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White Paper

TSN

Time Sensitive Networking

Introduction

Depending on the era and application, industrial automation technology has been influenced by a wide variety of fieldbuses and protocols for connecting individual field devices and control systems since the 1980s. So far, these specific fieldbuses have satisfied the real time conditions of the relevant application while remaining incompatible with one another.

In IT by contrast, Ethernet has established itself as the dominant data transmission technology. The Ethernet used today was set out in IEEE 802.3 in 1983. Layer 1 (physical layer) and Layer 2 (data link layer) are thus defined in line with the OSI network reference model. Familiar modes of data transmission include LAN cable at 100Mbit/s; 1Gbit/s; 10Gbit/s, WLAN (IEEE 802.1) or fiber optics.

Hitherto it was customary to keep IT apart from OT (operational technology) or the industrial automation layer. In the wake of Industry 4.0 and the Internet of Things (IoT) this approach is undergoing a radical rethink. IT and OT should and must be dovetailed in order to converge the physical and virtual worlds. This is the only way to record and analyze key sensor and production data in big data systems and cloud applications and perform targeted production improvements.

It would seem natural to use Ethernet for data transmission in both worlds, however the current (standard) Ethernet does not meet real time requirements, as it can only send data packets on a best effort principle, thus precluding time-synchronize data transmission.

A new transmission standard called "Time Sensitive Networking (TSN)" is therefore gaining ground. The TSN standard is specified in der IEEE 802.1 Working Group, see: *(http://www.ieee802.org/1/pages/tsn.html)*

TSN is based on (standard) Ethernet and enables deterministic OT data transmission with guaranteed latency and QoS, parallel to conventional IP traffic (from IT, for instance) on the same medium, thus paving the way towards merging the two worlds.

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Overview of Real Time Communication

When it was developed, the success of the first Ethernet standard was not a foregone conclusion. After all, who remembers the Fiber Distributed Data Interface FDDI, Asynchronous Transfer Mode ATM or Token Ring these days?

Ethernet meanwhile dominates all areas of local data transmission. All?
Not quite, for where real time is demanded, Ethernet has had to take a back seat up to now.

Figure 1 shows an overview of system solutions for real time conditions in industrial communication.

Fig. 1 System solutions for real time communication

While it uses Ethernet, EtherCAT cannot be combined with Ethernet on the same line. EtherCAT has special hardware that is not suitable for Ethernet.

EtherCAT data programs are processed on the fly, so read and write access is always confined to a small section of the overall telegram, which is immediately forwarded to the next EtherCAT device. Frames are only processed by the EtherCAT device in this direction and forwarded to the next device until all the devices have been covered. The last device returns the telegram to the master on the second pair of wires in the cable in the forwarding direction. In doing so, EtherCAT always forms a logical ring structure, irrespective of the selected topology. As such, EtherCAT is an autonomous fieldbus that cannot be directly integrated into the Ethernet or future TSN.

Nowadays, established fieldbuses like PROFINET IRT, Ethernet IP, SERCOS III, ETERHNET POWERLINK can transmit data in real time. However, they can only do it on a physical Layer 2 that has been modified for this purpose (specific hardware). So they are island solutions that are not compatible with one another and do not comply with the Layer 2 standard for Ethernet.

Time Sensitive Network (TSN) is now standardized in IEEE 802.1 and is based on a standard Layer 2 for Ethernet with synchronization, small or fixed latencies for data packets and negligible packet loss.

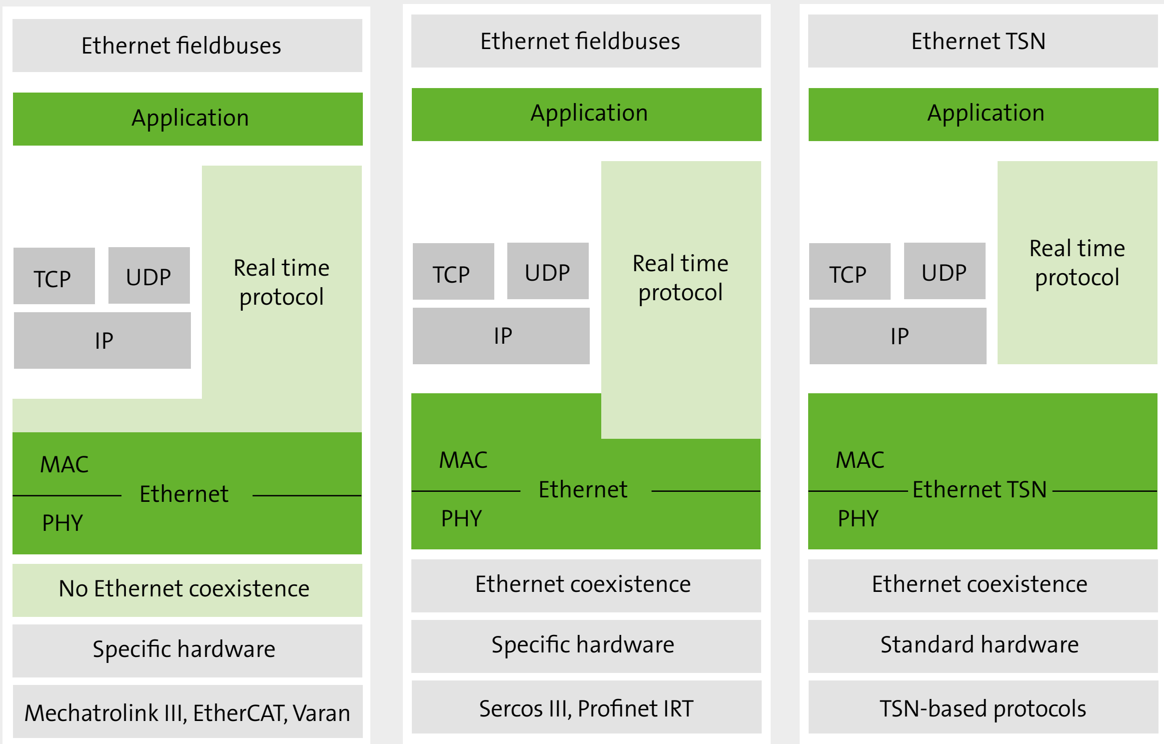

Fig. 2 The development from fieldbus to Ethernet TSN in the OSI reference model

5G Wireless Ethernet

5G has the potential to offer wireless connection for a variety of industrial applications (Ethernet). In the long term, many of the communication technologies used today may be converged in the future. This will enable a considerable reduction in the number of relevant industrial connection solutions. TSN usability for 5G services is being examined at the moment in the ITU-T/IEEE.

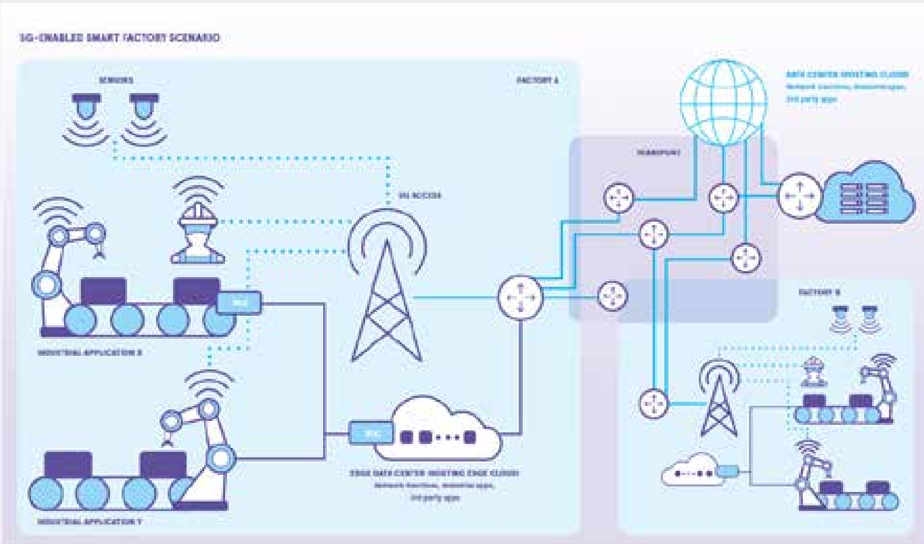

Fig. 3 5G smart factory scenario *Source ZVEI (AMPERE 2.2018)*

Due to the availability of two transmission frequencies 3.7-3.8 GHz and 26 GHz for private networks, industrial plant owners can deploy independent 5G base stations. (According to ZVEI "Industrie 4.0 Conference / 12 December 2018)

Use case		Availability	Cycle time (ms)	Payload (bytes)	No. of devices	Service area (m)
Motion Control	Pressure m.	>99.9999%	< 2	20	>100	100x100x30
	Tool m.	>99.9999%	< 0	50	~20	15x15x3
	Packaging m.	>99.9999%	< 1	40	~50	10x5x3
Mobile Robot	Cooperative	>99.9999%	1	40-250	100	1000x1000
	Video rem.	>99.9999%	10-100	15-15k	100	1000x1000
Mobile panels with safety function	Cutting m.	>99.9999%	4-8	40-250	4	10x10
	Mob. crane	>99.9999%	12	40-250	2	40x60

Table 1 Use cases in automation *Source ZVEI: 5G*

Functional reliability is set to become one of the key aspects of 5G applications in industrial environments.

TSN Standard

Although the most widespread network technology, Ethernet only operates on a best effort principle for transmitting data packets in a network. TSN (Time Sensitive Networking) turns Ethernet into a deterministic network technology. The most important features of TSN and its future standards are:

- Synchronization of network elements: endpoints, switches and gateways
- Controlled, calculable delays (latency)
- Prioritization of traffic flows
- Guaranteed bandwidth reservation
- Redundancy (ring)
- Reliability

TSN consists of many standards that were/are exclusively developed for various aspects and functions. The table below shows active and pending standards currently being developed for TSN:

TSN standards	Title	Remarks
IEEE 802.1Qbv	Scheduled Traffic	approved 2015
IEEE 802.3br	Interspersing Express Traffic	approved 2016
IEEE 802.1ASrev	Timing and Synhronisation	09.09.2019 Draft 8.1
IEEE 802.1Qbu	Frame Preemption	approved 2015 / HW-specific
IEEE 802.1Qch	Cyclic Queuing and Forwarding	Final 2016
IEEE 802.1Qcr	Asynchronous Traffic Shaping	approved 2019, ongoing
IEEE 802.1QCB	Frame Replication and Elimination	Final 2017
IEEE 802.1Qca	Path Control and Reservation	Final 2015, ongoing in P802.1Q-Rev
IEEE 802.1Qcc	Stream Reservation Protocol (SRP)	Final 2018
IEEE 802.1Qci	Per-Stream Filtering and Policing	Final 2016

Table TSN standards (from http://www.ieee802.org/1/pages/tsn.html)

TSN is aimed at standardizing functions on OSI Layer 2 to let different protocols use the same infrastructure. TSN is therefore fully compatible with conventional IT networks and all higher layers can benefit from the availability of TSN functions (Figure 2).

The challenge is to organize the coexistence of critical and non-critical traffic in the same network so that real time characteristics and performance are not compromised. If this ensured, production and IT networks can use the same infrastructure.

TSN will not be established as an overall standard for real time Ethernet. It should be seen in the light of a toolkit, whose new additions expand the possibilities of Ethernet deployment. So, from this, we can surmise that many new projects will be included that are still being developed at the moment (see Table 2).

The many separate standards are explained by the fact that the TSN Task Group aims to keep the individual systems separate. They can be combined as you like, although they can also be deployed singly for straightforward inexpensive components.

Many TSN systems have to be directly implemented in the hardware of switches and microprocessors. Chip producers like Broadcom, Intel, Marvell, Texas Instruments, NXP, Renesas, Hilscher are already involved in the development of TSN standards for this purpose. Manufacturers of the relevant products have teamed up in the Avnu Alliance (*https://avnu.org/*) to form a TSN ecosystem, guarantee interoperability and program applications. This alliance also certifies products.

TSN in Automation

Several incompatible Ethernet-based fieldbuses are currently deployed in automation.
As the new standard for lower communication layers, TSN unlocks higher interoperability to satisfy deterministic requirements at field level.
Along with OPC UA- standards for the application level, an open architecture is created.
OPC UA TSN links the IP-based world of information technology with protocols for hard real time requirements.

Users can send time-sensitive data over the same network as standard data at rates of up to 10 Gbit/s with TSN.

At SPS IPC Drives 2018, the OPC Foundation announced a lot of details about OPC UA over TSN: for one thing, it is now extending its standardization and harmonization activities for OPC UA to include TSN-enabled Ethernet networks for the field level. And on the other, it has managed to gain Siemens' support in this venture. This means that the Field Level Communications Initiative launched by the OPC Foundation is firmly based with a wide circle of supporters.
(Source: DIGITAL FACTORY JOURNAL 30.09.2018)

In all, since 27.11.2018, the subject of OPC UA over TSN is now supported by a total of 22 companies including ABB, Beckhoff, Bosch-Rexroth, B&R, Cisco, Hilscher, Hirschmann, Huawei, Intel, Kalycito, Kuka, Mitsubishi Electric, Molex, Omron, Phoenix Contact, Pilz, Rockwell Automation, Schneider Electric, Siemens, TTTech, Wago and Yokogawa.

see press release "Major Automation Industry Players join OPC UA including TSN initiative“ of the OPC FOUNDATION:

https://opcfoundation.org/news/press-releases/major-automation-industry-players-join-opc-ua-including-tsn-initiative/

The manufacturers of all currently relevant Ethernet-based fieldbuses have therefore acknowledged TSN as the future common transport layer.

PROFINET over TSN

PROFINET over TSN requires the following four 4 IEEE amendments, three of which have already been finalized: IEEE 802.1Qbv, IEEE 802.1br, IEEE 802.1Asrev (see table 2) and IEEE 802.1Qbu, definition ongoing.

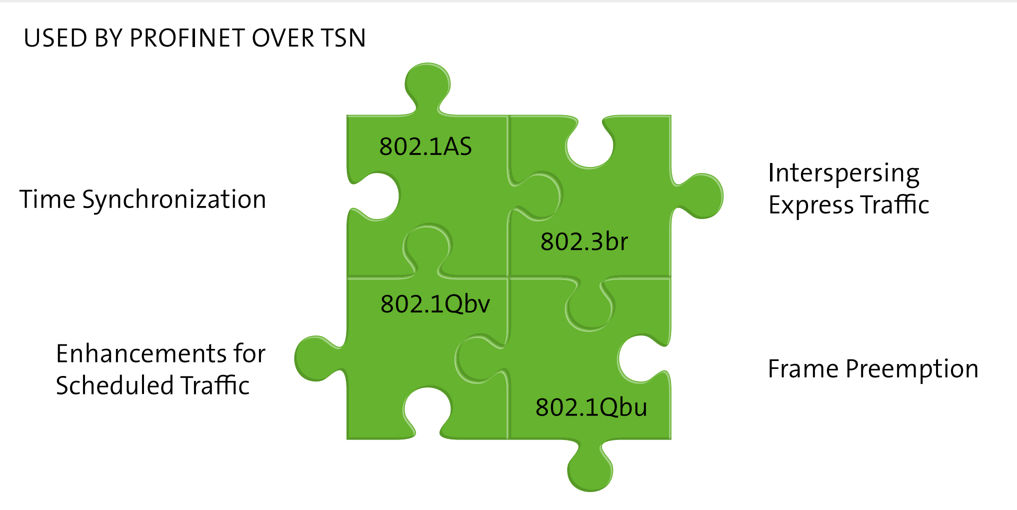

Fig. 4 IEEE TSN-related amendments used (Source PI Dec. 2018)

PI (PROFIBUS & PROFINET International) aims to publish the specification for the use of PROFINET over TSN in the first quarter of 2019.

TSN will be used consistently as Layer 2. PROFINET RT (PN V2.3) can also be integrated into a PROFINET over TSN network. PROFINET IRT (PN V2.3) will remain consistent as a separate Layer-2 and is not compatible with TSN.

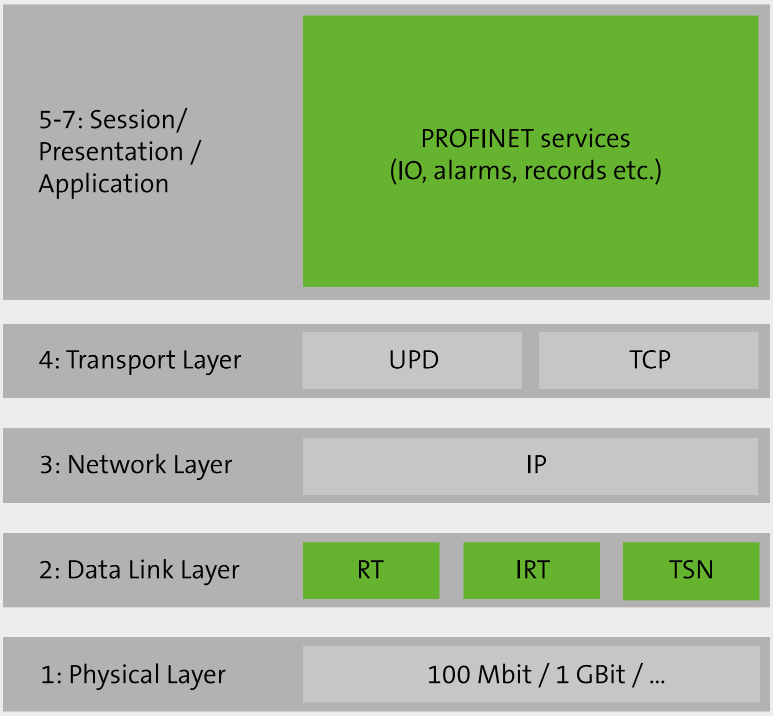

Fig. 5 PROFINET & TSN (Source PI HMI 2018)

PROFINET mapping and services are defined in an OPC UA Companion Specification. In 2017, a PI OPC Working Group launched an in-depth analysis based on use cases in order to find a comprehensive solution. The initial aims are diagnosis and asset management in order to generate added value for vertical integration.

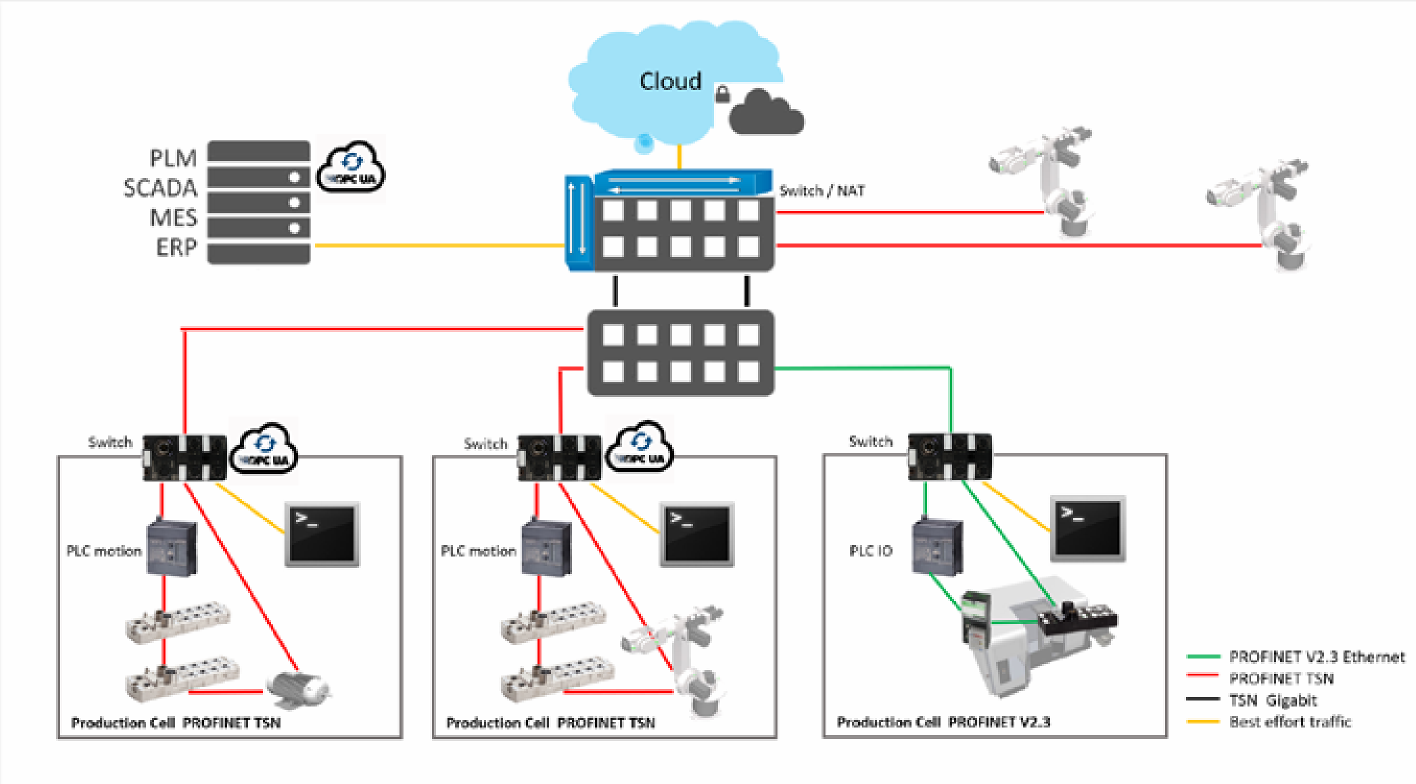

Fig. 6 Example of a PROFINET automation TSN hierarchy for Industry 4.0

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About Murrelektronik

Murrelektronik is an international, family-run company in the automation technology sector with more than 2700 employees. The vision and mission of Murrelektronik is to optimize machinery and plant installations and thus generate a competitive edge for its customers. Decentralization is the company's speciality: the control layer of machinery and plant is optimally connected to the sensor-actuator layer with proven concepts and innovative technologies. Close customer cooperation is vital to develop customized solutions for optimum machine installation. High product availability rounds off the Murrelektronik portfolio and the customer experience.