Getting your TSN product to market

Introduction to TSN product development

Executive summary

Connected Industries heavily rely on data and the insights that can be gained from it. In such facilities, it is fundamental to set up seamless interconnectivity from the smallest sensor on the factory floor up to enterprise-level systems and beyond. Only in this way it is possible to set up data-driven operations for smart manufacturing.

To help companies create such futureproof infrastructures, automation vendors should adopt the latest and most promising developments in industrial networks in their products. One of them is Time-Sensitive Networking (TSN), an innovative technology for Ethernet-based industrial communications that can support smart operations within current facilities as well as tomorrow's Connected Industries.

How can automation vendors deliver advanced solutions that leverage this technology? What do they need to consider in order to create successful, highly competitive solutions?

This white paper discusses the CLPA TSN development ecosystem, what solutions can be used and how to integrate TSN-compatible functions in existing devices using conventional industrial Ethernet. The document also includes recommendations for automation device manufacturers on the successful implementation of TSN and delivery of key solutions for future-oriented applications.

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Chapter 1 - Introduction

Technology trends & Industry 4.0

Industry 4.0 enabling technologies such as the Industrial Internet of Things (IIoT) are helping businesses to develop an increasingly digitalised, connected and data-driven manufacturing landscape. By adopting technologies that support digital transformation strategies, companies can create smart, interconnected factories. The vision of the factory of tomorrow is one of machines, production lines, plants and entire supply chains that communicate with each other to enhance productivity, efficiency and flexibility. The benefits that can be achieved with these frameworks are significant.

For instance, companies can combine shop floor data with higher enterprise-level information and perform advanced Big Data analytics to gain unique business intelligence. This actionable insight can then be leveraged to set up self-regulating automated processes to optimise manufacturing activities and deliver high-quality products while minimising cycle times. So called “value chains” are dependent on highly interconnected enterprises building on established strategies such as just-in-time manufacturing to reduce inventory costs while increasing flexibility. Moreover, businesses can streamline maintenance activities by predicting potential equipment failure ahead of time using condition-based monitoring and scheduling repairs to minimise downtime.

To help companies thrive in a world where competition is fierce and customer demand requires increasingly agile operations, automation vendors need to offer advanced solutions to help customers realise smart manufacturing strategies. A key technology to achieve this is Time-Sensitive Networking (TSN), which was specifically developed by the IEEE 802.1 working group to enhance standard Ethernet and support futureproof capabilities.

TSN functionality

The core benefits offered by TSN are determinism and convergence.

Determinism is fundamental to supporting time-critical communications on the factory floor, as it ensures the predictable delivery of data by minimising latency and jitter. This, in turn, supports real-time applications and provides the foundation for convergence.

Convergence, the second key ability of TSN, enables companies to merge different traffic types onto a single network without affecting the performance of shop floor communications. This is fundamental to sharing operational insights and hence increasing process transparency across an enterprise, which can then be used to derive insights to optimise manufacturing facilities and entire organisations.

Since TSN is an extension of standard Ethernet, it is also interoperable with existing network technologies and devices. Hence it can be used alongside existing devices, reducing system investments.

TSN market opportunities

TSN is recognised across different sectors as the future of industrial Ethernet and industrial communications. Consequently, interest in and adoption of this technology are growing.

These trends offer particularly exciting commercial opportunities for automation device vendors. By developing and releasing state-of-the-art products with TSN capabilities, vendors can increase their market coverage and gain a competitive advantage.

To quickly tap into this market, device makers can leverage their existing portfolios to produce TSN-compatible products. Thanks to software or straightforward hardware modifications, it is often possible to update existing industrial Ethernet products to support next-level capabilities. This can also offer continuity to end users, who can rely on proven components and setups in their facilities.

To help vendors understand how to leverage this opportunity, the following chapters of this white paper will discuss the technology behind TSN, its development workflow and the methods available to develop compatible automation products.

Chapter 2 - Brief overview of TSN technology

IEEE 802.1 standards

TSN technology is defined by IEEE 802.1 standards [1], the most important for industrial communications being IEEE 802.1AS [2] and IEEE 802.1Qbv [3], as they are at the core of deterministic performance and convergence.

More precisely, the IEEE 802.1AS standard provides mechanisms to synchronise all devices within a network with high accuracy, thus supporting precise control of latency and jitter for transmissions across the network. This in turn defines predicable behaviour and provides the basis of determinism.

Using the network-wide time reference provided by IEEE 802.1AS, IEEE 802.1Qbv temporally organises the data transmissions based on their respective priorities, facilitating the convergence of different types of data traffic in a deterministic manner.

To achieve this, the time-aware shapers (TASs) defined by IEEE 802.1Qbv make network switches aware of the cycle times for real-time traffic. The periodic time windows created by the TASs, reproducing a Time Division Multiple Access (TDMA) model, make possible to merge different types of traffic and prioritise any urgent data. As the timing parameters of the TASs are shared by fully-synchronised network devices, these are aware of when time-critical data are sent and received.

In effect, some of these time intervals can be scheduled and reserved for priority time-critical traffic, while non-time-critical, best-effort traffic is held to avoid any interference. Departure and arrival times of this traffic are therefore predetermined. In this way, TSN can ensure deterministic communication for hard real-time applications.

Also, the ability to support network convergence enables users to blur the lines between operational technology (OT) and information technology (IT). The ability to share information between the worlds of OT and IT can help businesses to gain comprehensive, data-driven insights to enable smart manufacturing – and it is at the core of the Industrial Internet of Things (IIoT).

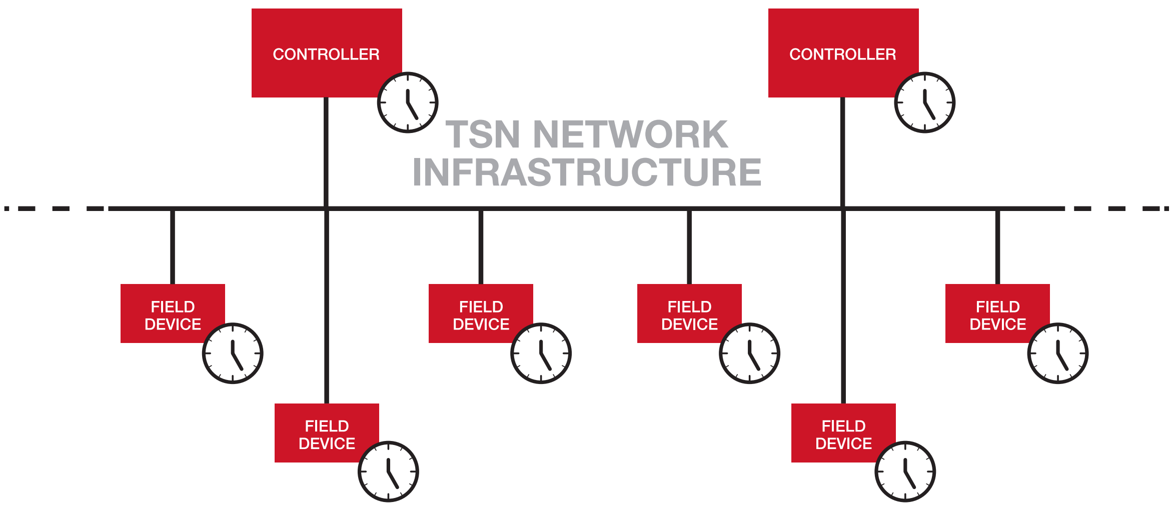


Fig. 1 - By using IEEE 802.1AS, all devices on the network have a shared time reference. This provides deterministic communications by controlling latency and jitter. Hence traffic travels across the network in a predictable manner.

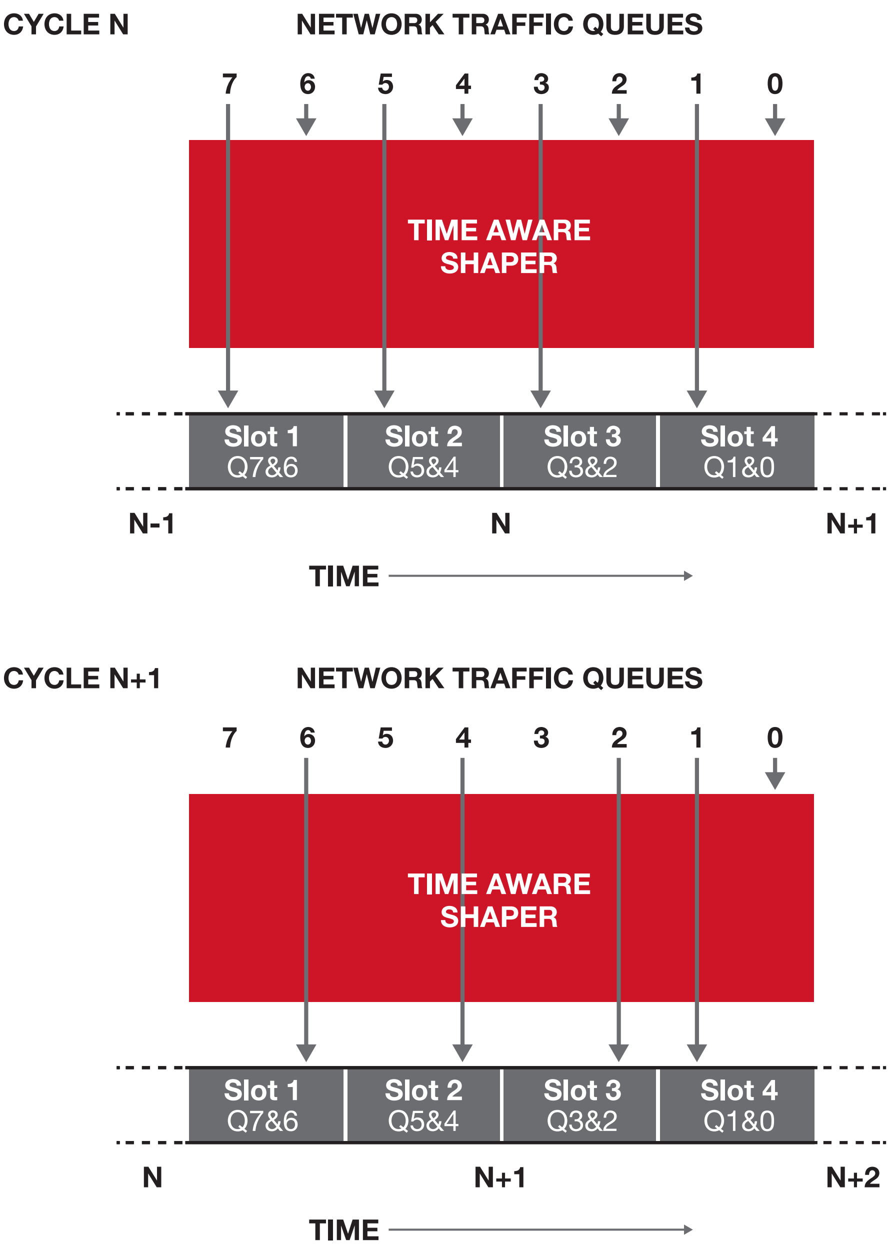


Fig. 2 - IEEE 802.1Qbv allows transmission time slots for different network traffic queues to be defined. This controls when each traffic type has access to the network. In this example, four time slots are divided between eight queues. Within each slot, the higher numbered queue takes priority.

The importance of gigabit bandwidth

It is clear that Industry 4.0 is increasing the amount of data being produced by devices and systems. To deal with this ever-increasing volume of data, additional bandwidth is necessary. This is driving the move towards gigabit Ethernet infrastructures, which offer significantly more bandwidth than the 100Mbit standards used in the past. TSN is well placed to benefit from this increase, since it was not conceived with any particular bandwidth requirements in mind. Hence it provides a scalable solution for the network systems of today, tomorrow and beyond.

Chapter 3 - Overview of TSN development workflow

It is clear why offering TSN-compatible products is highly beneficial for automation vendors. To successfully develop devices that provide added value to end users, it is necessary to consider the capabilities, performance and nature of the products themselves from the outset.

First, companies need to clearly define what the product should be able to do. This will determine the type of station that is to be developed, such as master or remote. Also, the required performance level, in terms of speed and synchronisation accuracy, needs to be decided. Once these features are set, vendors can look for existing products that may be suitable for an upgrade to deliver TSN functions.

Businesses then need to select the most suitable development method for the TSN device that they are producing. The decision should be based on the pre-identified performance requirements, along with a consideration of the suitability of their existing development methods.

Another key decision that companies need to make is where to conduct the product development activities. Should these be carried out using in-house resources? Or is it best to rely on a specialist contractor?

Once the TSN device is ready, it also needs to be certified in order to prove that the necessary technology requirements are met. To do this, vendors should undertake relevant third-party certification. This offers an independent assessment of the communications performance that can offer extra assurance to customers.

When all these tasks have been completed, the TSN-compatible device can be introduced to the market.

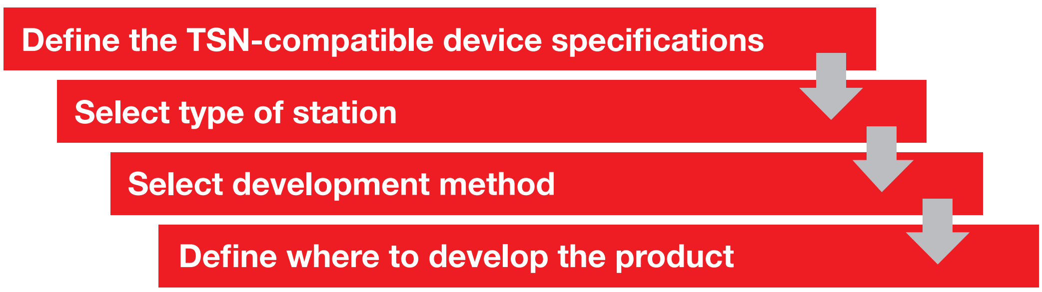


Fig. 3 - Workflow summary

Chapter 4 - TSN development methods

Introduction

In order to implement TSN for industrial communications, end users and OEMs need both a suitable network technology as well as automation devices that can support this technology's capabilities. This need is met by vendors offering innovative products, which address customers' needs while increasing their competitive advantage in the marketplace. In general, to minimise costs and time to market, a vendor will look to use their existing platforms and tools where possible to develop these products.

Hence it is important that the type of industrial Ethernet technology used offers an open development ecosystem that includes options that match the vendors' existing methods. The broader the range of options, the better chance there is of catering to the needs of the most vendors. Typically, this means there should be both hardware and software solutions in addition to different bandwidth options, such as 100Mbit and gigabit.

Each development method will offer different advantages while perhaps being more suited to one application or another. It is therefore important for developers to know what options are available and how they might fit with their existing designs and hardware architectures. This chapter provides an overview of the different ways that a TSN product might be developed.

Deciding what kind of TSN product to develop

The first consideration that vendors should take into account is to decide what type of device network functions they want to support, i.e. what is the role of the end product within a network. In the context of this white paper, this means master, remote or local stations.

- Masters manage networks by controlling the traffic of other stations. This may include cyclic (synchronous) and transient (asynchronous) transmissions. Typical master devices include PLCs and industrial PCs.
- Remote stations, conversely, are overseen by masters and represent field devices, such as I/O, valve blocks, HMI, inverters and servos. They can perform 1:n cyclic and transient transmissions with other stations. Transient communications are handled by client/server functions.
- Local stations are often PLCs or industrial PCs. They can perform n:n cyclic transmissions with themselves and the master. They can also perform 1:n cyclic and transient transmissions with other stations. Transient communications are also handled by client/server functions.

Vendors should also consider whether they want to develop devices for motion or safety applications. The first typically require full TSN support to provide the necessary axis synchronisation capabilities. This can typically deliver microsecond synchronisation accuracy as would be required in demanding applications such as a printing press.

Safety devices are another key market area that can also be served by TSN networks. One implementation method is to use a software stack combined with a safety stack to provide a "black channel" approach. This is a specialised application area, which is outside the scope of this white paper.

New design or migrate existing products?

Once the type of station has been selected, vendors should decide if they should add TSN capabilities to an existing product, or if new product development will be necessary. In the case of a new product, after taking market requirements into account, a specification that fixes what the new TSN-compatible products should do, the capabilities they should offer and the investment required to implement this is essential. These elements are key to defining the performance, ease of implementation and time-to-market.

In the case of upgrading existing products, while this may decrease the time to market and investment required, it may also require compromises that may not fully exploit the potential of TSN.

In order to offer further development flexibility, it is possible to decide what level of performance is required. This allows the right balance to be found between device performance, development investment and time to market. One option is to follow a generally software-based approach. This can offer a quick upgrade of existing devices. Thus, it offers a key tool to speed up the adoption of this innovative technology, although the device performance may be lower.

The converse of this is a generally hardware-based approach, which although may require additional development effort, can avoid the compromises in performance that software development may require.

Finally, bandwidth and heat dissipation are key considerations to determine the communication speed. While a gigabit PHY is preferred for best performance, this has to be balanced against thermal considerations, which may be an issue for smaller devices, or those with advanced ingress protection ratings.

Once these decisions have been made, it is crucial for businesses to be able to access a suitable development method, whether software or hardware. Hence selecting a network technology that can offer a comprehensive open development ecosystem is essential.

The following sections explore what development ecosystem solutions and features are available for the creation of TSN-compatible products.

Software solutions

A software protocol stack, or just “stack” is a collection of independent components that work together to support the execution of an application. It can be configured to address the specific needs of a product. In the case of TSN, this should provide support for IEEE 802.1 standards. They generally have low operational overheads, meaning they can run on economical CPUs platforms. These are usually microprocessors or microcontrollers.

Generally, software stacks are compatible with a variety of real-time operating systems, such as RTLinux, VXworks® or µITRON. Nonetheless, device makers should check the specification of the software stack they intend to utilise to ensure compliance.

A TSN stack is typically part of a software development kit (SDK). This is a collection of software development tools, often in a single installable package, that support the creation of the required solutions.

Software methods offer perhaps the fastest solution to provide TSN capabilities to existing products, as they reduce in-house development time and costs for vendors. Furthermore, they are generally portable, so they can be applied with minimal changes. Hence, they offer a versatile solution to businesses interested in quickly implementing TSN.

Hardware solutions

In order to harness the full potential of TSN, it may be beneficial to consider a hardware-based solution.

While this route may require more investment and development time, the benefit is a more competitive product and longer lifecycle. Several different solutions are available, enabling vendors to select the right platform for their needs.

ASIC/LSI

Application Specific Integrated Circuits (ASICs), also referred to as dedicated communication Large Scale Integration (LSI), are integrated circuits made of a “hard-wired” design of logic elements. These can be found with two different structures. One may offer a network interface that includes a switch and possibly one or more PHYs. The other takes this design and adds a CPU.

Ideally, two network ports should be available to allow “daisy chain” or line topologies without needing an additional switch. However, this will depend on the platform being used.

With their hardwired nature, they are intended to support a specific application very effectively but cannot be changed, unlike Field Programmable Gate Arrays (FPGAs), which will be discussed afterwards.

Since ASICs address a specific function, this determines the design of the chip. This means that while ASICs offer rigid, application-specific designs, they are able to achieve high performance in terms of speed and energy efficiency. Hence, in applications where the system functions are fixed for the service life of the product, ASICs can offer a good combination of high performance and economical cost.

In addition, the fixed nature of ASICs makes them quick to implement, as no programming is required, streamlining time to market. They may also have compact dimensions, making them suitable for smaller devices. This, combined with their often cost-effective nature, makes them suited to high-volume mass production of economical, compact devices.

Built-in/embedded modules

Embedded module solutions, or built-in modules, cover a wide range of devices that usually combine a processor core, such as a microcontroller or a microprocessor, for key operations and a network interface that focuses on data exchange. These two elements can help the product - as well as the resulting application - to achieve high performance, as the functions can be divided between them. In addition, they can include supplementary components to support the intended use.

Thanks to these features, developers choosing built-in embedded units can benefit from an easy to integrate solution as well as a flexible framework to exchange the network interface to suit specific applications.

Based on the setup of a specific embedded module, vendors can offer systems with various degrees of complexity. These can range from relatively simple solutions with low levels of complexity, with a single microcontroller chip, to complex designs composed of several units. Therefore, developers can select the solution that best addresses their needs and intended use. Moreover, vendors may be able to include these as add-ons or expansion boards to support TSN functions in existing products.

Finally, these solutions are generally compact and economical. These help developers reduce time-to-market and keep production costs down, while fitting in most applications, even if there are space constraints.

FPGA/IP core

Field Programmable Gate Arrays (FPGA) are integrated circuits whose logic functions can be specified via hardware description languages (HDLs), typically VHSIC Hardware Description Language (VHDL) or Verilog. These solutions are based on programmable (and reconfigurable) interconnects that link different configurable logic blocks (CLBs), which are made of basic logical units, known as ‘slices’. These, in turn, typically feature look-up-tables (LUTs), flip-flops (FF), different types of multiplexers and a network of carry logic to implement complex logic functions.

The CLBs within FPGAs enable developers to implement virtually any logical functionality. Therefore, these devices can be programmed according to the requirements of the desired application and can be used as a basis for the design of complex logic structures. For instance, they can fulfil the role of microprocessors, network interfaces or a combination of both.

Besides being field programmable, these devices can also be reconfigured, offering a high degree of flexibility to vendors, as their functions can be altered during their service life. Moreover, it is possible to redesign a single part of a FPGA while leaving the other areas unaltered.

The level of adaptability and programmability offered by FPGAs make them particularly suitable for applications where the component design and functions may require upgrades during a device’s lifetime. Similarly, these solutions can also support prototyping and validating activities.

To have the FPGA provide the required functions for the application (TSN in this case), these functions are usually defined by an intellectual property (IP) core, which configures the elements of the FPGA to provide these capabilities. Hence it is often the case that an off the shelf FPGA can be selected and programmed with a third-party IP core. This provides a high degree of design flexibility

FPGAs are extremely powerful and flexible because of their fully customisable designs. However, their cost may limit them to higher end products with lower production volumes where this is offset by the functionality they can provide. In effect, they result in typically larger printed circuit board (PCB) areas and higher product costs. These factors typically limit the scope of FPGAs to lower production volume devices for high-end applications. Their advanced functions may also result in higher power consumption, an aspect that should be considered if heat dissipation is an issue.

Specialised applications

Developers can also rely on TSN-compatible PC boards to implement key capabilities on industrial/standard PCs and similar devices within advanced industrial Ethernet networks. This allows the connection of PCs without any special development. This is especially useful in edge computing applications where a PC/IPC may be used as the gateway to higher level IT systems, providing a component of an OT/IT converged system.

	Software Based	Hardware Based		
	Software Stack/SDK	ASIC/LSI	Built-In/Embedded Modules	FPGA/IP Core
Performance	Suitable for general applications	Suitable for general and high performance applications		
Typical Application	Upgrade of existing design	New products/re-design of existing products		
Flexibility	Typically portable	Dedicated function		Permits updates
Volume	Low, medium, high			Low, medium
Time to Market	Quick introduction	Part of planned development roadmap		

Table 1 - Comparison of Development Methods

Chapter 5 - The importance of conformance testing

To validate the capabilities of TSN-compatible devices, developers need to conduct thorough conformance testing, i.e. confirm that the product complies with all the requirements of a given network standard and that it is correctly implemented.

By testing the conformity of their products, developers are able to identify performance issues that may prevent correct operation with other vendors' compatible products or make them incompatible with the relevant communication specifications. This testing gives end users the confidence that the selected automation component will be fully interoperable with all other devices tested and used on the same network.

Third-party certification

Conformance and interoperability testing can be performed in-house by vendors and/or by independent organisations. Since end users usually look for an independent third-party certification, in house testing is generally only used to confirm that a product is ready to be tested by a third party.

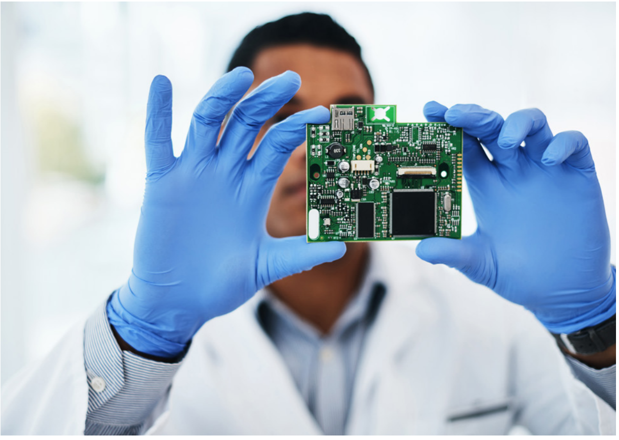
In effect, third-party testing provides an impartial and unbiased evaluation from an external source. As a result, it provides a high degree of confidence to end users that they can use the vendors' products without any problems. In addition, by choosing an independent tester, vendors can take advantage of a fresh set of eyes reviewing the network capabilities of their products, helping to spot anything that may have been missed.

On top of these advantages, accreditation organisations tend to have dedicated testing facilities with specialised, state-of-the-art equipment. Therefore, it is possible to conduct advanced assessments using a wide range of instruments that vendors may not otherwise have access to. Preliminary testing with this equipment is often available to avoid vendors having to invest in it while preparing for the final tests.

Finally, as conformance testing is conducted by a third-party, automation vendors can focus on development activities whilst specialised engineers assess the products. Test engineers are well trained and experienced in compliance and interoperability testing, providing a level of expertise that may be difficult, time-consuming and/or expensive to match in-house.

Global testing network

Many vendors are global companies that operate development facilities around the world. Having to send products to a single location for testing can be inconvenient, due to language, time zones and other issues. Having access to a global network of test facilities increases convenience and can reduce project lead times. It is also critical that a global testing network use standardised testing procedures so that regardless of where a test is conducted, the outcome will be the same



Chapter 6 - Industrial Ethernet protocols that support TSN

To quickly deliver innovative TSN-compatible products for industrial automation applications and tap into this market, businesses need to leverage proven network technologies, such as CC-Link IE TSN. This is an open network that combines TSN functions, as defined by IEEE 802.1 AS and Qbv standards, with gigabit bandwidth.

By selecting this solution, product developers can benefit from a comprehensive development ecosystem that supports the creation of master, local and remote stations. In particular, multiple members of the CC-Link Partner Association (CLPA) already offer ways to implement CC-Link IE TSN via software and hardware and more are being added continuously. As a result, companies can benefit from a comprehensive development ecosystem

Moreover, the CLPA can support vendors by assessing the conformance of their products, ensuring compatibility with CC-Link IE TSN specifications. The organisation offers development support, pre-certification testing as well as actual conformance testing via a global network of specialised certification facilities.

The workflow to achieve the CC-Link IE TSN conformance certification starts with vendors checking the regulations for the conformance test, which can be accessed on the CLPA website. Based on this, companies can perform an initial assessment in-house. Afterwards, they need to apply for the CLPA's conformance test. For the organisation to conduct this, vendors must send their product and a copy of the in-house test report to the selected testing facility.

Upon successful completion of the conformance test, a certificate and report are issued to the company. This then confirms compliance with CC-Link IE TSN network technology. As a further benefit, the product can be included in the CLPA's online catalogue, making it visible to customers worldwide. Joint promotion with the CLPA is also possible.

Chapter 7 - Conclusions

TSN is a key enabling technology for the digital transformation of manufacturing, and can offer four key benefits for end users and OEMs:

- Simpler network architectures/machine designs
- Greater process transparency and better management
- More productivity
- Better integration of OT and IT systems

To enable futureproof industrial communications and next-level performance, automation vendors need to act now to deliver TSN-compatible products or upgrade existing devices with TSN capabilities. By doing so they can help their customers to create the factories of the future whilst enhancing their own competitiveness in a fast-growing market.

For further reading on the business case for TSN, please refer to “TSN: The Case for Action Now”, available from https://eu.cc-link.org/en/campaign/2020/tsnwp

About the Author

John Browett spent the first 18 years of his career in various engineering and marketing roles for Mitsubishi Electric's automation businesses in Japan, the USA and Germany. He has spent the last eleven years with the CC-Link Partner Association (CLPA) in Europe where he is now General Manager.

In 2018, he oversaw the launch of CC-Link IE TSN in the European market, the first open industrial Ethernet to combine gigabit bandwidth with Time-Sensitive Networking (TSN). He is committed to working with leading automation vendors in Europe and beyond to deliver the converged network architectures required by Industry 4.0 to enable the connected industries of the future.

He holds a BEng in electronic engineering from Lancaster University in the UK which included study at the University of California, Los Angeles, plus a post graduate management diploma from the University of Cambridge. He is a Chartered Marketer (CMktr) and Member (MCIM) of the Chartered Institute of Marketing (CIM).

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References

[1] Institute of Electrical and Electronics Engineers, Inc. Time-Sensitive Networking Task Group. Available at: https://1.ieee802.org/

[2] Institute of Electrical and Electronics Engineers, Inc. 802.AS - Timing and Synchronization. Available at: https://www.ieee802.org/1/pages/802.1as.html

[3] Institute of Electrical and Electronics Engineers, Inc. 802.1Qbv - Enhancements for Scheduled Traffic. Available at: http://www.ieee802.org/1/pages/802.1bv.html

Bibliography

Groß, F., Steinbach, T., Korf, F., Schmidt, T. C., & Schwarz, B. (2014). A hardware/software co-design approach for ethernet controllers to support time-triggered traffic in the upcoming IEEE TSN standards. In: 2014 IEEE Fourth International Conference on Consumer Electronics Berlin. ICCE-Berlin, 9-13.

Insam, E. (2003). CHAPTER 1 - Networking Embedded Systems. In: Edward Insam (Ed.). TCP/IP Embedded Internet Applications. Newnes, 5-27, ISBN 9780750657358.

Kuon, I., & Rose, J. (2007). Measuring the gap between FPGAs and ASICs. IEEE Transactions on computer-aided design of integrated circuits and systems, 26(2), 203-215.

Monmasson, E., & Cirstea, M. N. (2007). FPGA design methodology for industrial control systems—A review. IEEE transactions on industrial electronics, 54(4), 1824-1842.

Muller, K., Steinbach, T., Korf, F., & Schmidt, T. C. (2011). A real-time Ethernet prototype platform for automotive applications. 2011 IEEE International Conference on Consumer Electronics -Berlin (ICCE-Berlin).

Rittman, D. (2004). Structured ASIC design: A new design paradigm beyond ASIC, FPGA and SoC. [Online] Available at: http://www.tayden.com/publications/Structured %20ASIC%20Design.pdf.

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