with bounded latency

- The prime example of Cyclic Control loops in EtherNet/IP is CIP I/O traffic

- CIP I/O traffic can be adapted to 60802 by just-in-time production of data, aligning the application cycle with the network, or buffering traffic until a network cycle is available.
  - We cannot assume that the network cycle or management is under control of the EtherNet/IP sub-system

Use Case 3 – Sequence of Events

- IEEE802.1AS is a profile of IEEE1588 with much commonality with 1588 Default Profile
  - There should be no impact on either application or user of the switch to TSN
- Record time stamped events for the whole plant with known maximum deviation to the grandmaster time in the range from 1 µs to 100 µs
- Existing features of EtherNet/IP such as implicit messaging can be used.
  - QoS parameters should be used to be sure that these events are transmitted at the required urgency.

Use Case 4 – Machine to Machine / Controller to Controller Communication

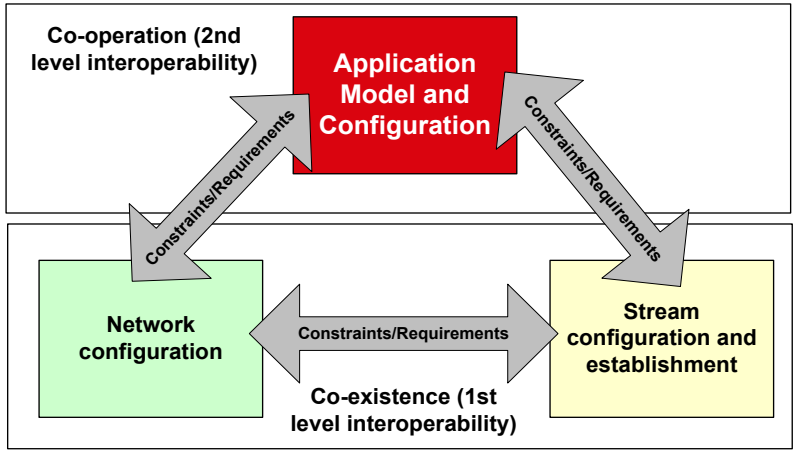
- This use case uses CIP Explicit messaging (Class 3 or unconnected) or Vendor-specific CIP Implicit Messaging (Class 0/1) mechanisms for communication.
- Once mechanisms are provided to transmit EtherNet/IP traffic via TSN streams, CIP Implicit Messaging will need to be managed appropriately for the M2M/C2C use case.

Additional features required for EtherNet/IP over TSN

- The solution needs to be secure. This will be met through the use of CIP Security on the application plane, and NETCONF with TLS on the network configuration plane.
- The solution needs to use industry standard redundancy protocols.
  - IEEE 802.1CB is the TSN Redundancy Mechanism
  - New high-risk invention needed to make DLR, PRP & HSR both backwards-compatible and compatible with 1CB

Co-Existence with Other Industrial Protocols

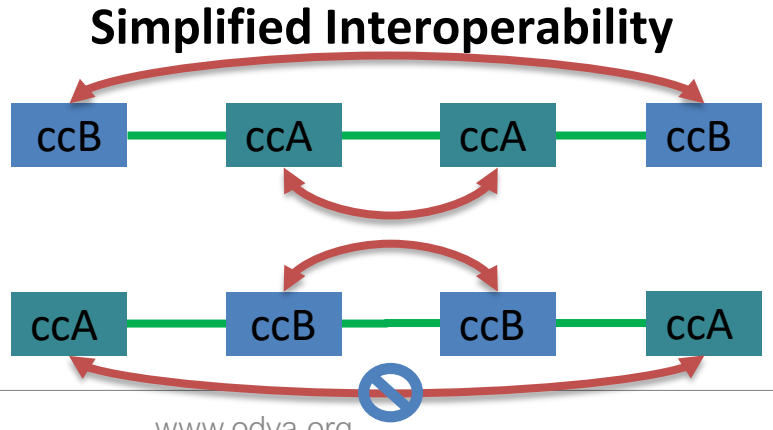
- Discussions regarding TSN often refer to interoperability. However, interoperability may be achieved on different levels and in terms of application protocols, it is more appropriate to use the term coexistence. The figure shows three areas, which need to be covered:
  - network configuration (managed objects according to IEEE definitions), and
  - stream configuration and establishment, and
  - application configuration.
- The three areas mutually affect each other



- Application configuration is not expected to be part of the 60802 profile, but common network management, path establishment and stream configuration methods are vital to the coexistence of application protocols.

- The selections made by the 60802 profile covers IEEE 802 defined layer 2 and the selected protocols to configure layer 2. Applications make use of upper layers of the OSI model as well, but these are out of scope for the profile.

- Stream establishment is initiated by applications to allow data exchange between applications. The applications are the source of requirements, which shall be fulfilled by network configuration and stream configuration and establishment.



Example of EtherNet/IP System SIG Activities

- Define an optional end-station TSN Device Profile
  - Implement scheduling mechanisms for the optional TSN Device Profile
  - Include support for bridged end-station devices
- Define and describe traffic types for EtherNet/IP over TSN
- Assign CIP Connections to TSN Streams
- Ensure resulting profiles for EtherNet/IP over TSN are secure
- Ensure Redundancy/High Availability is supported
  - Including DLR

Example of EtherNet/IP Infrastructure SIG Activities

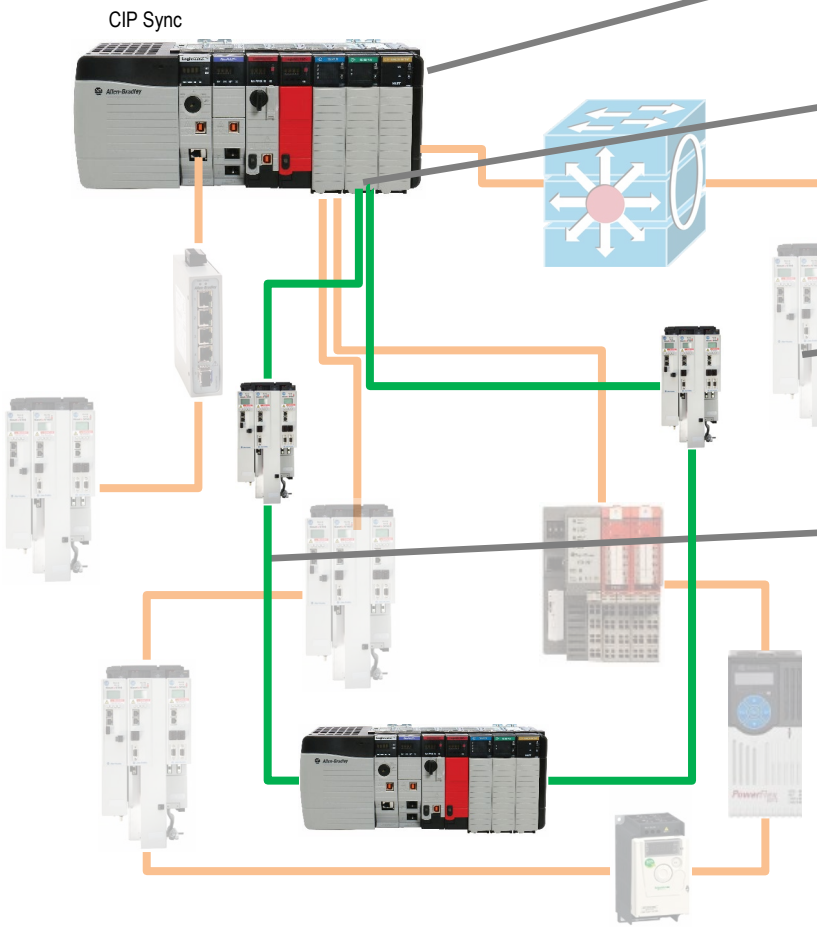
- Create an optional TSN Bridge Device Profile
  - Implement scheduling mechanisms for bridges
- Work with the EIP System SIG to Ensure Redundancy/High Availability is Supported
  - Enhance Specifications for PRP, HSR & RSTP over the optional TSN Bridge Device Profile
    - Dependent on necessary modifications from source specifying bodies
  - Enhance Specifications to provide support for 802.1CB over the optional TSN Bridge Device Profile
- Implement LLDP Extensions for EtherNet/IP TSN Management
- Support the System SIG with the optional bridged end-station TSN Device Profile
- Enhance Specifications to provide support for a TSN Gateway for brownfield traffic on a TSN domain edge port
  - And incremental CIP services potentially needed in the brownfield network

Example of EtherNet/IP Distributed Motion and Time Synchronization SIG Activities

- Enhance Specifications for 802.1AS-2020 Time Sync
  - Time Gateway Support
- Define the Management Model Protocols
  - Add support for NETCONF to EtherNet/IP
- Enhance Specifications for New CIP Motion Profiles to support the optional TSN Device Profile

Conclusion – IEC/IEEE 60802 1.0 Integration with EtherNet/IP

IEC/IEEE 60802 Edition 1 will enable limited coexistence and will look similar to this.



Controller needs to support synchronous and asynchronous timing

Dedicated TSN network interface in controller

All TSN components utilizing a single conformance class on a single subnet

Dedicated isolated network for TSN components

Additional IEC/IEEE specification work will be necessary to achieve true plantwide coexistence

Thank you!