Time Sensitive Network (TSN) Protocols and use in EtherNet/IP Systems

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1. Abstract

There is a high demand for a converged IEEE 802 solution for deterministic Ethernet allowing any kind of traffic and meeting the needs of existing and emerging markets. Efficient utilization of the communication bandwidth, and plug-and-play capabilities are the topmost requirements in IEEE 802.1.

TSN is being specified to provide deterministic Ethernet capabilities to innovative networked control solutions to support mixed traffic in:

- Transportation: Traffic Control Systems; Vehicular/Automotive Networks; Railway-Rolling stock; Autonomous cars;
- Motion Control: Wind Turbines, Printing machines;
- Power Utility Automation;
- Industrial Distributed Control Systems/Networks.

TSN offers solutions that will provide secure internet connectivity while guaranteeing critical real-time communication on the same physical network infrastructure based on existing and upcoming IEEE 802.1 and IEEE 802.3 Time-Sensitive Networking standards.

TSN allows maintaining determinism with the confidence of being able to satisfy the requirements of less demanding traffic sharing the medium. The meaning of convergence in TSN is the successful convergence of critical control, non-critical control, and data streams on a single network.

The goals of the Time Sensitive Networking Technology are to achieve the following industrial markets' needs:

- Make IEEE 1588 PTP simpler to use, more robust, and more accurate, while keeping its plug-and-play capabilities;
- Create an L2 transport protocol for time-stamped latency-sensitive data;
- Offer the ability to reserve bandwidth for particular streams, and to absolutely guarantee those streams a low, specified latency and zero congestion loss;
- Allow a single data stream to take multiple pinned-down (Redundant) paths through the network to ensure that media/equipment failure will not cause packet loss;
- Allow any data stream to reserve any level of Quality of Service (QoS), whether Unicast or multicast, regardless of high-layer protocol, whether L2 or L3 end-to-end;
- Converge all the usual existing Qualities of Service into the TSN network (at reduced bandwidth) while maintaining the TSN guarantees;
- Support these features no matter what best-effort traffic is also present.

Keywords

Industrial Internet-of-Things, Availability, Redundancy, Time Sensitive Networks

2. Objective

The purpose of this whitepaper is to inform the ODVA community of vendors of an upcoming technology and set of standards that may be relevant to that community, namely Time-Sensitive Networks. TSN is a technology that is nearing viability, but is not yet complete. In addition, as with many technologies now recognized as core, common Internet standards, TSN starts with a core foundation in IEEE standards and will likely include standards and concepts developed in a range of standards development organizations (SDOs).

Understanding that the standards work reflected here is not yet ratified by the relevant SDOs, the ODVA community should keep in mind aspects of this whitepaper may need to be updated or changed as ratifications occur. Nonetheless, the authors of this document do think it is important to start describing to the ODVA the current state of thought on TSN and how it is envisioned to work in industrial applications.

Additionally, as with any key concepts within the Internet space, core concepts are defined and receive updates and enhancements overtime. TSN will be no different. This whitepaper will identify concepts that are not yet a focus or are in early development phases and consider them scope for future whitepapers as those concepts mature.

3. Use Cases

TSN is an enhancement to open, standard Internet networks that enables control systems to converge on a single, interconnected network with real-time and bulk data communication without disrupting the mission critical control tasks. TSN provides the following key benefits that are top of mind for customers with mission critical networks:

1. Real-time – Guaranteed latency, low-jitter and zero congestion loss for all critical control loops. Control loops can have different rates.
2. Convergence – Reducing complexity and costs converging networks
3. Open, Interoperable Standard – truly open standard, hence IEEE 802.1 and other relevant groups to ensure long-term viability and innovation
4. Immunity – Critical traffic is immune to effects of converged, non-critical traffic
5. Ease-of-Use – making networking easy both design, provisioning, and maintenance

These benefits make the technology beneficial to the following industrial verticals and use cases described in the following Table 1.

Table 1: Use Cases

Vertical	Use Case
Industrial control systems (Discrete Manufacturing)	Machine to Machine communication. Motion Control applications.
Transportation	On-train control applications Control and monitoring of Transportation infrastructure (rail, road, etc)
Machine Builders	Small networks with high reliance on control traffic passing reliably between elements. Enable connecting the machine to plant networks maintaining the network performance for critical control.
Wind Turbines	Safety certified control system (integrated approach to networking and control) Motion control applications
Oil and Gas	Support convergence of Process and Control networks Provide high availability network communications for Process and Control networks
Automotive	Automotive in-vehicle network for control and integration of higher bandwidth devices and applications (vision, radar, etc.) High performance, cost-effective, weight reducing from integrating safety and non-safety traffic on one network
Space	Spacecraft backbone Network, redundant fail- operational network Enabled robust network where maintenance is not an option
Aerospace	Avionics Backbone network, simple redundant mechanisms that fulfill fail operational requirements Enabling highest performance

4. IEEE 802.1 TSN Working Groups & Related Standards

The following standards are relevant and associated with TSN. Each will be covered in a separate section. These standards are in various phases of completion noting that none have been finally ratified. These standards are built upon earlier work in the IEEE referred to as Audio-Visual Bridging (AVB). The chapter will start with a brief review of AVB.

Table 2: Current IEEE TSN Standards (Non currently published)

Standard	Area	Title
IEEE 802.1AS-Rev, IEEE 1588	Timing & Synchronization	Enhancements and Performance Improvements
IEEE 802.1Qbu & IEEE 802.3br	Forwarding and Queuing	Frame preemption and Interspersing Express Traffic
IEEE 802.1Qbv	Forwarding and Queuing	Enhancements for Scheduled Traffic – Time-Aware Traffic Shaping
IEEE 802.1Qca	Path Control and Reservation	Path Control and Reservation

IEEE 802.1Qcc	Stream Reservation (SRP)	Enhancements and Performance Improvements
IEEE 802.1Qci	Time Based Ingress Policing	Per-Stream Filtering and Policing
IEEE 802.1CB	Stream Reservation (SRP)	Frame Replication & elimination for Reliability

Although the core of TSN standards are being developed in the IEEE, there are at least 2 other key organizations involved in developing standards and concepts around TSN; the Internet Engineering Task Force (IETF) and the AVnu Alliance. The role and scope of these groups will be described at the end of this section.

In general, the IETF has been the focus point of OSI Model layers 3 and up, whereas IEEE has focused on layers 1 & 2.

4.1. TSN Foundation: Audio-Visual Bridging

An understanding of the set of IEEE standards known as Audio-Visual Bridging (AVB) is needed to better understand the development of TSN. As well as being the foundation for TSN, there were several lessons learned with the development of AVB.

The goal of AVB was to create a set of standards that allowed users to create plug-and-play ad hoc networks where talkers and listeners would request paths through the network allocating bandwidth and guaranteeing tight jitter and well bounded latency. The core set of standards developed under AVB are:

- **802.1BA**: Audio Video Bridging (AVB) Systems,
- **802.1AS**: Timing and Synchronization for Time-Sensitive Applications (gPTP),
- **802.1Qat:** Stream Reservation Protocol (SRP), and
- **802.1Qav:** Forwarding and Queuing for Time-Sensitive Streams (FQTSS).

The basic AVB workflow being that a Listener would request a path to a talker with bandwidth, latency, and jitter requirements using SRP. The request would be forwarded hop-by-hop to the talker, reserving bandwidth, accumulating latency and calculating jitter along the way. Once a flow was established and the packets began flowing, the bridges (aka, switches) would shape the traffic using the "Credit Based Shaper" defined in 802.1Qav. The endpoints, having a common concept of time based on 802.1AS (gPTP), a profile of IEEE 1588 PTP, would transmit their respective streams strictly shaped using the common time base.

During the development of AVB, several players from the industrial segment saw that, given the above capabilities of guaranteed latency and bandwidth, this new AVB standard would be useful in a range of industrial applications. However, rather late in the development of these AVB standards, it was discovered that the Credit Based Shaper of 1Qav was not as robust as previously thought and that there were cases in which congestion loss of critical traffic would occur. This was seen as a major issue for the industrial markets. It was therefore decided in the AVB workgroup to finish up the work for the Audio-Visual markets and start new work to fix the problem with the credit based shaper. In 2012, the group then renamed themselves to the "Time Sensitive Networking (TSN)" Workgroup to better reflect the expanded market scope, and began work on the new set of standards.

The key challenges the group focused on that were learned in the development of AVB included:

- Centralized Control is better than Decentralized Control for industrial applications
- A new shaping method to eliminate Congestion Loss is needed
- Expanded Market Space (i.e. industrial applications) necessitates different requirements

4.2. IEEE 802.1AS-REV and IEEE 1588 - Time Synchronization on Networks

The Precision Time Protocol (PTP) [IEEE 1588v2] uses physical layer timestamps to compute network delays and define synchronization events.

For TSN systems a 1588 profile was developed (IEEE 802.1AS) that defines fewer options, but extends some physical layer options. This profile was developed for Audio-Video Bridging (AVB) to provide the following PTP features:

- Provides performance specifications for switches as “Time Aware Bridges”;
- Uses accumulated “Neighbor Rate Ratio” calculations to improve accuracy and speed up convergence
- Includes Plug and Play operation and startup with a specified Best Master Clock Algorithm (BMCA) used by switches.
- Requires the use of Peer-to-Peer Transparent Clocks and Path Delay Processing;
- Requires Two-Step Delay message processing (Sync & Follow-Up Messages);

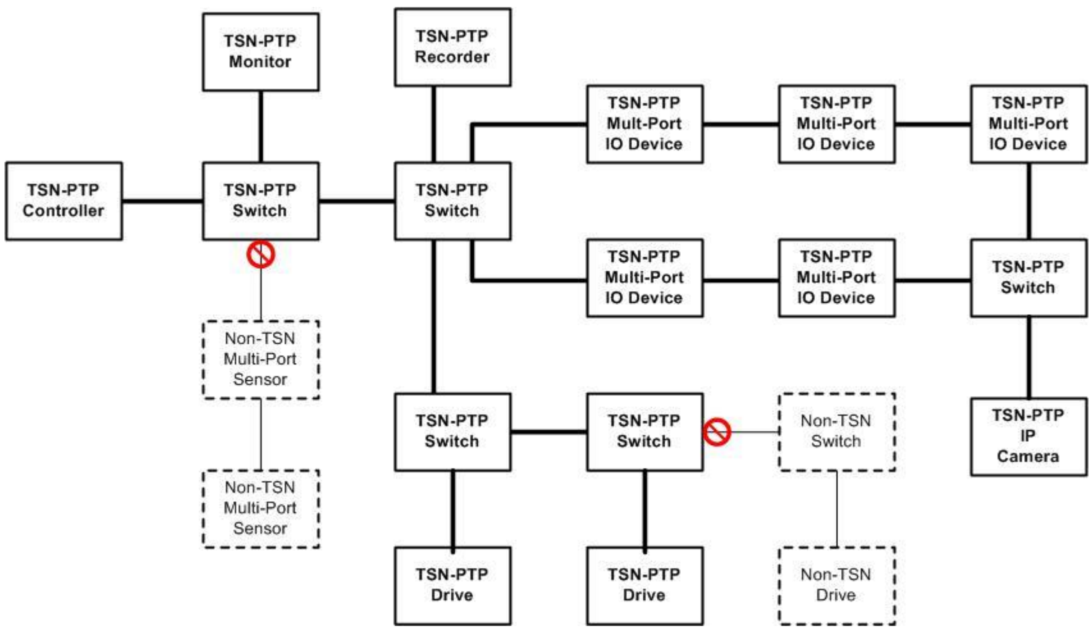


Figure 1: Time Synchronization

Figure 1 illustrates the devices that supply the discussed PTP features, and supply Additional TSN enhancements are being defined (802.1ASrev). These enhancements are:

- Explicit support for One-Step Processing with backward compatibility to Two-Step processing.
- Redundant Grandmaster (GM) clocks possibly in a Hot-Standby;
- Multiple paths for clock propagation with clock path quality metrics.

IEEE 802.1AS-Rev represents a different profile of IEEE 1588 which uses peer-to-peer on layer 2 Ethernet vs. end-to-end on Layer 4 UDP as in CIP-Sync. As such, it would require changes to CIP-Sync if it were adopted by the ODVA. Although a precise sense of time is required within TSN, IEEE 802.1AS-Rev is not the required means to do such. In other words, it is also distinctly possible to adopt other aspects of TSN and maintain CIP-Sync as the means to precisely deploy time. What should be considered by the ODVA is whether IEEE 802.1AS-Rev becomes an adopted standard in other industrial ecosystems, there may be both technical and economical factors for the ODVA community to adopt IEEE 802.1AS-Rev as well.

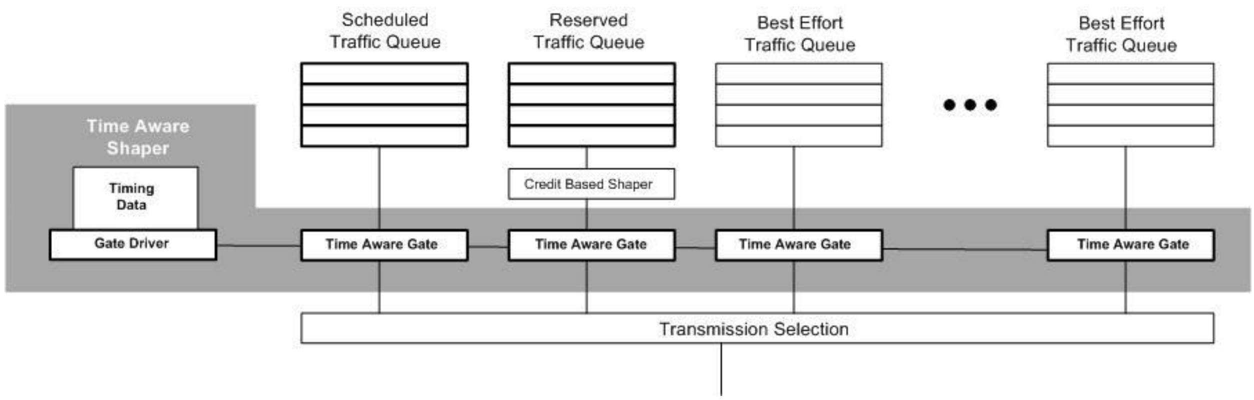
4.3. IEEE 802. 1Qbv – Time Aware Traffic Shaping

Audio/video streams require high bandwidth utilization. It was necessary to set the maximum bandwidth for this new traffic class quite high (75%). **Credit Based Traffic Shaping (CBS)** was introduced to support this. The CBS spaces out the frames as much as possible in order to reduce bursting and bunching.

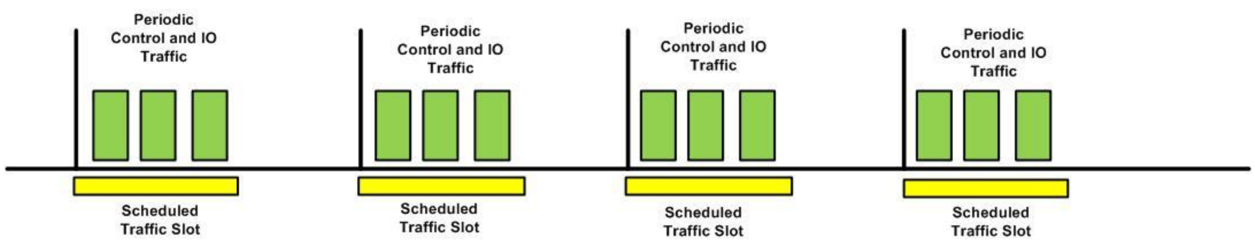
This behavior protects the best effort traffic as the maximum interference from the AVB traffic (AVB stream burst) on the highest "best effort priority" traffic is limited and known. CBS protects the AVB streams, as it limits the back-to-back AVB stream "bursts" which can cause interference in a switch.

The latency requirements in the industrial and vehicle control networks imply a significant reduction of latency. It is necessary to prevent interference with other lower priority or even same priority traffic. To prevent interference, the high priority traffic is scheduled.

Time Aware Traffic Shaping (IEEE P802.1Qbv) allows for scheduled traffic. In order to enforce the schedule throughout a network, the interference with lower priority traffic has to be prevented, as this would not only increase the latency bus also the delivery variation. The Time Aware Shaper blocks the non Scheduled Traffic, so that the port is idle when the Scheduled traffic is scheduled for transmission.



(a) Example Time Aware Shaping Queues



(b) Example Shaped Traffic

Figure 2: Time Aware Traffic Shaping

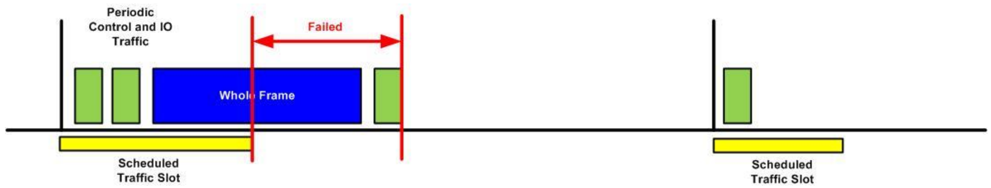
Figure 2 illustrates **Time Aware Traffic Shaping** of scheduled traffic. Figure 2-(a) illustrates example Time aware shaping Queues, and Figure 2-(b) illustrates example shaped Traffic.

4.4. IEEE 802. 1Qbu & IEEE 802.3br - Frame Preemption and Interspersing Express Traffic

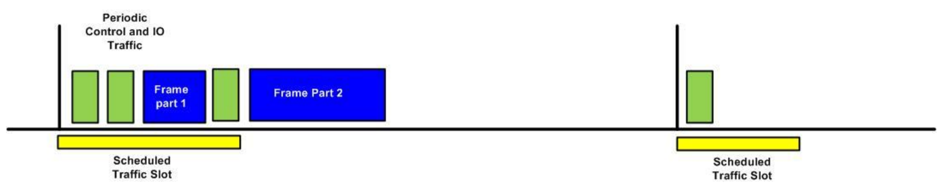
The Frame Preemption (p802.1Qbu) amendment specifies procedures, managed objects, and protocol extensions that:

- Define a class of service for time-critical frames that requests the transmitter in a bridged Local Area Network to suspend the transmission of a non-time-critical frame, and allow for one or more time-critical frames to be transmitted. When the time-critical frames have been transmitted, the transmission of the preempted frame is resumed. A non-time-critical frame could be preempted multiple times.
- Provide for discovery, configuration, and control of preemption service for a bridge port and end station.
- Ensure that preemption is only enabled on a given link if both link partners have that capability.

The purpose of this amendment is to provide reduced latency transmission for scheduled, time-critical frames in a bridged LAN.



(a) Non-Critical Frame interruption



(b) Frame Preemption

Figure 3: Frame Preemption and Interspersing Express Traffic

A large, non-time-critical frame (in blue) [Figure 3-(a)] may start ahead of time-critical frame (in green) transmission. This condition leads to excessive latency for the time-critical frame. Transmission preemption preempts the non-time-critical frame to allow the time-critical frames to be transmitted [Figure 3-(b)]. This provides the capabilities of an application that uses scheduled frame transmission to implement a real-time control network.

Other mechanisms (not discussed here) may be applied to avoid this situation, such as guard-bands to delay transmission of large packets that would overlap with scheduled time-critical packets.

4.5. IEEE 802. 1Qcc - Stream Reservation Protocol (SRP) Enhancements

The Stream Reservation Protocol (SRP) utilizes the Multiple Stream Registration Protocol (MSRP) to establish stream reservations across a bridged network.

The Multiple Stream Registration Protocol (MSRP) is a signaling protocol that provides devices with the ability to reserve network resources that will guarantee the transmission and reception of data streams across a network with the requested quality of service. These devices are referred to as Talkers (devices that produce data streams) and Listeners (devices that consume data streams).

Stream Reservation Protocol (SRP) provides the following features:

- Adds TLVs to IEEE Std 802.1AB-2009 Link Layer Discovery Protocol (LLDP)
- Allows one to discover which neighbors participate in AVB.
- Bridges tell end stations what classes of latency are available on what priority levels, and what VLAN to use.
- Used to ensure that 802.1AS doesn't use non-time-aware devices.
- Bridges protect AVB priority levels by remapping any input from a non-AVB neighbor away from the AVB priorities.
- Runs a protocol, "Multiple Stream Reservation Protocol (MSRP)" to actually make reservations.
- Talkers advertise streams, each with a network-unique multicast destination MAC address (likely obtained via IEEE 1722.1), via MSRP, a hop-by-hop flooding protocol.
- MSRP advertisements can be flooded to all AVB-capable bridges and end stations, or can follow multicast listener reservations (made by either 802.1Q MVRP or by IGMP).
- Hop-by-hop replies from Listener(s) actually enable hardware queues, from Listener to Talker.
- When Talker gets reply, transmission can start with guarantees enforced.

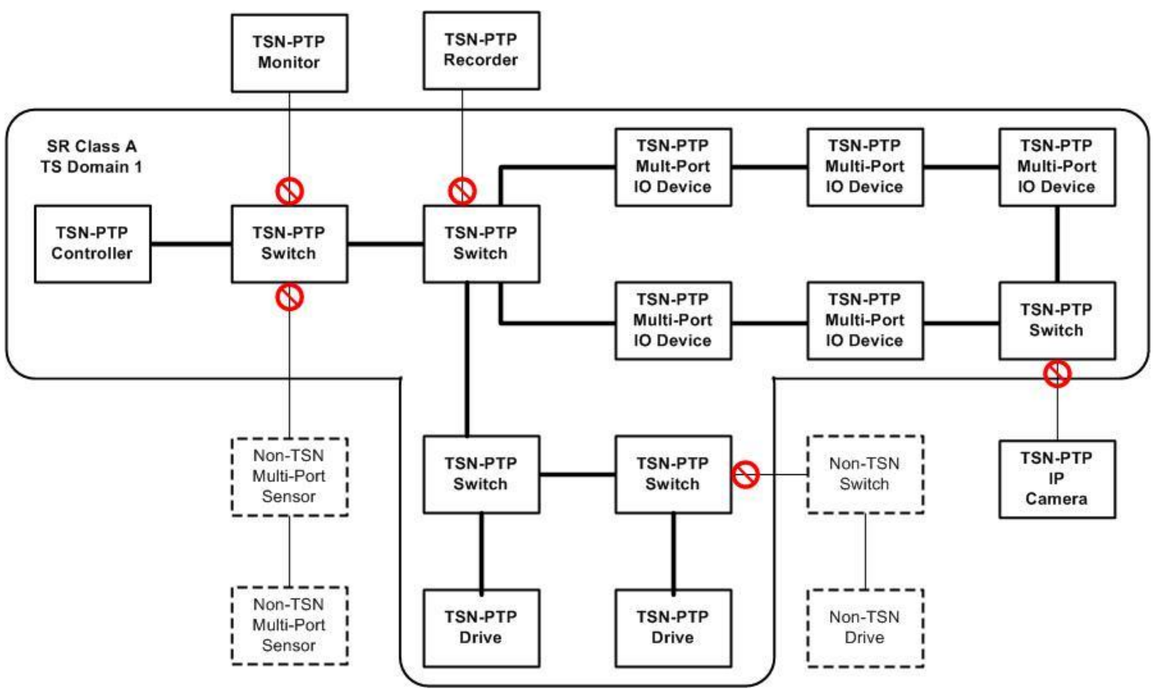


Figure 4: Stream Reservation (SR) Class A

The first generation of the Stream Reservation Protocol (SRP) has been accepted by the Professional, Industrial, Consumer, and Automotive markets. The addition of a set of TSN enhancements extends the capabilities of SRP as requested by those markets.

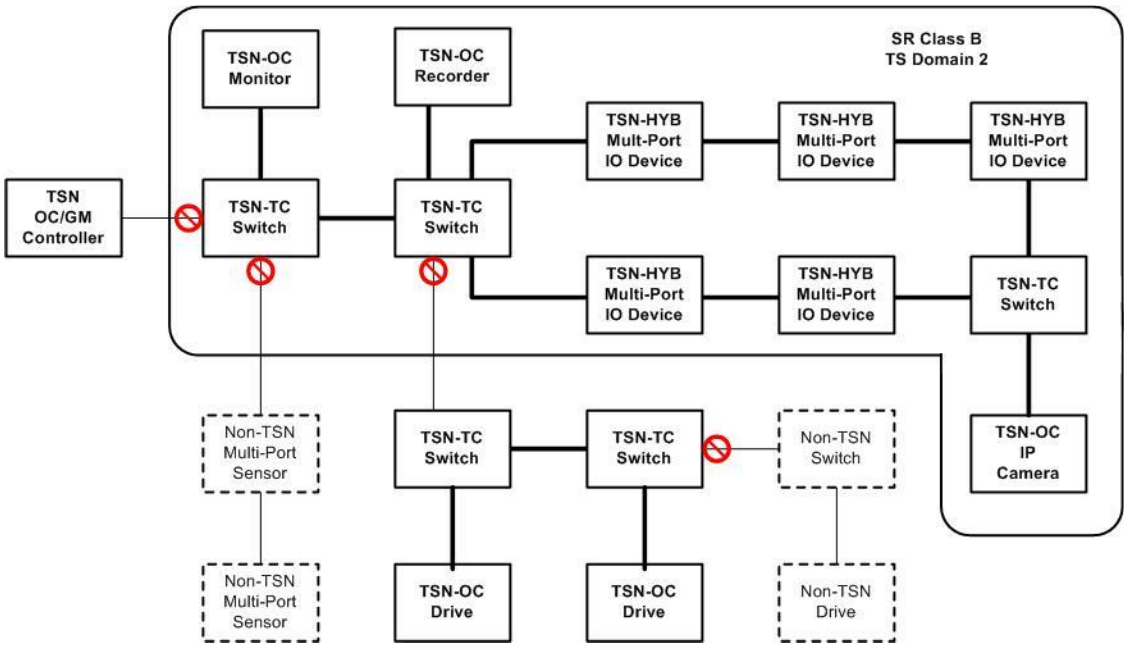


Figure 5: Stream Reservation (SR) Class B

The TSN enhancements are being defined in the specification 802.1Qcc - Stream Reservation Protocol (SRP) Enhancements and Performance Improvements. This amendment provides protocols, procedures and managed objects for bridges and end stations that are compatible with existing mechanisms and provide:

- Support for more streams
- Configurable SR (stream reservation) classes and streams (illustrations in Figure 4 and Figure 5)
- Better description of stream characteristics
- Support for Layer 3 streaming
- Deterministic stream reservation convergence
- UNI (User Network Interface) for routing and reservations

4.6. IEEE 802. 1Qca - Path Control and Redundancy (Seamless)

Path Control and Reservation (P802.1Qca) extends the application of Intermediate System to Intermediate System (IS-IS) to control bridged networks (beyond the capabilities of Shortest Path Bridging) and specifies additional protocols, procedures and managed objects. The new standard will provide explicit path control, bandwidth and stream reservation, redundancy (protection or restoration) for data flows and distribution of control parameters for time synchronization and scheduling.

The new control protocol will provide explicit forwarding path control thus enabling the use of non-shortest paths. It will also integrate a tool for bandwidth and stream reservation along the forwarding path. Resiliency control mechanisms will be also provided for the data traffic. In addition, the new standard will support carrying control information using IS-IS for time synchronization and scheduling.

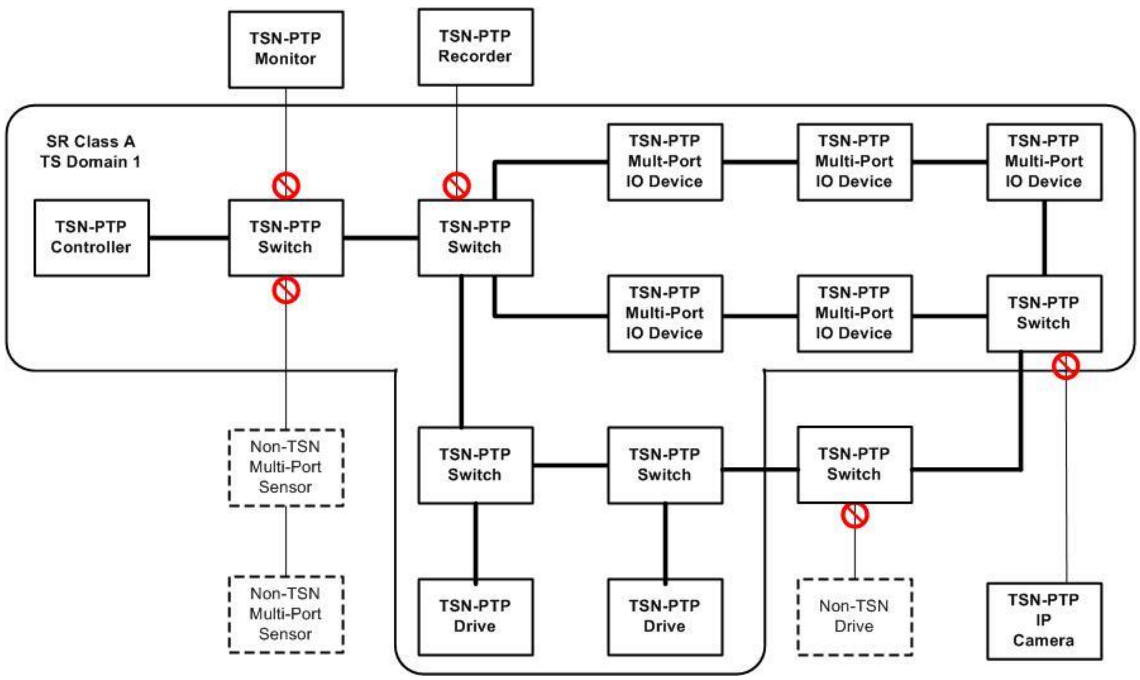


Figure 6: Seamless Redundancy 802.1CB

The Frame Replication and Elimination for Reliability standard (802.1CB – illustrated in Figure 6) specifies procedures, managed objects and protocols for bridges and end stations that provide:

- Identification and replication of frames, for redundant transmission.
- Identification of duplicate frames.
- Elimination of duplicate frames.

To achieve this, it is necessary to create and eliminate duplicate frames. This can be done in end stations and bridges. An existing set of protocols as an alternative to 802.1CB for duplicate frame generation are defined in IEC 62439-3

IEC 62439-3: Parallel Redundancy Protocol (PRP) and High-availability Seamless Redundancy (HSR), allows a dual-attached device to connect to two completely independent bridged networks, and to talk redundantly with another, similar, dual-attached device (illustrated in Figure 7). HSR defines encapsulation for a dual attached device to operate in a ring of similar hosts, sending data in both directions.

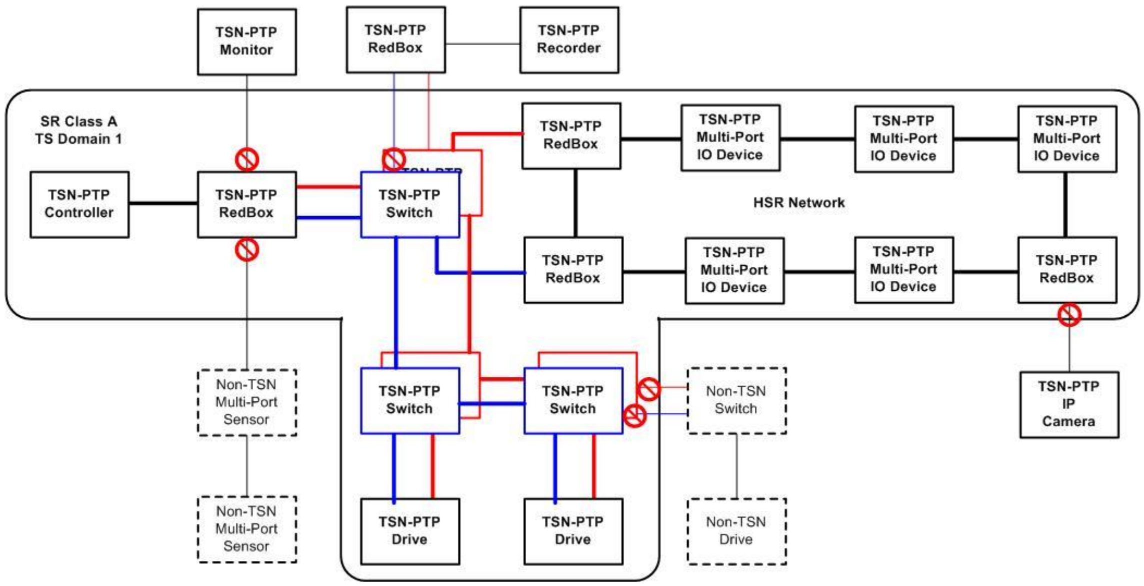


Figure 7: Seamless Redundancy – PRP and HSR

4.7. IEEE 802. 1Qci - Time Based Ingress Policing

This standard specifies procedures and managed objects for a bridge to perform frame counting, filtering, policing, and service class selection for a frame based on the particular data stream to which the frame belongs, and a synchronized cyclic time schedule. Policing and filtering functions include the detection and mitigation of disruptive transmissions by other systems in a network, improving the robustness of that network.

The current revision provides time-base Access Control Lists, and the MIBs to control them. ACLs can run on a closed-loop schedule, rather like P802.1Qbv scheduled output queues. ACLs identify flows, and can determine pass/fail, MTU size, and output queue.

Time-based ingress policing is an important consideration in Scheduled Networks as flows are strictly scheduled to exit one element a particular time every cycle and (within the bounds of necessarily known ambiguity) enter the next node. This allows for a simple time based mechanism that monitors the TSN flows on ingress to a TSN network element using time. If a packet of a flow arrives out of the “window” it is scheduled for, it is dropped. From a security perspective, this means that even if a scheduled flow is maliciously hijacked, the hijacker can gain no more than bandwidth allocated to that hijacked stream. This also eliminates many man-in-the-middle attack vectors as well as problems with “Babbling Idiots”.

5. TSN System

5.1. Overview

As indicated above, TSN is in many ways enhancements to AVB made to support critical control traffic often found in Industrial applications. Some of the key enhancements include:

- Centralized Control is better than Decentralized (e.g. hop-by-hop) Control
- A new shaping method to eliminate Congestion Loss

Centralized vs. Decentralized Control

The general consensus in the IEEE TSN working groups is that a centralized approach to creating the schedule for TSN elements is better than the hop-by-hop approach reflected in AVB. Some of the reasoning behind this is around the fact that there is a need for a “master” network configuration to automate and make easy to use more sophisticated network infrastructure required by the complex IACS applications. Such a controller role could also generate TSN schedules for the network elements. This eliminates the problems of a decentralized approach where reallocation of flows from one congested node to another less congested node to accommodate new flows is difficult (if not impossible) to accomplish. As such, the stream reservation mechanisms standardized in 802.1Qca have little relevance to a TSN system.

Time Based Shaping (802.1Qbv)

One of the key differences between what was done in AVB and what is being done in TSN is that with AVB time was only used by the endpoints to shape traffic, and the bridges simply passed time along – trying to distort it as little as possible. The idea with AVB was that time would be used by the endpoints for strict shaping of their flows and the bridges would use credits for shaping. However, with TSN, the bridges not only pass time through as before, but also use time to both strictly police the traffic on ingress (802.1Qci) as well as shape the traffic.

To address the new shaping mechanism, the 802.1Qbv standard is of primary concern. This shaper is analogous to the AVB Credit Based shaper defined in 1Qav, but instead of using “credits” it uses time gating to shape. How best to use the 1Qbv shapers is the subject of much debate, and there are many ways currently under consideration in the IEEE WGs as to how best to use this shaper to achieve the goals of bandwidth reservation, latency and jitter guarantees. This paper assumes the use of a shaper to implement Scheduled Networks, whereby the Centralized Network Config (CNC) calculates and distributes schedules for the entire TSN network. This is similar to existing forms of deterministic proprietary networks.

We envision an Industrial control application with TSN support therefore to look like Figure 8:

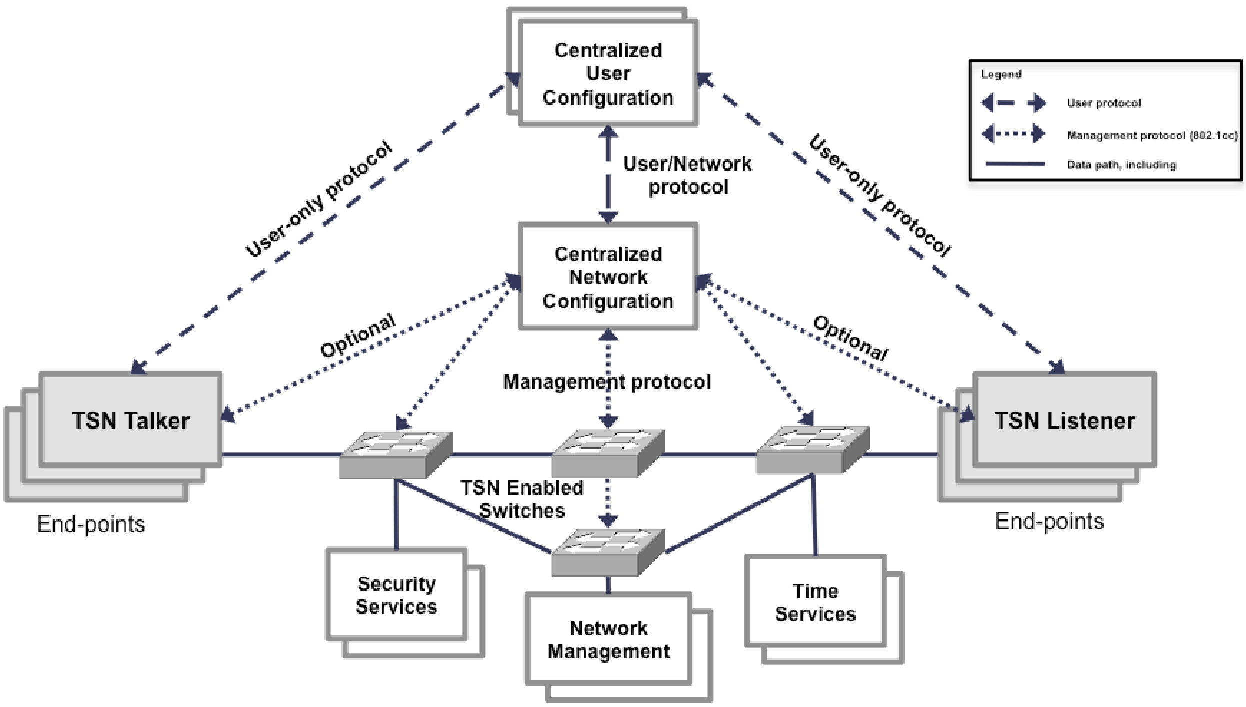


Figure 8: TSN System

These roles are not defined in the IEEE 802.1 working groups. We envision these roles to be defined in AVNU under the Industrial focus groups. Therefore, the exact definition and detail may be enhanced as those definitions are developed and ratified.

5.2. Roles in the TSN System

This section will describe the key envisioned roles in a TSN System, including:

- Centralized User Configuration (CUC),
- Centralized Network Configurator (CNC),
- TSN Network Elements (e.g. Switches),
- TSN End-points,
- Security Services,
- Network Management
- Time Services

Central User Configurator (CUC)

The "Central User Configurator (CUC)" is an Industrial Automation and Control tool used to configure the Industrial Automation and Control system. These tools are used to develop IACS applications and deploy the relevant configuration and programs on the IACS devices, such as PLCs, HMIs, Drives and I/O devices. For example, these applications would configure the ODVA certified EtherNet/IP devices, which may be Talkers and Listeners in the described system. Examples of CUCs include PLC Application Program Development/Maintenance software tools.

REST stands for Representational State Transfer, which is an architectural style for networked hypermedia applications; it is primarily used to build Web services that are lightweight, maintainable, and scalable. A service based on **REST** is called a **RESTful service**.

The CUC is not a defined concept by the IEEE. Its participation in TSN is limited to the user configuration. Therefore, it can be any tool used by the end user or an application (e.g. a user interface) that is used to configure TSN network configurations. The CUC will interface with the TSN systems, in particular the Centralized Network Configurator via a set of RESTful **service** APIs, through which flow requests can be made. A flow request would include Talker/Listener identity (e.g. IP address), communication frequency, availability requirements, latency/jitter requirements and other information required to establish a TSN flow.

AVnu, in its focus to establish interoperability and certification standards for TSN applied in industrial applications, is considering the development of standard APIs which CUC applications can use to communicate requests for TSN flows.

Centralized Network Configurator (CNC)

The CUC will interface with the TSN network via a set of RESTful service APIs, through which topology information, paths, latency, cycle times, etc. will pass to and from the CNC.

Another of the key elements in the architecture is the Central Network Configurator (CNC). From the IEEE perspective, the CNC is the primary center for all TSN network configuration.

The CNC is expected to take topology information (from either a “virtual topology” from the northbound API or a discovery of the “physical topology” from the southbound API) and identify the TSN-relevant capabilities for each network element and the network overall (e.g., switch fabric latency, link speeds, PTP precision, etc.).

Using the path constraints (“A talks to B with latency x, bandwidth y”) provided by the CUC, the CNC would compute a schedule that satisfies all the constraints or return errors if unable to satisfy the constraints.

If given a virtual topology, the CNC is then expected to discover the existing physical topology and verify that the virtual topology input by the CUC matches. The means by which a CNC will discover the existence and capabilities of TSN Network Elements will be defined in IETF RFC xxxx (this is the plan). Also as a part of the Topology Verification, the CNC is expected to verify that the capabilities of the various elements match with those provided by the CUC. For example, the CNC might receive a Virtual Topology from the CUC with a particular switch model and particular TSN endpoint, only to find that the switch is actually a different model and the cabling connections are not as expected. This would raise an alarm to the end user warning of the discrepancies and potential operational impact.

The CNC is also expected to distribute the calculated schedules to the various TSN network elements. This is done via YANG models (defined in 802.1Qcc) via either NETCONF or RESTCONF (network configuration protocols established by the IETF) through the southbound API or via YANG models back to the CUC via the northbound RESTful API. The reason for the latter, northbound path is because sometimes the CUC has the responsibility for delivering the schedules to the endpoints. Therefore, there are two main ways endpoints receive their schedules: (1) directly from the CNC via NETCONF/RESTCONF or (2) indirectly from the CUC via proprietary protocols determined by the end user CUC specific tools.

TSN Enabled Network Elements

TSN enabled network elements (e.g. switches or routers) will support the handling of TSN packets as well as interfacing with the CNC. The key TSN standards currently envisioned as requirements for a minimum viable application include:

- Time Synchronization via IEEE 802.1ASrev and/or IEEE 1588
- Traffic Shaping via IEEE 802.1Qbv
- Configuration from a CNC via IEEE 802.1Qcc
- Potentially Time Based Ingress Policing via IEEE 802.1Qci

The other TSN relevant standards (e.g. IEEE 802.1Qbu Frame pre-emption, IEEE 802.1Qch Cyclic Scheduling, etc.) are not currently considered requirements for an AVnu TSN network. They will certainly add functionality and improved performance of the TSN system, especially for industrial automation applications. AVnu is developing relevant standards for interoperability and certification.

In addition to the IEEE standards, AVnu is also considering development of specific interoperability standards so that any certified CNC can configure any certified Network Element, regardless of vendor.

TSN Enabled End-Points

End-points in a TSN system are meant as originations (talkers) and/or destinations (listeners) of TSN traffic. End-points in industrial applications may come with multiple ports. For a TSN system, its important to distinguish multi-port end devices that use multi-ports as paths in the network, i.e. there is some form of bridging/switching capacity. Other multi-port end-devices that only generate/receive traffic from multiple points in the network, for TSN purposes, are simply end-points.

TSN End-points without bridging capabilities should suffice to receive TSN schedules from the CUC, as the CUC are assumed to distribute end-device configurations, including schedules with which to send traffic.

Multi-port TSN end-points with TSN-capable bridging capacity will have to be considered by the CNC and receive schedules either directly from the CNC or, potentially, via the CUC. The options and specific mechanisms are still under development. The Figure 9 depicts TSN enabled, multi-port end devices with bridging capabilities.

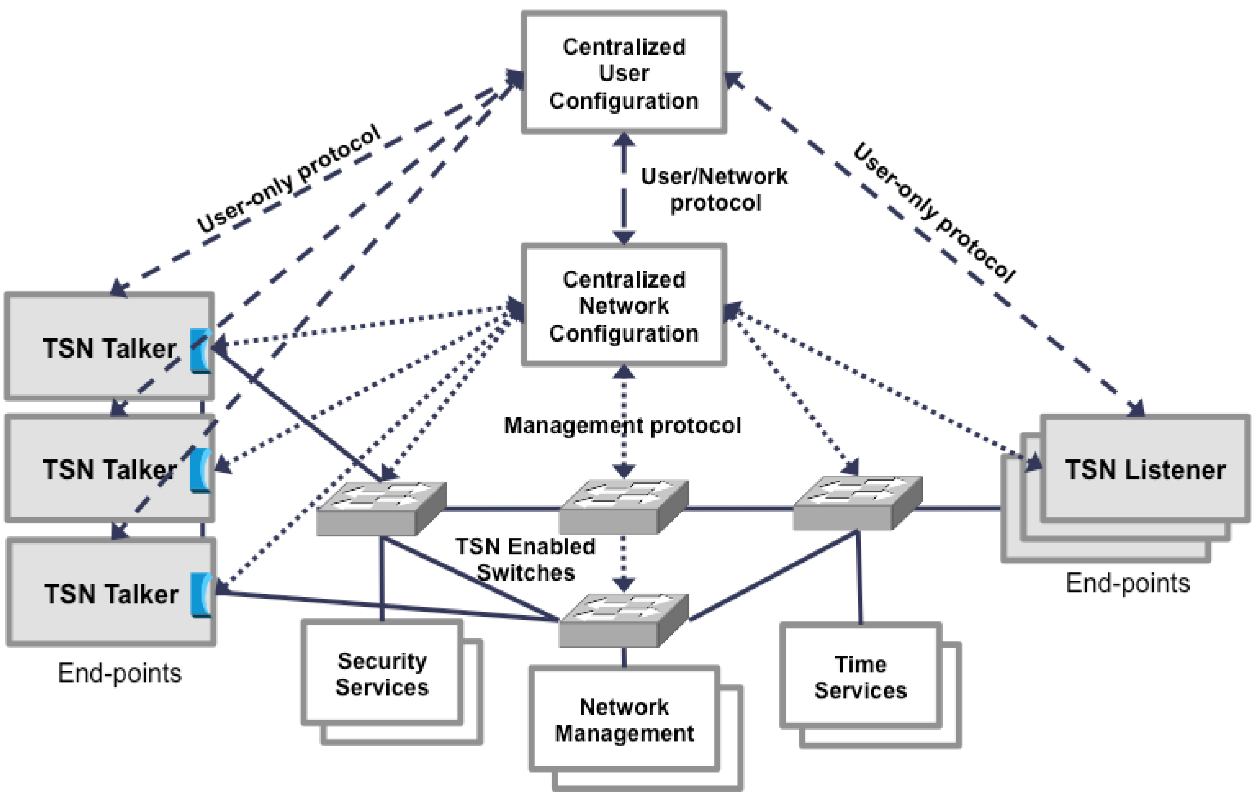


Figure 9: TSN System with Bridging TSN end-points

Non-TSN Enabled End-Points and Network Elements

The TSN community has certainly understood the need to incorporate existing, “Brownfield”, use cases (see Figure 10). In these, non-TSN end-points and network elements may need to exist in an overall TSN system. There are concepts under development to create “Proxy” functions that incorporate non-TSN end-points or network elements by providing gateways into and out of TSN systems. Without a Gateway, a non-TSN end-point can communicate as before, without TSN benefits. The below TSN System depictions shows how non-TSN talkers and listeners can be proxied into a TSN system and receive some, if not all, the enhanced network services of a TSN network.

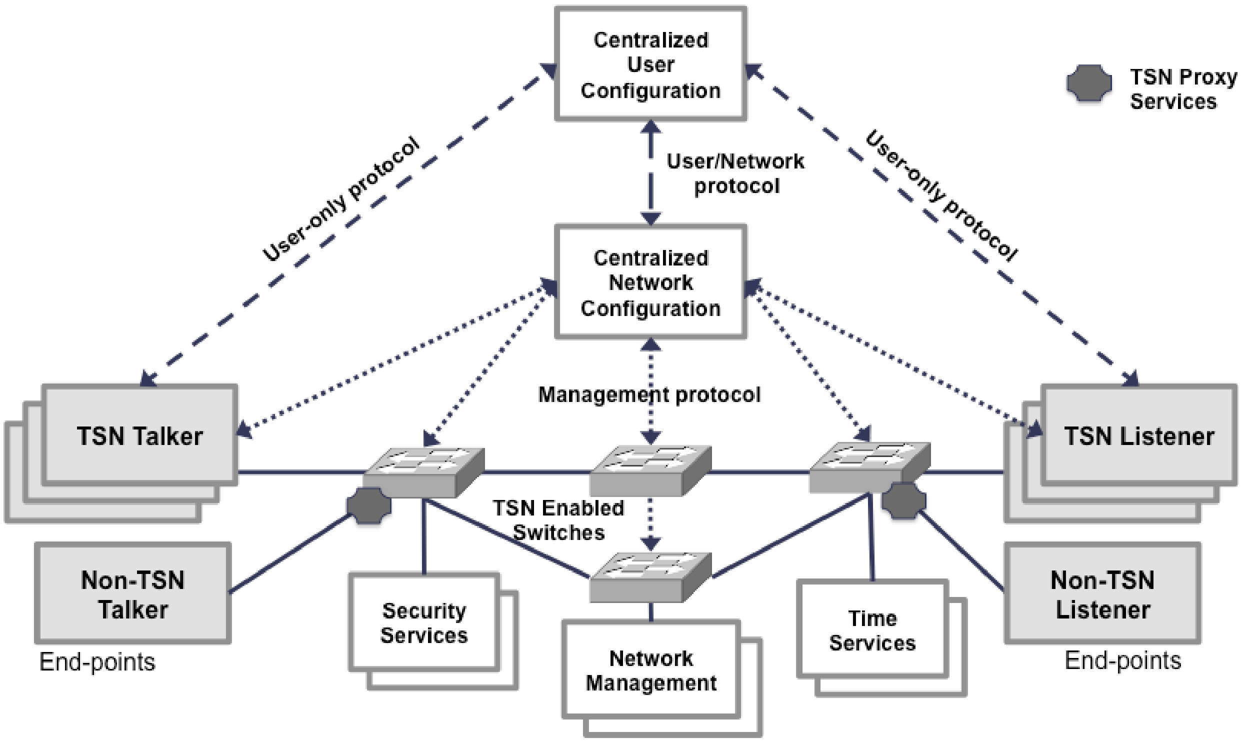


Figure 10: TSN System with non-TSN end-points

For the purposes of this paper though, the TSN Proxy Service is not included in the scope and may be the focus of a future paper.

Time services

TSN is a technology based upon a system-wide, precise sense of time. A key part of the TSN standards are the network-based precise time standards; IEEE 1588 (PTP) and IEEE 802.1AS-REV. So, not only is it expected that a TSN Enabled network element be able to pass precise time within the system, they must understand and use that precise time to perform their TSN functions. The bridges not only pass time through as before in AVB, but also use time to both strictly police the traffic on ingress (802.1Qci) as well as shape the traffic. That is the key difference between AVB and TSN, as described earlier in this chapter.

In the precise time protocols mentioned above, there are defined roles and responsibilities, such as Master clocks, Boundary clocks, Transparent clocks and Slave clocks. These functions will need to exist as part of a TSN system. Many of these functions will be incorporated into some of the TSN devices. For example, a TSN end-point may have a Grand Master function implemented and could be selected to provide that service for the system.

The AVnu alliance is looking at which specific Time protocols, profiles and configurations will best support a general set of industrial applications and systems. Time services will be a key aspect of the interoperability standards and certification AVnu will establish.

Network Management services

TSN is a new function within standard networking tool-kit. As such, those functions will need to be incorporated into Network Management services to provide operational and maintenance perspective on how the TSN function is performing. For example, is a TSN flow active, are invalid TSN packets being received and have any TSN flows seen disruption.

It's foreseen that new Management information bases (MIBs) may be required to describe the TSN services and functions to support the IETF defined SNMP (Simple Network Management Protocol) based network management applications.

Security services

There are a number of security considerations with TSN. These considerations will require interfacing with network-based Security functions, for authorizations, authentication and management reasons. The key considerations for TSN security include securing key TSN features and functions, such as:

- TSN flow requests and scheduling between the CNC and the CUC
- Control/Management plane security of TSN, e.g. schedule distribution between the CNC and the TSN Network elements
- Time masters and time distribution

AVnu is considering the security requirements on top of the TSN standards to create a secure, interoperable TSN system.

6. Summary

This paper outlines how the enhancements to IEEE 802.1 “Ethernet” known as Time-Sensitive Networks tackles challenging network requirements of industrial applications; such as availability, resiliency and real-time delivery. That enables a much broader adoption of standard networking and thereby connectivity of industrial devices and applications, which is a key tenet of the ODVA. The core TSN standards are stable and nearing ratification. Other groups, such as AVnu, are looking at creating a concept of how to implement TSN in an interoperable and certifiable fashion, for use by industrial application ecosystems such as the ODVA.

We think the ODVA should review the technology for potential adoption. Some of the enhancements, in particular those around time synchronization, may require changes or enhancements to ODVA capabilities such as CIP Sync. But, the benefit of the technology to the vendors, customers and overall industrial ecosystem are significant and warrant the work to change or enhance ODVA standards and products to use TSN.

7. References

7.1. IETF

The IETF has a number of relevant standards and working groups applying directly to TSN or being used in the overall TSN system. These include:

Routing - DetNet

In the IETF, a new working group for Deterministic Networking is in the creation process. The charter includes a requirement to align with IEEE 802.1 TSN. Its core objective will be to establish standards around routing TSN traffic across larger networks. See the mailing list archives for the proposed charter.

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7.2. AVnu Alliance

The AVnu Alliance is a community creating an interoperable ecosystem servicing the precise timing and low latency requirements of diverse applications using open standards through certification. Key market focus groups include Automotive, Consumer, Professional Audio-Visual (Pro AV) and Industrial. The Industrial Group in particular is focused on developing interoperable standards and certification guidelines based on IEEE TSN standards.

The TSN System described below will be a key concept around which AVnu will identify and/or develop standards to use and to eventually establish a certification capability.

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