Time-Sensitive Networking (TSN) – The Case for Action Now

Why TSN should be part of your company's strategy today

Foreword

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The vision of the connected Smart Factory

Global industry is facing a common set of challenges. End users are looking to automation vendors to deliver systems and technologies that will address these problems. Call them Connected Industries, Smart Factory, Industry 4.0[1] or the Industrial Internet of Things (IIoT); regardless, these challenges broadly fall into the following key areas:

1. Ensure consistent quality and performance across global operations
2. Balance manufacturing with demand to optimize material usage and asset utilization
3. Improve and meet regulatory compliance
4. Implement more flexible and agile manufacturing operations to respond to rapidly changing market conditions
5. Meet demanding requirements and metrics for on-time delivery through reduced mean-time-to-repair (MTTR) and increased overall equipment effectiveness (OEE)
6. Reduce the cost of design, deployment, and support of manufacturing and information technology (IT) systems at global manufacturing plants
7. Improve response to events that occur on the plant floor, regardless of their location

One obstacle to achieving these goals is the inability of existing industrial network systems to share information between different technologies. This limitation leads to data 'islands', which prevent information from being shared effectively.

The key to resolving this problem is better access to information. In other words, manufacturers of industrial automation control systems (IACSs) and their customers understand the value of the data produced in their factories and therefore require seamless access to that data. Hence the kind of transparency required by Industry 4.0 applications is becoming the preferred approach to addressing these challenges.

Taking terabytes of data from the shop floor and turning them into useful information is all part of the strategy to address Industry 4.0. But more importantly it is being able to really solve the customers' problems as we look at a complete solution based architecture focused on IT/OT convergence and the ability to take data from the factory floor, provide seamless integration and convert it into information accessible to enterprise-wide applications.

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Overview

Industry 4.0 has moved beyond the novelty stage and has become a strategic focus for many companies. For the purposes of this white paper, we will focus on how Industry 4.0 applies to communication in industrial processes and will require multiple industrial Ethernet protocols as well as general information protocols to be run on the same networks in order to deliver the necessary process transparency.

The adoption of Industry 4.0 is being driven by its ability to address the challenges faced by today's users of industrial automation control systems, allowing them to increase competitiveness by optimizing their operations. More precisely, this adoption provides greater process transparency, which in turn allows businesses to better manage their activities.

Transparency is all about being able to extract more data from processes and analyze it to gather meaningful information to get a better and deeper comprehension of what is happening on the factory floor. In fact, it is not possible to know how to improve and control a process if there is not a clear understanding of what it is doing.

This need to extract process information has led to the rise of the Industrial Internet of Things (IIoT), as it provides an effective framework to generate, collect, share and analyze data. This solution is based on the Internet of Things (IoT) with the idea of connecting physical assets, such as sensors and actuators, to controllers and higher-level systems to monitor, control and manage them.

In practice, the IIoT applies the IoT to industrial activities, such as manufacturing. The result is an ecosystem of sensors, machinery and people all connected together that offers a granular view of operations and enables control of any variable that could affect production. The two technologies not only differ in their areas of application, but in their performance capabilities. For example, the IIoT was developed to handle highly time critical processes, such as high-speed packaging machines. Therefore, it required very reliable and predictable communication methods to connect devices such as sensitive and precise sensors to highly sophisticated, advanced controls and analytics. Collected together, these properties as are known as determinism, which is an essential requirement for industrial Ethernet applications.

While the IIoT offers an effective technology platform for Industry 4.0 applications, its foundation is a suitable network with the necessary level of determinism to share all data generated by a process. This transparency depends on convergence, i.e. the ability to combine multiple types of traffic on a single network, which in turn depends on determinism.

The technology that automation is moving towards to address this need for convergence is Time-Sensitive Networking (TSN).

Chapter 1 - What is TSN, how does it work and why is it important?

The basics

TSN is an extension of standard Ethernet that regulates the data communication in Layer 2 – Data Link of the OSI (Open Systems Interconnection) reference model. The technology's main aim is to make standard Ethernet deterministic. By doing this, it also provides the basic mechanisms to allow multiple types of traffic to share the same network, hence providing the basis of convergence.

More precisely, TSN allows engineers and technicians to precisely understand the exact time it will take for traffic to travel across a network, and also the nature of any delays (called "latency") and variation in travel time (called "jitter") that the traffic will experience. Latency and jitter were some of the main reasons why it took time for Ethernet to enter the industrial space. In the IT world, there is a far higher tolerance for latency and jitter, beyond what could be accepted in many industrial processes. Since originally Ethernet could not guarantee when events would happen (a lack of determinism), it could not be used reliably in many machine applications where this lack of determinism could lead to poor quality or even machine damage.

Various open protocols, such as CC-Link IE, were adopted to address these issues, and they will still provide valuable functionality for Industry 4.0 applications when combined with TSN.

Determinism is crucial for industrial automation applications which need extremely precise control of process events, such as high speed closed-loop motion control. In these cases, the predictable and reliable delivery of information is critical to maintaining system performance.

LAYER	OSI MODEL
7	APPLICATION
6	PRESENTATION
5	SESSION
4	TRANSPORT
3	NETWORK
2	DATA-LINK
1	PHYSICAL

Figure 1 – TSN technology lies at Layer 2 of the OSI 7 layer model, defined by ISO/IEC 7498

Printing presses require high-speed and precise control. These requirements are met by deterministic communications

For example, printing presses produce thousands of copies an hour while requiring extremely precise registration of the different process colors in order to avoid unacceptable print quality. Packaging lines typically produce thousands of items per hour with negligible levels of waste. Modern machine tools combine high speed machining with nanometer accuracy. To ensure that these systems can meet such requirements and deliver the necessary level of quality, machine control – and hence the transfer of key data – must consistently occur within set timeframes to support this level of performance.

However, while determinism is essential, it would be simplistic to assume that TSN providing this capability is all we need for Industry 4.0. TSN is just the foundation of the bigger picture of convergence. With previous open industrial Ethernet protocols, we already had the ability to mix various types of traffic. But this traffic was generally only related to machine control tasks – I/O data, safety and motion control. If you wanted to combine other types of traffic, such as TCP/IP video frames from a machine vision system, then generally this was not possible.

So while these protocols provided a way to make Ethernet deterministic for industrial applications and hence enabled what is now called industrial Ethernet, they still did not offer much of a solution for convergence. The current trend towards TSN will finally address this missing piece. We shall see how TSN provides the required mechanisms for all types of network traffic to coexist on the same network and hence finally provide the convergence necessary to enable the transparency required by Industry 4.0.

TSN standards

TSN is defined by the IEEE 802.1 Ethernet specifications[2], which describe how the technology can provide deterministic performance and consequently convergence by implementing time synchronization and traffic prioritization, amongst other functions.

1. IEEE 802.1AS - Timing and Synchronization for Time-Sensitive Applications

Time synchronization[3] provides the basis for determinism, as it ensures that all devices on a network share the same sense of time. For example, if it is 10:00 AM, then all the devices on the network know this and their operations are synchronized to the same clock. Therefore, this makes it possible to minimize the likelihood of time drifts that may lead to delays and variation in data transfer (latency and jitter), thus supporting the timely and predictable transfer of critical data traffic. IEEE 802.1AS borrows from the IEEE 1588 Precision Time Protocol (PTP) standard[4] to implement this capability.

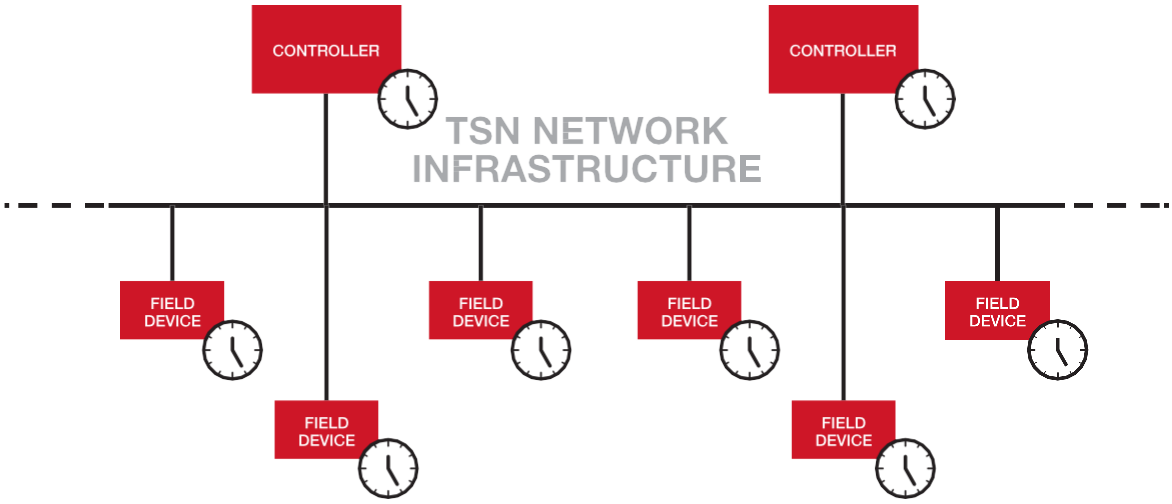


Figure 2 - By using IEEE 802.1AS, all devices on the network have a shared time reference. This provides deterministic communications by controlling latency and jitter. Hence traffic travels across the network in a predicatable manner.

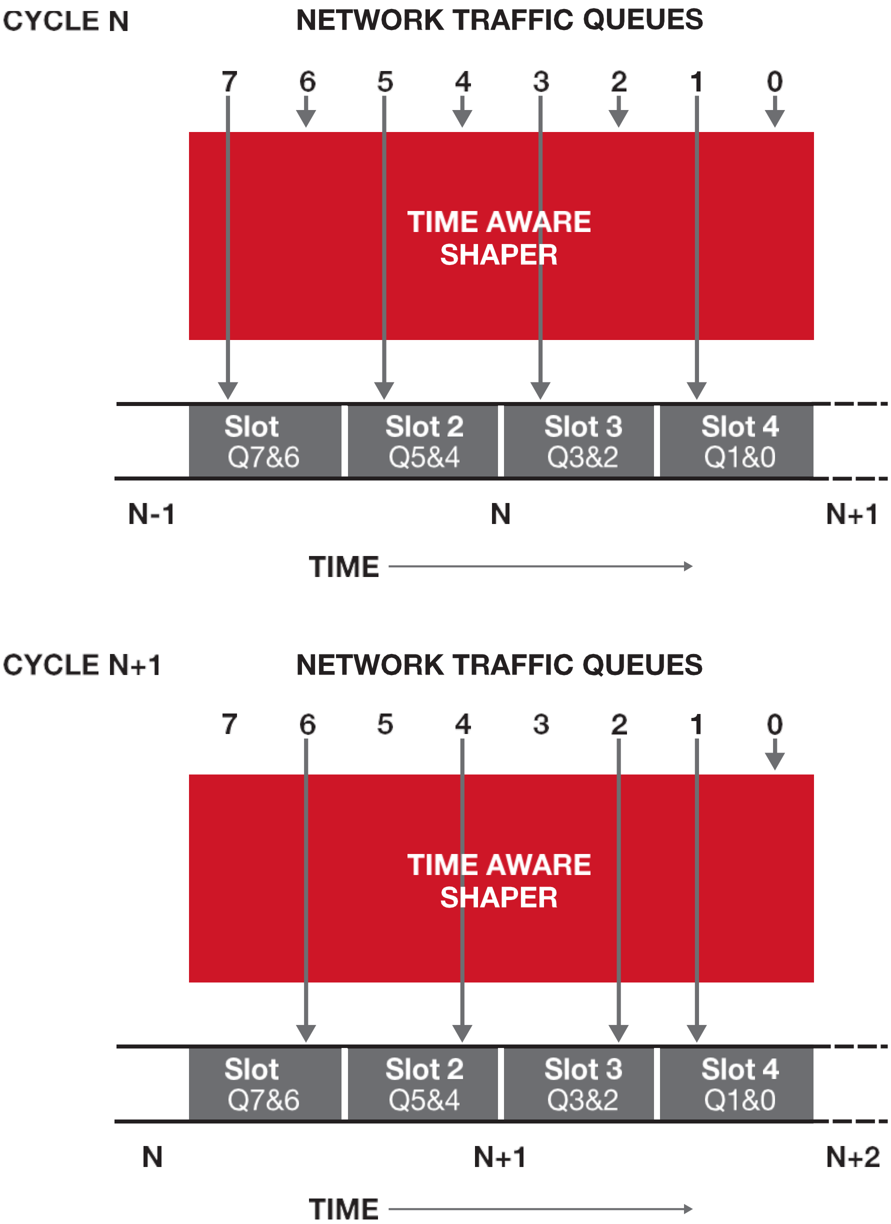


Figure 3 - IEEE 802.1Qbv allows transmission time slots for different network traffic queues to be defined. This controls when each traffic type has access to the network. In this example, four time slots are divided betweeen eight queues. Within each slot, the higher numbered queue takes priority.

2. IEEE 802.1Qbv- Enhancements for Scheduled Traffic

Once a shared sense of time is in place across a network, IEEE 802.1 Qbv defines "time-aware shapers"[5]. These define specific time "slots" that are assigned to different types of network traffic, which are prioritized according to the type of traffic. For example, the traffic related to an emergency stop being pushed would take priority over video frames from a machine vision system. By assigning these time slots using a principle called Time Division Multiple Access (TDMA), different types of traffic can all travel across the network in a predictable way, further supporting deterministic communications. Hence this method supports convergence, while maximizing the use of network bandwidth.

3. Additional IEEE 802.1 standards

Besides these key functions, there are many other IEEE 802.1 TSN standards (currently about 30) that are either published or under development. However, many of these do not relate to industrial use cases, partly because TSN originated from the professional audio-visual industry. Hence, we do not need to consider them in this white paper.

4. Evolution of TSN standards

As with any technology, the IEEE 802.1 standards that define TSN are continuously evolving, with existing standards being refined while new ones emerge. Even as these standards evolve, the technology is mature enough to be implemented in projects. An evolving technology can be regarded as more valuable – as it continues to change, it continues to address current demands, hence is less likely to become obsolete. Therefore, this evolution is positive.

The counterpoint to this evolution is that the Ethernet standards have a track record of backwards compatibility. Ethernet technology has been around for about forty years and yet in many cases, earlier devices can often be used with more recent devices. TSN is expected to also follow this trend. Therefore, companies who need to get projects done now can include TSN in them now, confident that they are unlikely to face obsolescence in a few years. There is no need to wait for some undetermined future point when TSN will be “ready”, as this time is not likely to arrive. A similar example is mobile phones – while mobile networks have evolved from 2G, 3G and 4G to 5G, in each case, there was no need to wait for the next generation before adoption.

This confidence will be further reinforced by the IEC/IEEE 60802[6] project on the use of TSN in industrial automation, whose role is to define standardized profiles for use of the technology in a variety of use cases.

As a result, forward-looking businesses implementing this innovative technology will be able to benefit from a migration path that addresses current needs while providing a way to support future requirements. Thus, the adoption of TSN now can offer a system that helps companies to optimize their current systems and operations while offering the scope for future enhancements.

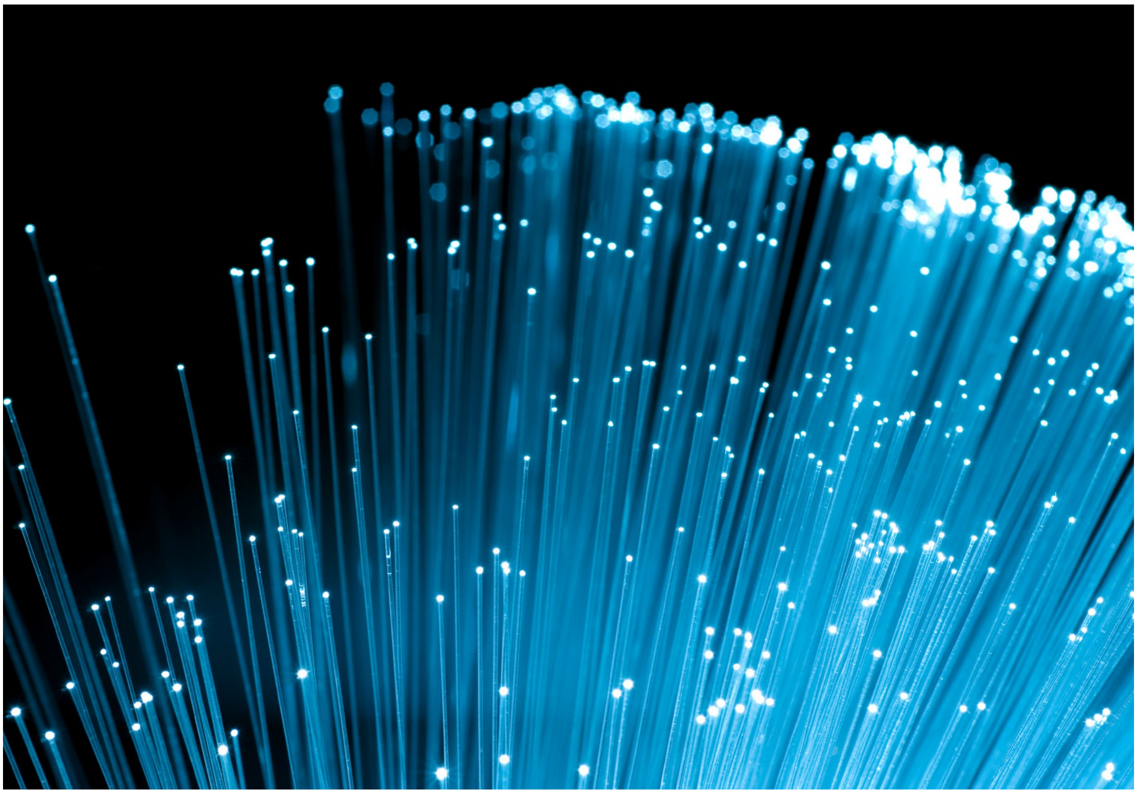
5. The importance of bandwidth

A final consideration in TSN networks is bandwidth. In addition to determinism, the standards behind TSN allow industrial Ethernet to utilize this typically fixed commodity with greater efficiency.

The prioritization features of TSN allocate the necessary bandwidth required to allow all traffic to flow on the network without less critical data interfering with that of higher priority. In the past, many industrial Ethernet technologies ran using 100Mbit bandwidth. While TSN will allow this bandwidth to be used in the most effective manner, the increase in data generated by Industry 4.0 is driving the trend towards gigabit bandwidth. TSN is well placed to benefit from this trend. Even though it can improve the use of bandwidth, it is clear that a wider "pipe" will infer fewer compromises between types of traffic and hence the performance of even less critical data transmissions can be improved.

This trend also addresses the way that some systems may have multiple networks to cope with occasional traffic peaks. The move to gigabit will ensure that a single network can meet increased bandwidth requirements, with TSN providing the scope for making sure it is used in the most efficient way as traffic volume increases.

This means that we will have the scope to build future systems where networks have the capacity to combine multiple types of industrial Ethernet protocols along with conventional TCP/IP traffic on a single network, therefore reducing costs and improving productivity and transparency.



Chapter 2 - Benefits of TSN

Make standard Ethernet deterministic and hence provide the foundation of convergence

As discussed in the previous chapter, the aim of TSN is to make standard Ethernet deterministic. As a result, it is possible to deliver information in a predictable manner and enable converged networks. Hence it is a technology that will benefit vendors, machine builders and end users.

For vendors – build devices that offer precise control of latency and jitter while being able to share networks with devices using dissimilar traffic. This will provide the key components of future automation systems.

For machine builders – design systems that are simpler, lower cost and easier to maintain, as the convergence enabled by TSN will allow all traffic to be handled by the same network.

For end users – benefit from the transparency delivered by these converged networks in order to gain better understanding of their processes and hence optimize them.

Benefits of converged networks

In the past, it was commonplace to have multiple networks, each dedicated to a specific task. For example, one would address general control, such as communications between PLCs, I/O and similar devices. Another network would handle communications for safety functions, such as emergency stops, light curtains, and safety controllers. There could also be a separate network responsible for motion control communications, connecting servos, drives, encoders, and motion controllers.

Getting these isolated setups to work together could be a significant engineering challenge. Time to market was slow, project timeframes were long, costs were high and maximizing performance could be an issue, along with maintenance.

To address these challenges, many modern-day industrial Ethernet technologies allow the combination of general, motion and safety control on one network, delivering substantial improvements.

However, Industry 4.0 is requiring end users to go beyond this. In order to address the challenges outlined in the overview, it is necessary for Ethernet to support the convergence of all kinds of networks and traffic types typically found in an industrial setting. Therefore, the integration of equipment such as barcode readers, vision systems and printers that may be using normal Ethernet networks without any specific industrial protocol also needs to be considered.

Moreover, it is commonplace for plants to evolve over time, with different projects using different technologies. As a result, many factories have multiple incompatible industrial Ethernet 'islands'. Since it is often difficult to combine this dissimilar traffic to get the 'big picture', process transparency is hampered and hence optimization and management is difficult. As TSN will allow this dissimilar traffic to share the same network, these islands will become a thing of the past.

TSN also allows this to be taken one step further. As the concept model of Industry 4.0 matures, common IT technologies such as cloud computing are entering manufacturing. While many cloud systems can theoretically absorb a large volume of plant data, in practice, it is not necessary for these IT systems to track every tiny detail of machine operation. This is why so called ‘edge servers’ have also appeared. Their function is to act as a filter to transmit the most valuable data to the cloud, where it can be processed into information that provides the required process insights. It is clear to see that network architectures that deliver a single converged stream of data to these edge servers will provide a more efficient base for operation and optimization. This is one of the main ideas behind ‘OT/IT convergence’ where ‘OT’ is Operational Technology, or the factory floor.

The business benefits

In summary, the automation marketplace is a symbiosis of end users, who specify projects to machine builders, who in turn look for vendors who can offer products and solutions that meet these specifications. TSN can deliver benefits to all market participants as follows:

1. **Simpler network architectures/machine designs**
   In general, the advantages highlighted above allow end users to reduce the number of networks required for their operations to just one. This, in turn, allows machine builders to pass on substantial decreases in costs, as less equipment is required and engineering work to design, configure and install network systems is also minimized. In addition, timescales for complete factory automation projects are decreased.

2. **Greater process transparency and better management**
   The convergence supported by TSN strengthens data transfer across the enterprise, allowing end users to have greater process transparency. In effect, transparency is all about being able to extract more data from industrial processes and analyze it to gather meaningful information that helps to better understand factory floor operations. This insight can then be leveraged to optimize performance, productivity, efficiency and end product quality.

3. **More productivity**
   By supporting the creation of single networks that transfer all types of traffic, it is easier to troubleshoot and identify any potential issues. Therefore, downtime associated with maintenance or repair activities can be reduced, while overall uptime can be increased. As a result, the entire end user’s manufacturing system can become more productive.

4. **Better integration of OT and IT systems**
   By converging multiple types of process data, TSN offers a key way to merge OT and IT. This convergence is at the heart of data-driven smart manufacturing, as it promotes innovation and collaboration by sharing and utilizing actionable information across the entire enterprise. Consequently, by embedding TSN capabilities within their products, vendors can deliver solutions with increased interoperability, along with the capability for device data to be visible across the enterprise via cloud connectivity.

Chapter 3 - What TSN cannot do

TSN is just a 'pipe'

Since TSN resides at Layer 2 of the OSI hierarchy, it is only intended to make sure that the data, the '1's and '0's, get from A to B with a predictable amount of latency and jitter. This provides the necessary determinism foundation for convergent networks, but goes no further than this.

So while this improves the applicability of Ethernet to industrial communications, it is important to keep in mind that TSN is ultimately just a 'pipe'. It does not care what application functions the '1's and '0's represent and hence there are many aspects of an automation system that TSN does not address per se.

Higher level application related functions, such as safety, motion control and device profiles for easy network configuration and maintenance are still needed. TSN does not address any of these functions itself. Hence, for the foreseeable future, it will probably still be necessary to have higher level protocols to deliver these. Moreover, because TSN is just a pipe, it also does not address issues such as cyber security, which have become increasingly important for automation in recent years.

Nonetheless, it will also be important for these protocols to be compatible with TSN in order to deliver the benefits of converged networks described earlier. Hence, companies who are implementing factory automation projects now should ideally look for open network technologies that will address their current needs, such as responding to the demands of Industry 4.0 with gigabit bandwidth, while also providing forward compatibility with TSN.

Chapter 4 - TSN: The case for action now

The importance of TSN technology is reflected by the way that many standards bodies and industrial Ethernet organizations have quickly taken positions on incorporating it into their respective portfolios. Their work will provide a solid foundation for data and information integration between all the complex, disparate devices and applications that have previously been disconnected and which we think of as 'islands' of automation.

Connecting up all of the different technologies and making things work from a seamless interoperable standpoint is required for end users to successfully build complete automation systems. Furthermore, standardization allows these end users to design and deploy complete systems using products from a range of vendors. TSN is a platform that will provide many opportunities for convergence and interoperability and enable us to have devices and applications, which were previously disconnected, be part of a cohesive system. It will allow different industrial Ethernet protocols to share the same network, and OPC-UA will allow incompatible systems to talk to each other with a common language at the controller level and above.

To deliver this vision, various open industrial Ethernet associations in addition to the OPC Foundation have been working on adding TSN compatibility to their portfolios. At the time of writing, these projects are expected to deliver full results in around one to two years from now.

The IEEE 802.1 group includes over 30 different standards, some of which may not apply to industrial use cases. It is clear that some agreement is required regarding which ones should be used for automation. To address this, the IEC and IEEE are working together in order to define a standard set of profiles for TSN in automation based on an extensive set of use cases. This is known generically as IEC/IEEE 60802. This activity is expected to be completed in one to two years from now. However, many automation use cases are covered by the core IEEE 802.1AS and Qbv standards, which address time synchronization and prioritization, as we have already seen. Vendors have already introduced products to the market that incorporate these standards. Moreover, the IEC and IEEE have a track record of backwards compatibility. Hence any future standards will likely "grandfather" in any previous standards.

The IEC/IEEE 60802 project is also planning to address the issue of TSN conformance testing. At least one open network organization is already offering this today and it is likely that these activities will be combined with future, wider reaching programs that will also include other organizations.

So what does a company convinced of the benefits of TSN and wanting to adopt it now do? The answer is to look for a current technology that supports TSN now while also providing the necessary application functionality, such as safety and motion control. This will then address current project requirements, while providing future compatibility with other TSN-based technologies as they are introduced since multiple protocols will be able to share the same network.

In 2018, the CLPA introduced CC-Link IE TSN. This took the established open industrial Ethernet solution of CC-Link IE and added TSN compatibility to it. This delivered the world's first open industrial Ethernet technology to combine gigabit bandwidth with TSN. As such, CC-Link IE TSN clearly provides the gateway to the future of open industrial Ethernet. The result is a proven technology that end users, machine builders and vendors should adopt now in their respective products and projects. The ecosystem of development options that are available to vendors who want to offer CC-Link IE TSN certified products is broad and flexible. Compatible products and solutions from leading vendors such as Mitsubishi Electric are already available. Therefore, end users and machine builders can leverage this opportunity today. For device vendors, by developing CC-Link IE TSN compatible products now, it will be possible to help shape the future of automation by participating in this new market opportunity.

CC-Link IE TSN helps to deliver the promise of Industry 4.0 in three key ways:

- Performance: The only open industrial Ethernet currently available to combine gigabit bandwidth with TSN to provide the highest productivity via maximum bandwidth availability.
- Connectivity: Being an open technology maximizes the freedom of choice for end users and machine builders, while also providing implementation flexibility for vendors. TSN takes openness one step further by offering the ability to combine CC-Link IE TSN traffic with that of other protocols.
- Intelligence: Reduce engineering time and maximize uptime with a range of features intended to simplify system design and maintenance.

What does this all mean to the end user, machine builder or vendor who is still wondering what to do with TSN? Great minds and great innovators have recognized the value of this technology and continue to work with the IEEE to develop and enhance it. More importantly, vendors and standards organizations are adopting and pushing the TSN technology into their own standards and portfolios now. End-users want choice, but at the same time, from a business value perspective, they expect that all of their networks and devices should coexist and be able to work together. This will allow data from all of these previously disconnected devices to be converted into useful information to provide a complete cohesive solution for industrial automation for today and tomorrow by leveraging TSN.

In summary, the risk is not in adopting TSN now, but rather in waiting several more years to implement it while possibly watching competitors move ahead in the meantime.

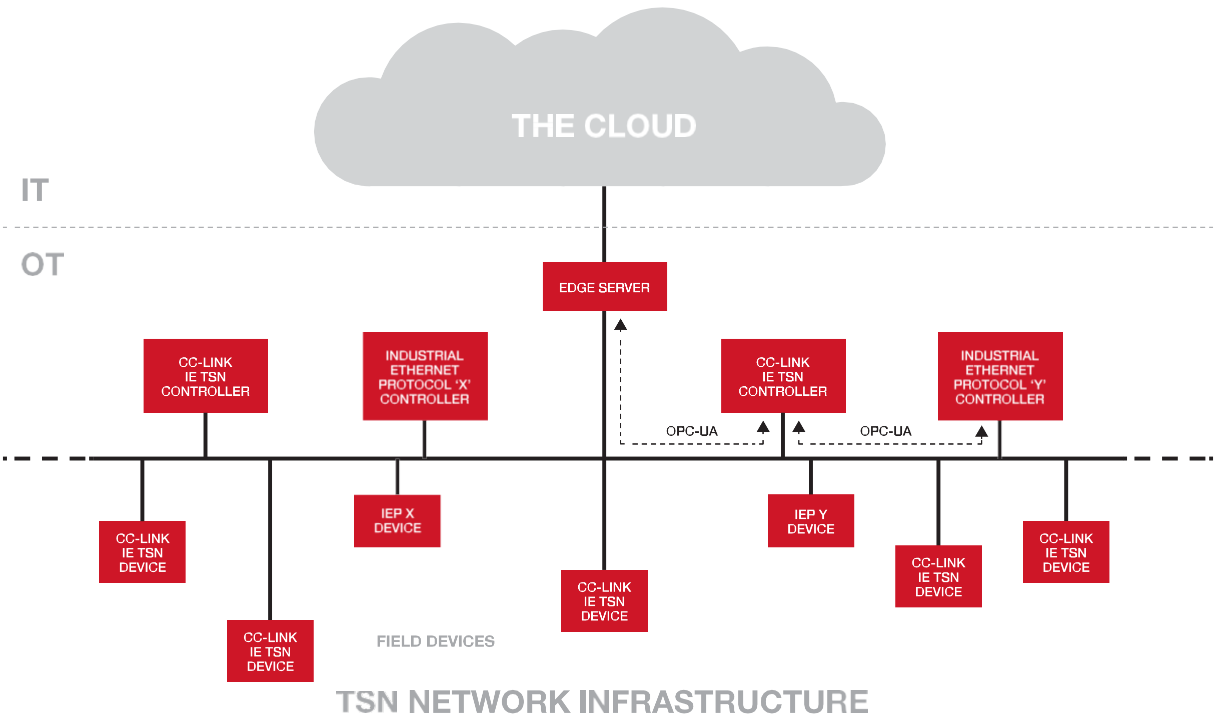


Figure 4 – TSN delivers the necessary process transparency to end users by converging the various aspects of the OT and IT worlds

Conclusions

TSN is *the* most significant technology for the future of industrial automation. It offers a number of opportunities, with the key ones being determinism and hence complete industrial and commercial network convergence. Network convergence is a key component addressing the challenge of greater transparency identified by Industry 4.0, allowing processes and manufacturing to be highly efficient, streamlined operations.

For current industrial automation projects, organizations need to investigate which technologies will address this challenge. Existing technologies that offer features, such as gigabit Ethernet, help with this. And of course, they should also be open.

At the same time, it is important to keep an eye on the future. This means identifying current technologies that will support TSN. These are important, as they provide an upgrade path to TSN-enabled systems of the future.

The technology landscape surrounding TSN is continuing to evolve, with the activities from the IEEE and IEC resulting in new advancements. However, based on previous experience, there is a high degree of confidence that the TSN solutions that will be installed now will also work with the systems of tomorrow. Ethernet has been around for about 40 years and has continuously evolved over that time, which is why it is still in use today. Therefore, companies should not be afraid of implementing TSN now. As we have already seen, this will avoid the risk of delaying and possibly watching competitors who take advantage of current solutions move ahead in the meantime.

Ground breaking technologies like TSN are going to continue to evolve to meet current needs while helping to shape the next industrial revolution. Machine builders and end users are going to be able to depend on TSN technology to connect their legacy systems with the systems of today and, at the same time, be able to address the complex needs of tomorrow. TSN literally provides timeless durability. Hence it is important that vendors, machine builders and end users invest in TSN technology now, because as it evolves, they will be able to stay ahead of the curve and be able to take advantage of seamless new functionality that TSN brings to the table.

CC-Link IE TSN provides a way to move forwards today. Contact the CLPA now to discuss how it can benefit development roadmaps, simplify machine designs and improve manufacturing operations.

About the Authors

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 ten 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. He also holds a post graduate management diploma from the University of Cambridge and is a Member of the Chartered Institute of Marketing.

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He is also the Global Strategic Advisor for the CC-Link Partner Association (CLPA) responsible for collaboration with other organizations and suppliers to grow the CLPA and corresponding adoption of the CC-Link IE TSN technology.

He is also the Director of Strategic Marketing for ICONICS providing leadership to increase market share of ICONICS' leading edge product portfolio.

His background includes being the former OPC Foundation President & Executive Director, pioneering the OPC Unified Architecture (OPC UA) as the foundation of information integration and interoperability.

His vision is about interoperability and information integration in the pursuit of making the digital transformation of reality and truly leveraging IT/OT convergence. He recognizes TSN is a game changing technology and is excited that the CLPA was the first industrial Ethernet organization to deploy the TSN technology into their open standards.
Mr. Burke has a bachelor's degree in theoretical mathematics from John Carroll University (Cleveland, Ohio), and a master's degree in computer engineering from the University of Dayton (Dayton, Ohio).

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References

[1] Federal Ministry for Economic Affairs and Energy. Plattform Industrie 4.0.
Available at: https://www.plattform-i40.de/ [Accessed October, 5 2020]

[2] Institute of Electrical and Electronics Engineers, Inc. Time-Sensitive Networking Task Group.
Available at: https://1.ieee802.org/ [Accessed October, 5 2020]

[3] Institute of Electrical and Electronics Engineers, Inc. 802.AS - Timing and Synchronization.
Available at: https://www.ieee802.org/1/pages/802.1as.html [Accessed October, 5 2020]

[4] Institute of Electrical and Electronics Engineers, Inc. IEEE 1588-2019 - IEEE Standard for a Precision Clock Synchronization Protocol for Networked Measurement and Control Systems.
Available at: https://standards.ieee.org/standard/1588-2019.html [Accessed October, 5 2020]

[5] Institute of Electrical and Electronics Engineers, Inc. 802.1Qbv - Enhancements for Scheduled Traffic.
Available at: http://www.ieee802.org/1/pages/802.1bv.html [Accessed October, 5 2020]

[6] Institute of Electrical and Electronics Engineers, Inc. IEC/IEEE 60802 - TSN Profile for Industrial Automation.
Available at: https://1.ieee802.org/tsn/iec-ieee-60802/ [Accessed October, 5 2020]

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