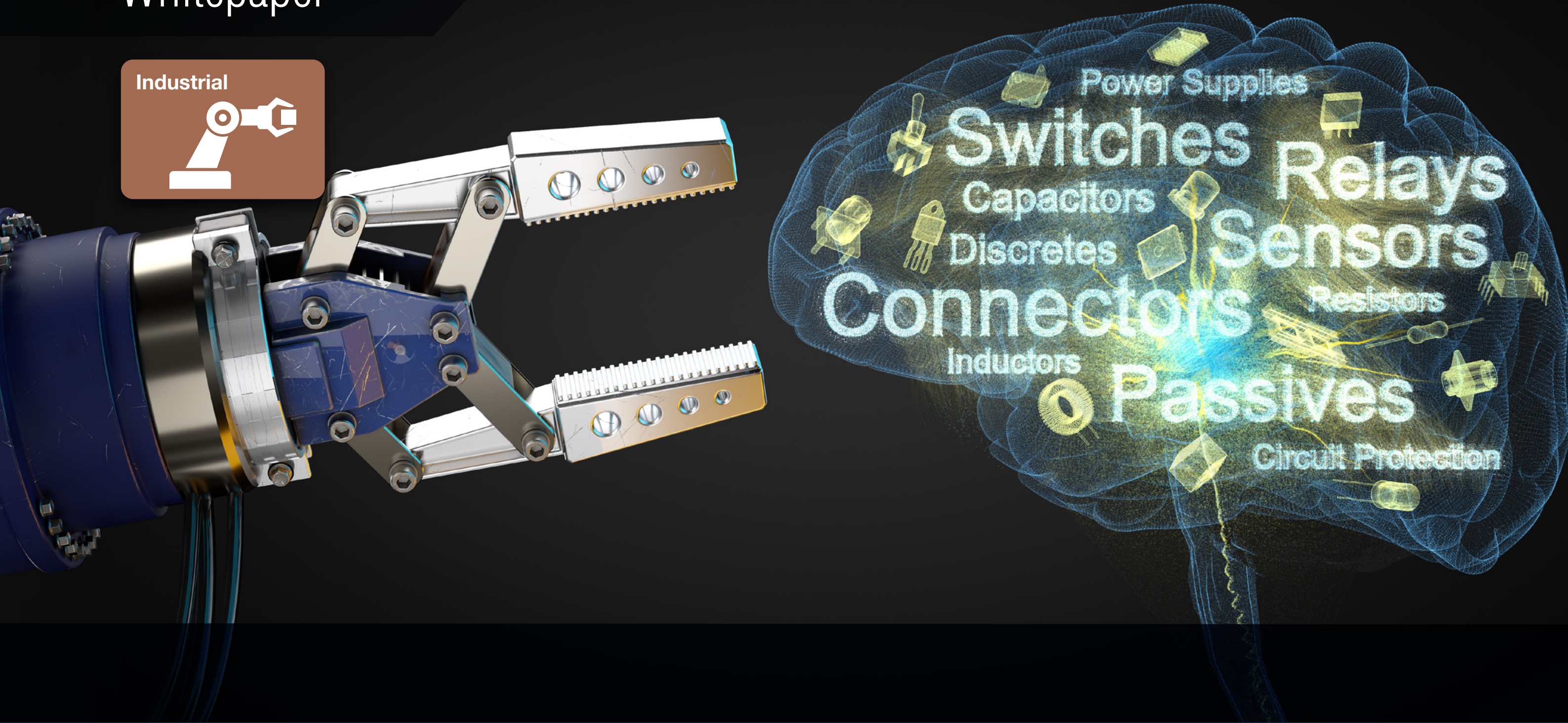
Whitepaper

Industrial



Ethernet Evolution for Deterministic Industrial Applications

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The Specialist in Electronic Component Distribution

Introduction

IEEE 802.1 Time Sensitive Networking establishes standards for real-time communication over Ethernet, relieving reliance on proprietary extensions and creating the opportunity to enhance the free flow of information between operational (OT) and IT networks, including the Cloud. Moreover, OT networks can take advantage of the scalability and security enjoyed by Ethernet-based IT networks.

This whitepaper examines the historic need for Ethernet extensions to support time-critical and real-time communication, and how TSN now standardizes capabilities at OSI network layers 1 and 2 to allow time-critical and best-effort data over a unified network. Although TSN promises to simplify infrastructures, to the benefit of end users and equipment providers, ongoing work to ensure interoperability remains important.

Industrial and IT Connectivity in the Digital Enterprise

The success of Ethernet as a technology for local area networking between IT systems has led to adaptations for operational (OT) purposes such as industrial automation, networked security systems, and automotive networking. The need for robustness to withstand harsh environments is satisfied through hardware such as industrial-specific RJ45 connectors. Transformers that provide electrical isolation are also typically employed in industrial applications. In addition to ensuring connected equipment is protected from surges and transients, they also are used for signal conditioning of single-ended to differential signals. An example is the Bourns SM51589PEL transformer. As Ethernet deployment becomes more widespread, the ability to power sensors and other network connected devices through the Ethernet cable can simplify installation and the need for additional power distribution and transformers. Murata, for example, offer the MYBSP range of isolated DC/DC converters specifically for POE applications.

More than robustness, Industrial Ethernet applications are characterized by the requirement to deliver data to the receiving device within a timely fashion, often with hard real-time requirements. These include automation such as control of process equipment or conveyor belts, where precision timing is required, or controlling CNC equipment or robotics that rely on real-time position sensing and motor control to ensure perfect coordination. Other time-sensitive applications include distributed monitoring, where measurements from multiple locations – such as from vibration sensors placed throughout a machine or a structure – must be synchronized to allow accurate analysis.

Several industrial Ethernet implementations are currently in the market, such as Modbus TCP/IP, EtherCAT, Ethernet/IP, Powerlink and Profinet. The differences between them require users to commit to just one, to the exclusion of others.

With the advent of the IIoT, enterprise networks must respond to extra demands such as increased bandwidth allowing the operations network to handle the large quantities of data emanating from huge numbers of data channels, and direct this towards IT systems and the Cloud for storage and analysis. In addition, assets connected to OT networks now need to protection against cyber-attacks that is both strong and able to keep pace with new and evolving threats.

These demands for interoperability, scalability, and security strengthen the case for a unified networking technology, standardized within the Ethernet specifications, capable of satisfying the industrial demands for low latency and deterministic real-time response while also supporting conventional Ethernet best-effort traffic.

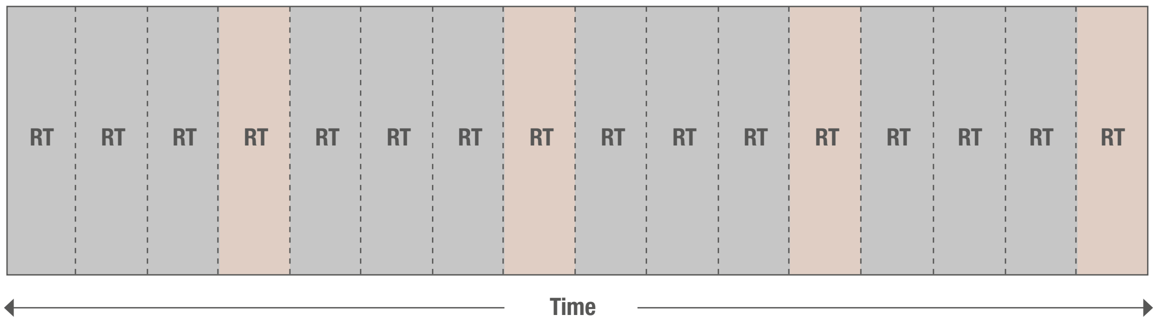
Standard Ethernet and Time-Critical Traffic

In standard Ethernet networks, communication is regulated according to the CSMA/CD - Carrier-Sense Multiple Access with Collision Detection. All devices share a common medium and coordinate sending data by sensing when the network is idle. The Ethernet frame contains the address of the destination device. All devices on the network receive each packet, compare the destination with their own address, and discard the packet if there is no match. Because the medium is shared, collision detection enables devices to detect if another device is transmitting at the same time and wait for a random period before retransmitting.

Network switches enable unpredictable delays resulting from collisions to be avoided. The potential for latency to be reduced and delays to become deterministic and thus better suited to industrial applications is clear. However, some problems remain. Typical commercial store-and-forward switches wait for the entire datagram to arrive before forwarding, which can result in delays or even loss of data if there is insufficient buffer capacity for long datagrams, particularly if many switches are cascaded. Industrial Ethernet topologies can use switches that begin forwarding before the full datagram is received. With Quality of Service (QoS), which enables prioritization of Ethernet datagrams, a protocol such as Profinet that uses Ethernet as a shared medium can achieve soft real-time performance with cycle times down to 1ms and jitter in the range 10-100µs. However, this not adequate for the most demanding applications. Different approaches have evolved.

Profinet Isochronous Real-Time (IRT) is an example of a hard real-time industrial Ethernet extension. The available bandwidth is divided into time slices, one of which is reserved for high-priority IRT traffic (figure 1). A high-accuracy clock is needed to determine when the IRT time slice should begin and end. IRT relies on elements of the IEEE 1588 specification to provide this precision clock. It must also buffer non-IRT data transmitted during the IRT reserved slices.

Figure 1. IRT time slices ensure dedicated bandwidth for hard real-time traffic.[1]



Other proprietary industrial Ethernet specifications take different approaches to achieving low-latency or hard real-time performance. Real-time Ethernet fieldbus protocols such as EtherCAT or SERCOS manage bandwidth and ensure real-time performance, but must control the Ethernet medium themselves.

These differing approaches show that there are multiple ways to create the extensions to Ethernet that are needed to support hard real-time networking. Unfortunately, their proprietary nature prevents interoperability and tends to lock customers into certain topologies, equipment types, and vendors. Currently, there are over 40 fieldbus variants and more than 15 different Industrial Ethernet variants.

Interoperability and vendor neutrality are not the only casualties of proprietary industrial Ethernet specifications. They also tend to be designed for a specific speed, such as 1Gb or 10Gb. To keep pace with the growing data demands of IIoT, industrial users need to take advantage of the bandwidth scaling associated with the evolution of standard Ethernet, not to mention security provisions.

As extensions, industrial Ethernet protocols exist at layers above Ethernet, which defines layers 1 (physical layer) and 2 (data link layer) of the standard OSI network stack (figure 2). If suitable features could be implemented in the lower layers as part of the standardized Ethernet technology, the need for proprietary extensions to enable real-time communication could be eliminated.

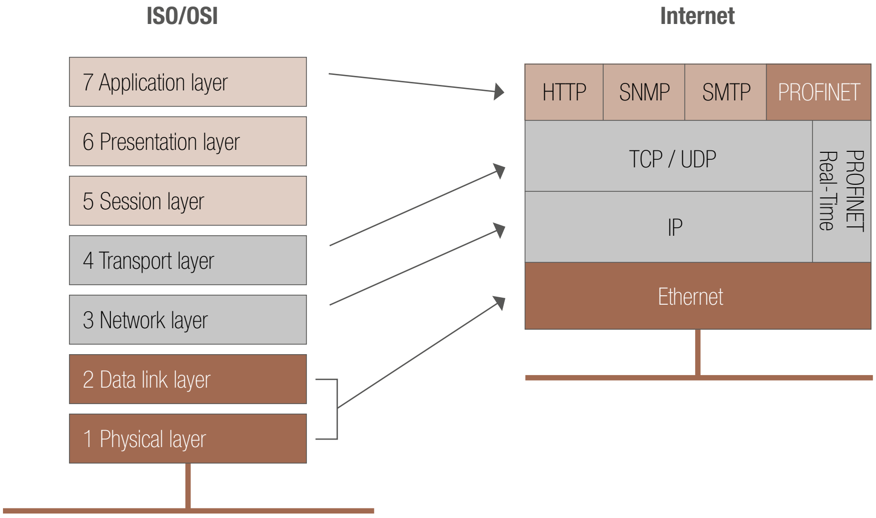


Figure 2. Ethernet standardizes layers 1 and 2. Application-layer protocols are needed for end-to-end communication.[2]

Time for TSN?

Time Sensitive Networking (TSN) introduces several mechanisms, standardized within the IEEE 802.1 Ethernet specifications at layers 1 and 2, to make this possible. These include IEEE 802.1AS, which covers timing and synchronization for time-sensitive applications, and IEEE 802.1Q that integrates several individual standards such as 802.1Qbv for time-aware scheduling and 802.1Qcc for TSN system configuration. IEEE 802.1AS is based on a profile of IEEE 1588, which defines the Precise Time Protocol (PTP). Although IEEE 1588 was developed for time-sensitive applications, it is not a part of IEEE 802.1 and contains optional profiles that complicate interoperability between equipment from different manufacturers.

The standards that comprise TSN enable ordinary Ethernet to handle the actions needed to eliminate congestion for time-critical traffic and provide low and guaranteed worst-case end-to-end latency – such as reserving resources for time-critical traffic, and applying queueing and shaping. In this way, TSN enables deterministic network communication satisfying the timing and control needs of industrial automation without proprietary extensions to Ethernet protocols. The TSN standards also allow for network topologies, such as star, ring, or line, and numbers of switches in the network. Redundancy is also catered for. At the same time, TSN enables a single bridged Ethernet network shared by diverse applications with differing QoS needs to carry time-critical traffic and non-TSN best-effort data.

By standardizing the provisions for time-sensitive networking, TSN brings several important advantages. One is scalability: whereas previous real-time extensions have been defined for a specific data rate, TSN can scale with the increasing bandwidth provided by successive generations of the standard Ethernet specification. In addition, the security mechanisms already deployed in IT networks can be applied to OT networks with TSN, potentially enhancing resilience and accelerating access to new updates introduced to tackle emerging cyber threats.

Moreover, a common standard for real-time communication has the potential to unify the market and thus enable industrial Ethernet users to benefit from economies of scale similar to those enjoyed in the IT world. Network installation and maintenance can also be streamlined, and TSN equipment can be used in areas other than the factory floor, such as building automation, energy distribution, automotive control networking, and professional audio and video. Indeed, the standardization work that resulted in TSN began as IEEE 802.1 Audio Video Bridging (AVB) to support low-latency, synchronized audio and video. TSN contains a published profile for AVB (802.1BA) as well as cellular fronthaul (802.1CM), and ongoing standardization work should result in a TSN profile for industrial automation based on IEC/IEEE 60802. The profiles simplify selection of various features and options and provide help to build networks for use cases such as AVB and fronthaul, intending to enhance interoperability and ease deployment.

It is also worth noting that, in addition to bringing the advantages of standard Ethernet to the industrial space, TSN also allows real-time communication to be extended beyond OT networks thereby supporting the development of new IT applications.

Ongoing Drive for Interoperability

While TSN has successfully standardized real-time communication capabilities at the lower layers, the opportunity for ongoing use of competing protocols at the application layer remains. This could be seen as a potential barrier to interoperability. However, it is also true that networks currently reliant on Industrial Ethernet protocols can continue using these while adopting TSN as desired.

Other industry initiatives are working to ensure interoperability, to maximize the benefits of network convergence leveraging TSN. The Industrial Internet Consortium has created the TSN Testbed as a platform for equipment providers to test implementations and interoperability at plugfest events. The AVNU Alliance is leveraging the work of the IEEE and IEC, such as the 80802 joint working group, to create test plans and procedures that will help manufacturers create TSN products that are interoperable with those of others.

Given the strong role anticipated for TSN in enhancing industrial Big Data applications, it is important that a standard solution for communication between industrial controllers and the Cloud is also being sought. A consortium of automation and IT suppliers is promoting OPC UA over OPC UA over TSN as the most suitable solution, leveraging the speed of OPC UA's publish/ subscribe (pub/sub) technology.

Digital enterprise networks can take advantage of the commonality, scalability and security that come with standardized Ethernet, leveraging an Industrial Ethernet application-layer protocol at the field level, using OPC UA for vertical communication to the Cloud (figure 3).

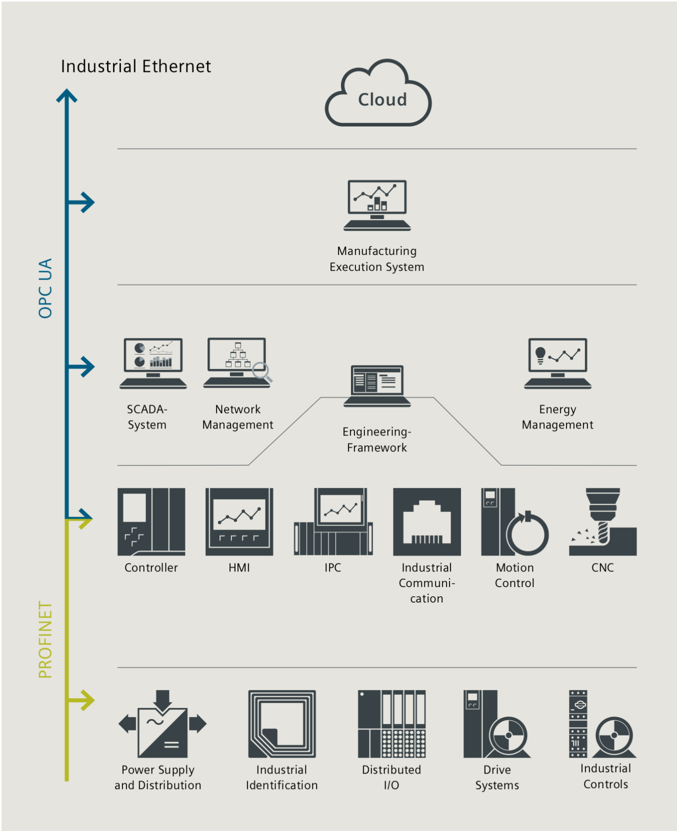


Figure 3. A unified infrastructure may mix Industrial Ethernet application-layer protocols with OPC UA.[3]

Conclusion

TSN brings easy interoperability and economies of scale to OT networking use cases such as industrial automation, professional audio/video, building automation, and automotive control and infotainment. Moreover, and driven by the emergence of the IIoT – with its demands for greater bandwidth, scalability, and security – TSN lets OT communications benefit from the ongoing evolution of the standard Ethernet specifications developed to protect IT networks and enhance performance.

TSN standardization work is ongoing, including the development of the 60802 profile for industrial automation. Interoperability initiatives are also live, aiming to ensure that ecosystem players and users of networked automation can enjoy the maximum potential benefits of standardized real-time communication over Ethernet.

[1] *https://profinetuniversity.com/profinet-basics/isochronous-real-time-irt-communication/*
[2] *http://profinews.com/2017/07/profinet-and-tsn/*
[3] *https://assets.new.siemens.com/siemens/assets/public.1532340167.2e1b43b59229eba58e69098f26a7c5e4f2461457.dffa-b10293-02-7600-opc-ua-flyer-72dpi.pdf*

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