EtherCAT and TSN - Best Practices for Industrial Ethernet System Architectures

Author:

Dr. Karl Weber, EtherCAT Technology Group

Abstract:

EtherCAT is the dominant technology in the fieldbus domain while the IEEE 802.1Q standard is the base of switching technology in office applications. TSN provides real-time capabilities in the IEEE 802 networks. The state of the art is to use EtherCAT at machine level and interconnect the machines with switches. Complex machines may require an enhanced communication infrastructure inside. The integration of EtherCAT segments in a TSN network can combine both technologies. No changes to the EtherCAT slaves are required. The adaptation can be done with an upgrade at the master side and a moderate extension in the switches connecting EtherCAT

Objective

Time Sensitive Networking (TSN) has been a well-known acronym since the task group was founded. The charter of the TSN TG is to provide deterministic services through IEEE 802 networks. TSN is a technology that can be used in a variety of applications. The initial design meant to be used for audio/video (A/V) streaming of a larger amount of data in a system with quite a few end stations. TSN extends the IEEE 802 best effort networking model by introducing a streaming concept. It supports a set of features to improve the real-time capability of streams.

Understanding TSN

The TSN Task Group

TSN task group is located in the IEEE 802.1 working group responsible for bridged networks. "Bridging" is the term used in standards activities, but the popular term is "switching". TSN improves the latency of frame transmission for a part of the traffic in IEEE 802 networks without losses due to congestion.

This implies changes in the switching world. However, it does not change the basic features of Ethernet networks, such as lack of efficiency of small amount of data per end node and flexible but time consuming complex forwarding procedures.

The communication between end stations via bridges in TSN is done by “streams”. The IEEE 802.1 standards use the term “talker” for the sender of a stream, and the term “listener” for the receiver of a stream. A stream is a unidirectional flow of data from a talker to one or more listeners. A stream requires stream identification in order to function in an IEEE 802.1 network. The destination MAC address and the VLAN-identification of an Ethernet frame can be used for that purpose.

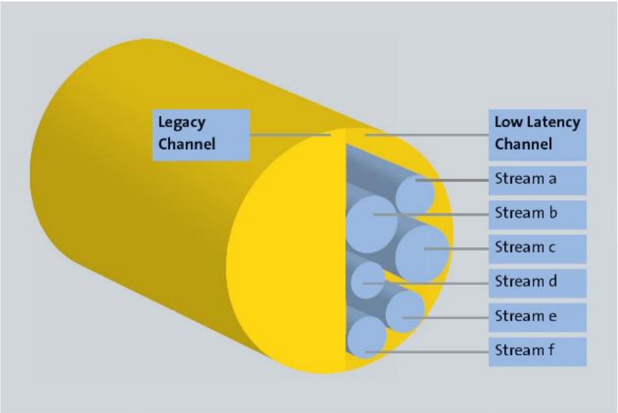

Figure 1. Streams are reserved communication channels within an Ethernet channel

TSN Standards

The TSN group has initiated several standardization projects which would be relevant for enhanced industrial Ethernet solutions. These projects include:

- **Improved synchronization behavior (IEEE 802.1AS-REV)**
  The previous version of IEEE 802.1AS had already specified a synchronization protocol for the timing of distributed clocks, based on the IEEE 1588 standard. It had promoted the integration into a standard Ethernet environment. However, compatibility with other 1588 Ethernet profiles was lost. The new version will incorporate the accepted features of one-step transparent clocks. The main area for improvement right now is the response to error situations. The new version can deal with different time domains in end stations.

- **Frame preemption (IEEE 802.1Qbu)**
  A major problem for deterministic transfer of time-critical messages is legacy traffic on the same network segment, where an individual frame can be more than 1500 bytes long. A frame interruption mechanism reduces the delay caused by long frames (specified within the IEEE working groups in Ethernet project P802.3br). Ultimately, this mechanism will require not only new network components, but also new Ethernet MAC (or NIC, network interface controller) in end stations.

- **Enhancements for scheduled traffic (IEEE 802.1Qbv and IEEE 802.1Qch)**
  The time control of send operations plays a key role in TSN. Just like in physical roadways, there may be traffic jams on information highways, and even with high-priority, real-time data and preemption, there may still be some variation in transmission times. Since the time-sensitive streams are transmitted cyclically, largely undisturbed communication can be accomplished by blocking less time-critical data just before cyclic communication starts. Cyclic Scheduling (IEEE 802.1Qch) forwards time-critical messages only to the immediate neighbor device during each cycle. This is advantageous if the cascading depth is low. It can be implemented without configuration efforts.

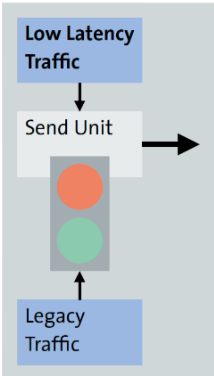

Figure 2. Blocking legacy traffic avoids interference with low latency traffic

- **Seamless redundancy (IEEE 802.1CB)**
  Although international standards already provide specified protocols for seamless redundancy such as High-Availability Seamless Redundancy (HSR), or the Parallel Redundancy Protocol (PRP), they require the complete data exchange between stations to be

designed for redundancy. The seamless redundancy in IEEE 802 networks apply only to individual critical data streams. This makes it possible to reduce the administration overhead.

- **Stream reservation enhancements (IEEE 802.1Qcc)**
  A stream reservation protocol was defined in IEEE 802.1 (MSRP) but with limitations in regards of scheduled traffic. IEEE 802.1Qcc was planned to be an extension of the existing reservation protocol. It has become clear, though, that it will not be feasible to meet all the extended requirements of TSN by merely extending the existing reservation protocol. Different approaches are proposed in the draft standard to achieve a certain level of performance. This ranges from a distributed model which does not provide optimized performance but allows a more flexible system up to a centralized configuration of the streams which may restrict the flexibility for a more optimized system but with significant change of the configuration of automation systems.

- **Per stream filtering and policing (IEEE 802.1Qci)**
  An additional aspect discussed by the experts is how to limit the effects of nodes that behave incorrectly. To this end, the incoming side (ingress) of the nodes must monitor the link traffic on a per stream base. If the bandwidth consumed expires a threshold, specific actions will be taken.

- **TSN Profile for Industrial Automation (Joint WG IEC/IEEE 60802)**
  This industrial automation profile selects features, options, configurations, defaults, protocols, and procedures of bridges, end stations, and LANs to build industrial automation networks.

EtherCAT combined with IEEE 802.1 Networks

It is not appropriate to compare TSN with an optimized Ethernet fieldbus (e.g. EtherCAT) as TSN is an add-on to the best effort principle of the switching technology enabling the combination of IT traffic and process data exchange with medium performance requirements. But higher bandwidth demands and scalability of control systems may be reasons to use TSN as backbone technology in complex machines in combination with EtherCAT segments.

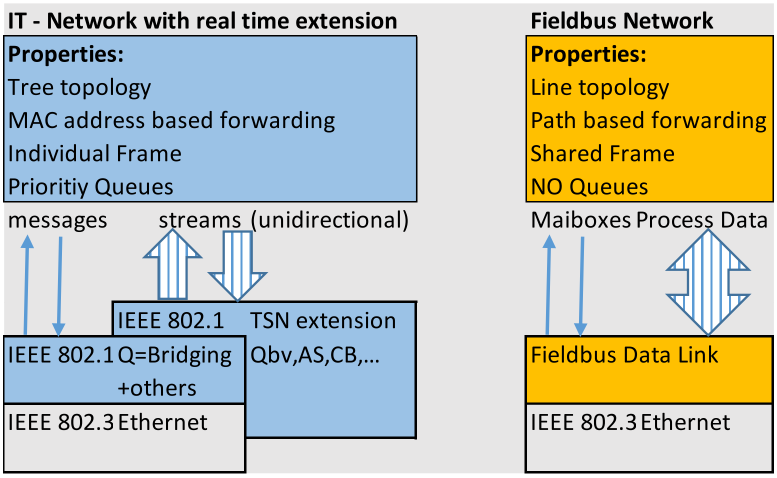

Figure 3. IT and Fieldbus have quite a few different properties

The structure and performance at the I/O level is quite different from a typical switched environment. The main elements are the master slave role in communication with a single control unit (master) and multiple cost sensitive field devices as slaves, low amount of real time data per device and the daisy chain connection of the devices. Adding a network infrastructure between the master and the slave segment transforms a physically separated network into a logically separated network. This enables a higher level of flexibility but will maintain a guaranteed latency as well as a predictable frame loss rate.

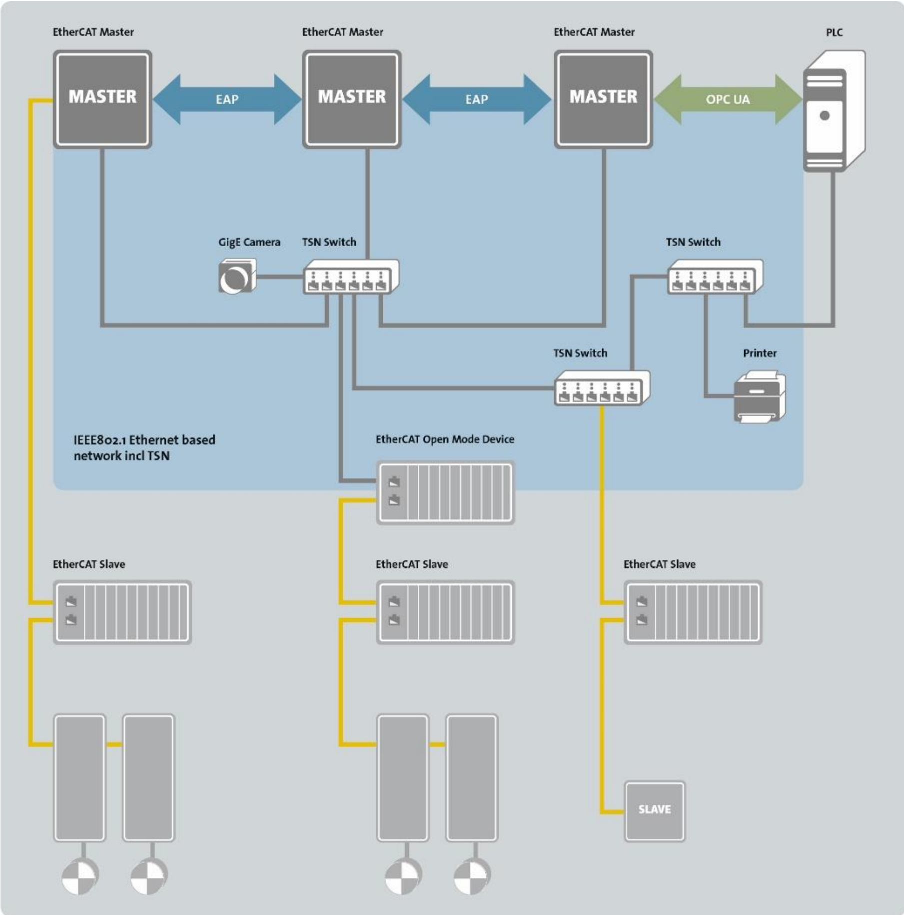

Figure 4. TSN enables isolation of EtherCAT communication in a network

How it works

The EtherCAT TSN integration approach does not mix both technologies, but defines a seamless adaptation to use both technologies with their respective advantages. EtherCAT uses the stream concept of TSN with a one-to-one relationship between talker and listener. At least two streams are established between a master and an EtherCAT segment for exchanging process data and other important information. One from the master to the slave segment and vice versa. Another pair of streams may be used for control purposes of EtherCAT slaves to transfer service data. This kind of communication may have different traffic characteristics and can be put in a lower priority class.

Further communication requirements, such as collecting data for condition monitoring, may use another pair of streams.

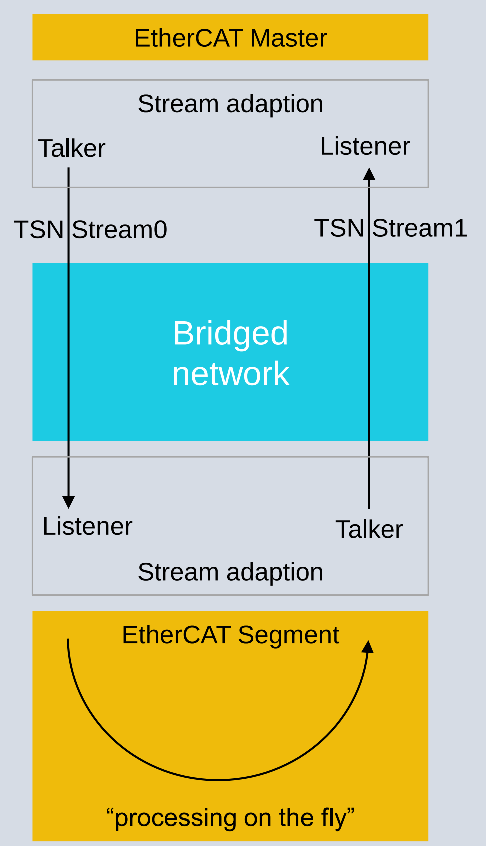

Figure 5. Stream adaptation and TSN provides a virtual Ethernet channel

The EtherCAT TSN profile describes how to use TSN streams to transmit complete EtherCAT frames within a bridged network. The configuration of the bridges and other bridge-related service functions can be used as specified in the TSN context. The basic requirements of a virtual EtherCAT channel in the master is to have a dedicated identifier of the related EtherCAT slave segment, the send interval and offset and the amount of data. These are the parameters defined for send streams at the master side. The maximum delay in the slave segment completes the schedule.

The architectural view is as follows: The identification of EtherCAT segments will be unique within a logically isolated part of the IEEE 802.1 network (can be a machine or a group of machines). The identification is a 12-bit value, which can be set up by an EtherCAT device within or next to a segment. Identification can be done at the switch port connecting the EtherCAT segment. It is recommended to use VLAN identification as segment identifier in the IEEE 802 context.

The stream adaptation uses the identification to set-up the unique stream destination addresses needed for TSN. This addressing is deduced from identification of the segment and the stream selector, combined with the EtherCAT specific identifier.

The mapping principle is straightforward: The EtherCAT fields will not be changed by TSN and the TSN fields are not used for EtherCAT processing.

Synchronized operation is possible in such networks by sending the frame with a fixed interval from the IEEE 802.1 network into the EtherCAT slave segment. The send time into the EtherCAT segment is determined by the worst-case latency. TSN allows synchronous operations distributed over multiple segments without specific additional efforts in the EtherCAT slaves. The quality of synchronous operation depends upon the TSN clocks (IEEE 802.1AS). It is recommended to use bridges that provide a precise timing in the 100 ns range between the EtherCAT master and the first slave to maintain the high degree of precision in the network.

TSN positioning

TSN does not provide an application layer and will not challenge the EtherCAT Device Protocol at the field level.
TSN will make inroads in existing and upcoming solutions, e.g. EtherCAT Automation Protocol (EAP), OPC UA Publisher/Subscriber.

EtherCAT and TSN: A Perfect Match

Adding EtherCAT segments as structuring elements in TSN reduces the complexity in backbones by using shared frames for a group of slaves and can enable a machine internal configuration. EtherCAT segments shall be protected from unwanted traffic by TSN while increasing the efficiency of the combined EtherCAT/TSN system. EtherCAT and TSN combined can enhance the flexibility at the automation cell level while maintaining total control of the various automation tasks.

In conclusion, EtherCAT allows perfect integration with TSN technology without changing the basis of EtherCAT technology.