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OPEN AUTOMATION NETWORKS

Delivering TSN's benefits to manufacturing

How Time-Sensitive Networking will help solve industry's problems today and tomorrow

Executive summary

The transformative potential of Industry 4.0-oriented digital technologies in manufacturing is widely recognised. However, the “explosion” of data these have created is a double-edged sword. On the one hand, the data has the potential to be transformed into valuable information that can deliver actionable insights for optimising processes. But on the other, if not managed well, this data threatens to become a tidal wave that will overwhelm companies and create more problems than it solves.

Key to the management of this data is a converged, high bandwidth network infrastructure in order to succeed with value-adding digital transformation strategies. In simple terms, convergence is the concept of allowing everything to share the same network architecture to communicate, hence avoiding the complexity and cost of multiple networks. The ideal system should be the foundation of high-speed, real-time deterministic communications between disparate devices and systems, allowing data to be shared across the entire enterprise, regardless of its source or destination. The ultimate aim is to provide the process transparency required for fully optimised operations by allowing the data to flow from its source to where it can be processed to obtain actionable insights and then fed back into the process. This does not just apply to supervisory systems. Having real-time control and coordination of multiple different shop floor or operational technology (OT) systems is also critical.

This white paper explores the network technology that can address these challenges, Time-Sensitive Networking (TSN). TSN can deliver four specific benefits to a range of industries, specifically:

1. Reduce costs, shorten project timelines and increase uptime by simplifying network architectures and hence machine designs. By employing convergence, systems no longer need multiple network types to handle all process traffic.
2. Deliver greater process transparency and optimised operations. As a consequence of converged network architectures, having data flow to where it is needed is simplified. As we discussed above, this is the key to managing processes in the best way.
3. Greater productivity, as optimised processes will run in the most productive way.
4. Better integration of OT and information technology (IT) systems, as a converged stream of data can be shared from the factory floor to supervisory systems more easily. Hence getting the data to where it can be analysed is simplified and this further contributes to process optimisation.

We will explore how TSN delivers these benefits and how it can do that for a selection of industries.

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Chapter 1: The challenge of Industry 4.0 and the promise of convergence

Introduction

The Industry 4.0 paradigm is continuing to reshape every industrial sector. The data-driven, automated technologies that this framework leverages are having a vast and lasting impact on every single aspect of manufacturing, from R&D to operations and the entire supply chain. By using the Industrial Internet of Things (IIoT), these technologies increase the digitalisation and interconnectivity within companies as well as with their suppliers and customers in their broader value chains. In this way, it is possible to develop smart, connected industries that benefit from fully optimised processes.

At the core of any digital journey is the ability of companies to navigate massive and ever-increasing volumes of data to gain unique, actionable insights that support real-time decision making. However, currently a key challenge for manufacturers is implementing effective data gathering and integration solutions to support visibility, analytics and therefore optimisation. A further challenge is to ensure disparate OT systems can also communicate for the most effective process operation.

While traditional industrial Ethernet offers proven value in supporting data-driven, automated factories, its limited ability to support the smart manufacturing operations of the future is now coming into focus. In effect, the higher levels of performance, connectivity and cybersecurity required by Industry 4.0 applications can rarely be met in full by current network technologies.

Delivering convergence across the enterprise

Typically, companies have been relying on multiple networks in their operations. The shop floor, or OT level, typically features production lines or processes where multiple networks are employed. These may handle real-time process signals such as I/O, motion and safety systems. Along with these may be non-real-time traffic, such as video frames from inspection systems, barcodes, printed information, quality and maintenance data and so on. These have often required separate networks, leading to complex architectures that could be costly and time consuming to install, operate and maintain. As a result, there is often a limited ability to provide the level of transparency required to control processes in an optimum way. When it comes to sharing this data with higher level IT systems to make it available across the enterprise, managing the multiple streams and combining them has also been difficult.

Allowing all the devices and systems involved to all talk on the same OT network architecture and to the upper-level IT systems, where required, can be addressed by employing a converged approach. As we have seen, convergence allows everything to share the same network architecture to communicate and hence avoids the complexity and cost of multiple networks.

By doing this, companies can apply the intelligence of IT to OT systems, creating an in-depth understanding of machines, processes and plant to optimise processes, drive up efficiencies and maximise productivity.

Given how the networks for these different domains were created, their convergence is often not straightforward, bringing forward key challenges and concerns that need to be overcome. More precisely, OT networks are made to deliver real-time, deterministic performance. If large volumes of non-real-time data are transmitted via the same infrastructure, this may impact the real-time data transfer performance due to traffic conflicts, lack of bandwidth and prioritisation. This may lead to sub optimal process operations that suffer from communications bottlenecks, decreased productivity and downtime.

Such a scenario is also optimistic, as it pre-supposes that the ability to combine non-real-time and real-time process data on the same network actually exists. While many industrial Ethernet protocols offer the ability to combine multiple types of process data, such as I/O, motion and safety, the ability to combine these with other data, as described above, is often missing.

Finally, many plants have evolved over time and hence have "islands" of different, non-interoperable industrial Ethernet systems. This further limits the ability to share data across the plant.

In summary, before companies can progress on their Industry 4.0 digitalisation journey to full process optimisation, they need a network infrastructure that addresses the following challenges:

1. Convergence of multiple types of real-time process related traffic, such as I/O, motion and safety.
2. Convergence of real-time process traffic with non-real-time traffic, such as vision system images, barcode readers, printers, quality and maintenance data and so on.
3. Convergence of different non-interoperable industrial Ethernet protocols.
4. Convergence of OT and IT systems.
5. Ensuring all this traffic is secure and protected from unauthorised access.

While conventional industrial Ethernet is not suited to address all these issues, an innovative, complementary technology can provide the right solution – Time Sensitive Networking.

Chapter 2: How will TSN help?

TSN at a glance

TSN is an extension of standard industrial Ethernet that is defined by the Institute of Electrical and Electronics Engineers (IEEE) 802.1 working group [1] and has been created to enhance its performance. This technology was originally developed to support Audio Video Bridging (AVB) in the professional AV industry, but its benefits were so obvious that the scope of TSN was quickly expanded, giving support to a wider range of industries and applications.

The main asset of this technology is that by making Ethernet inherently deterministic, it delivers the ability to provide a converged network architecture. In practical terms, determinism means that traffic flows across a network in a predictable manner, since latency (transmission delays) and jitter (variability in these delays) is controlled in a precise way. In turn, this allows the predictable transmission of all traffic types, allowing them to share the same network. The end result enables real-time performance of the network for any traffic, making it suitable for use for all control tasks since synchronisation of all parts of a system is guaranteed. Hence a converged network architecture is enabled.

TSN enables this by creating time synchronization and scheduling methods for traffic prioritisation. The first aspect, defined by the IEEE 802.1AS substandard [2], is implemented by having a common time reference across the network. This means that it is possible to understand how long it will take data to travel across the network and hence control latency and jitter. This provides the foundation of determinism by allowing all devices to be synchronised with high accuracy.

Traffic scheduling is defined by IEEE 802.1Qbv [3], which provides mechanisms known as time aware shapers (TAS). In simple terms, these allow different types of traffic access to the network according to their relative priority using a Time Division Multiple Access (TDMA) model.

TDMA creates intervals during which each type of traffic can travel across the network. In this way, the interference of real-time and non-real-time traffic can be prevented, allowing all traffic types to share the same network. The end result is a deterministic, high performance, converged network architecture to meet the demands of Industry 4.0 applications today and in the future.

The importance of bandwidth

By bringing industrial Ethernet to the next level, TSN can help manufacturers apply converged network architectures and provide a backbone for the IIoT. However, one final but essential aspect also needs to be addressed and that is bandwidth. While TSN will allow multiple traffic types to share the same network, if this is to provide the necessary performance, it's also essential to make sure the necessary bandwidth is available as more and more devices seek to use it.

Until recently, most industrial Ethernet systems could provide adequate performance with 100Mbit bandwidth. However, as Industry 4.0 is causing higher and higher numbers of devices to be connected, the consequent increase in traffic will also mean an upgrade to gigabit bandwidth is desirable.

Future benefits

Until recently, technologies such as artificial intelligence (AI) and machine learning (ML) were seldom seen in manufacturing. This has changed and these technologies are playing a key role in process optimisation. AI generally relies on large data volumes to draw conclusions on how to improve processes. Hence it is clear that TSN will enable the spread of these kinds of systems in the future by providing the necessary means to allow this data to be handled in the desired way.

Chapter 3: Automotive

The automotive sector is facing unprecedented change. In a few short years, the focus has shifted from conventional internal combustion engine vehicles to electric vehicles as the impact of climate change has become clear. This has led to rapid development and deployment of new manufacturing technologies related to electric powertrains, along with the rise of new competitors. At the same time, many things have also stayed the same – vehicles still need to be painted, bodies still need to be stamped and welded and so on. And this is all in the context of serving consumers that are demanding more and more features and options in their vehicles. Hence the industry is under more and more pressure to implement innovative manufacturing systems that can address all these needs while increasing operational sustainability overall.

Two challenges stand out – firstly the vast amount of data that must be handled in order to manage a huge variety of different processes in an assembly plant and across multiple plants, while at the same time communicating with a large and complex supply chain providing the majority of vehicle components on a just in time basis. This data relates to manufacturing processes in multiple ways – from the construction of the vehicles themselves to the preventative maintenance of the systems that build them.

Secondly, the huge variety of equipment and systems installed in a typical plant and the need for these systems to interact with each other and other systems whether at their own level or at higher levels. Many plants incorporate a broad spectrum of processes, from stamping and welding to injection moulding, painting and assembly and inspection.

TSN can help address these challenges in several ways. Since it offers the ability to support gigabit bandwidth, this also offers the ability to use networks with the bandwidth to handle the vast amounts of data being produced by plant systems in a timely manner. When corrective action is required, or maintenance issues are identified, the same bandwidth allows these measures to be implemented in real-time with negligible delays.

The ability to converge multiple networks on to a single architecture offers the chance to simplify the complex systems found in typical plants today. This can deliver concrete benefits such as reduced system costs and expedited start of production schedules. Moreover, since architectures can be simplified, uptime can be maximised, as faults will be addressed more quickly, leading to further cost savings and improved line efficiency.

Convergence also offers a way to address the “islands” of automation that typically occur in plants due to evolving installations. Hence systems that were once difficult to connect and extract data from now have the chance to contribute to greater visibility and improved operation of their processes.

Having multiple systems become more interoperable on a converged network architecture also offers the chance to simplify their integration between each other and also with higher level

IT supervisory systems. This can lead to increased process transparency and hence better management of the lines. Quality systems that require logging of process data can be supplied with the necessary data more easily, avoiding rework and increasing customer satisfaction. More optimised processes also lead to reduced cycle times and hence increased productivity.

Optimised processes will also be more sustainable. By operating processes in the optimum way, the trend towards designing them to minimise their impact on the environment will be further supported.

Finally, keeping systems secure against unauthorized access is a key concern. TSN provides a simplified foundation for monitoring network traffic so abnormal events can be quickly identified and action taken to prevent harm.

TSN is already being implemented in various automotive applications worldwide. This is further evidence that its benefits have been understood by the industry and that these are now being exploited in a variety of systems and processes at different end users.

Chapter 4: Food & beverage

From ensuring optimum process conditions in order to obtain delicious foods and beverages to filling, packing, inspection and casing, the needs of production in this industry are many and varied. Traceability of the finished product is also an important topic, since it is essential to be able to prevent potentially substandard items from reaching customers and affecting the potential impact on a manufacturer's reputation.

The food and beverage sector requires high production speed and volume to be profitable. Smart manufacturing is becoming a key topic to help meet these goals – and data is the enabler for this trend. Processes can only be run at the highest productivity when there is the necessary visibility of how close they are to maximum efficiency and what needs to be done to close this gap. In turn this allows companies to closely monitor manufacturing processes to prevent unsafe production. However, if despite best efforts, issues do arise, having close monitoring of production will provide the necessary basis for traceability.

Products can only be manufactured to the highest standards if the quality of the ingredients and their packaging is also closely monitored. Hence it is also essential to have the necessary level of understanding of ingredient quality and packaging component quality in real-time too. Raw material costs are one of the main determinants of profitability and therefore process optimisation can deliver significant benefits here too. Predictive maintenance can also deliver large positive impacts to the bottom line as lines are kept running uninterrupted.

Finally, cybersecurity is a key concern. Keeping the manufacturing process free of unauthorised interference is of paramount importance to safeguard consumers and protect company reputations.

TSN provides a way to address these challenges by providing the potential for a high degree of process transparency despite the use of many different systems across a plant by implementing a converged, gigabit communications architecture. It offers the opportunity for all systems from batching, mixing, forming, through to packaging to share information, thus providing the ability to see the big picture necessary to run a plant or line at maximum efficiency. Possible data islands caused by dissimilar systems may also be addressed by combining the traffic from different equipment onto the same network. This can ultimately all be combined into a common stream of data that is more easily shared with higher level supervisory systems and consequently allowing actionable insights to be derived to feed back into the processes for complete optimisation. AI is increasingly becoming a topic for the industry, and supplying these systems with the large volumes of process data required to derive the necessary process insights and corrective actions will become easier when supplied by TSN communication architectures.

TSN also provides the foundation of more secure processes by making it simpler to monitor process data when converged onto a single architecture. Hence unauthorised actions can be detected more quickly and processes safeguarded in real-time.

End users in the food and beverage sectors are already enjoying the benefits that TSN provides to their operations as they seek to address these challenges in the most effective, innovative ways.

Chapter 5: Lithium battery

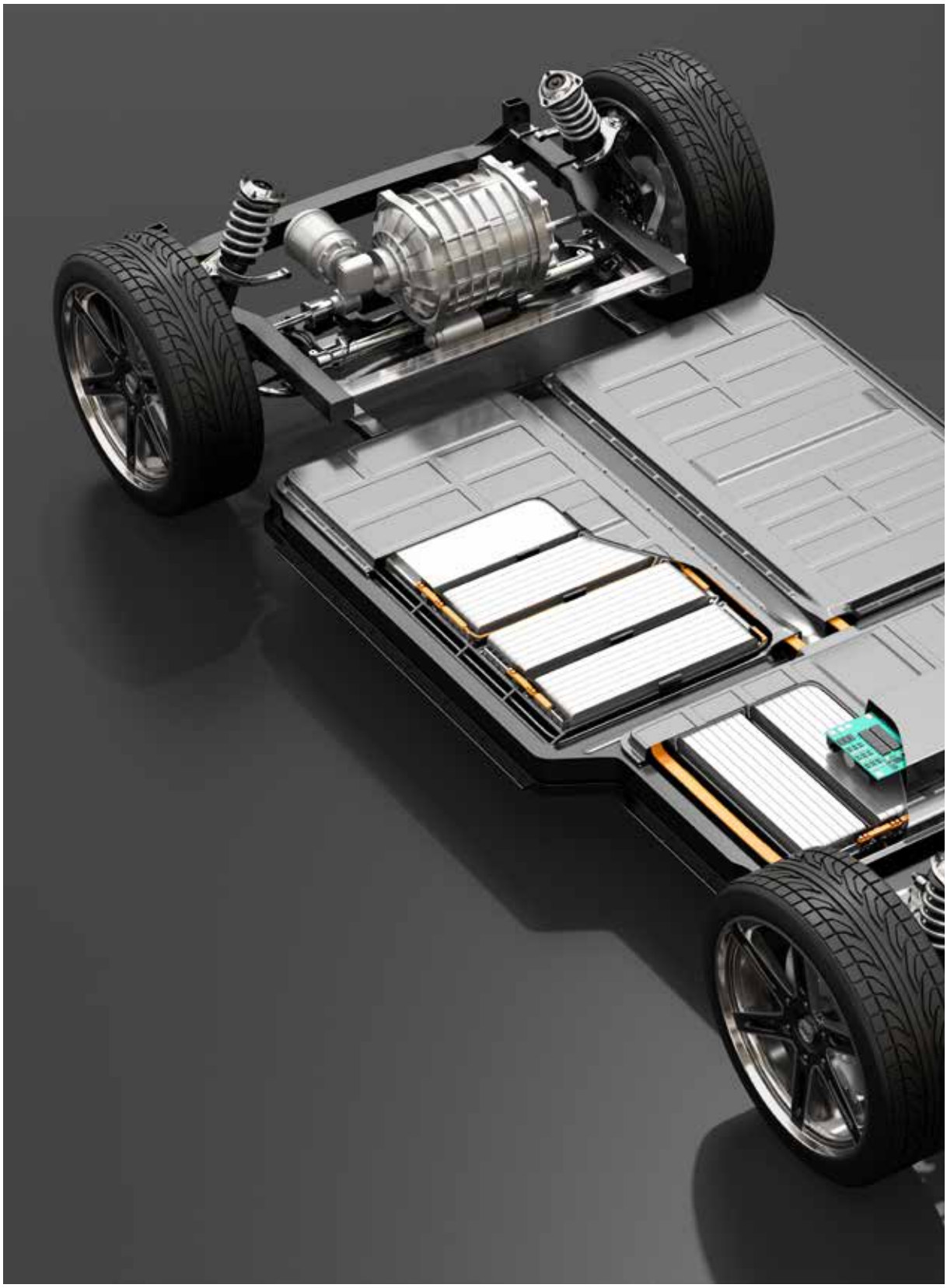
The lithium battery industry has seen exponential growth over the past several years as the automotive industry has been racing to implement electric powertrains in response to environmental pressures. This trend is set to continue. Hence the ability of the industry to respond to this continually rising demand is critical to its success. Being able to add manufacturing capacity while maintaining cell quality are key challenges.

The basic process of building most of these batteries is an example of a converting application, i.e. manipulating sheet materials in order to produce a finished product. Hence motion control is a key part of the manufacturing process. Multiple servo axes are used for coating the electrode film, winding the film into cells and so on. It is essential to maintain tight control over the axes in these processes to avoid compromising the quality and performance of the finished cells. This needs to be integrated with a range of other machine systems that relate to tab welding, vision system inspection of coating quality and so on.

TSN is especially suited to addressing these challenges. The ability to offer a converged network architecture with gigabit bandwidth means that it's possible to have high performance motion traffic for possibly hundreds of axes run over the same network as other types of machine control, while also integrating vision, safety and other systems. These may all coexist on the same network without compromising performance or quality. In addition to these performance benefits, TSN also offers the chance to reduce machine cost and complexity by reducing the number of networks required. This also leads to machines that can be deployed faster and can be maintained more easily, leading to higher productivity.

Having the process traffic share a common network also allows it to be shared with supervisory systems more easily. This opens the door for increased process transparency and further development of machine learning facilities that can optimise the quality of the cells, increasing yields and avoiding the high costs of scrap product.

TSN has already been implemented in cell manufacturing applications where these benefits are being actively exploited.



Chapter 6: Process industries

The process sector encompasses a wide range of different industries and processes, ranging from chemical plants to oil and gas, and overlapping other industries such as pharmaceutical and semiconductor. These plants are vital to many other areas, as they provide the building blocks and raw materials necessary for many other manufacturing processes. In most cases, the common feature is a distributed control system that monitors and manages processes, often spread out over a large plant area. Solutions that can optimise the design, operation and maintenance of these systems will help to reduce running costs while meeting key specifications, enabling delivery of quality products at competitive prices.

In these applications, once again, TSN can deliver potential benefits due to the ability to use a unified gigabit network architecture. This can avoid the need to install and maintain separate networks for different protocols and the associated use of gateways. In turn, this can deliver a significant reduction of engineering efforts and system complexity, while avoiding the loss of individual protocols' functions and benefits. Moreover, it can remove barriers to the necessary and seamless integration of all relevant plant systems (automation, instrumentation, networked IO, electrical distribution switchgear, safety instrumented systems, IIoT devices, edge gateways, etc.) for better plant operational and business performance.

As a result, it is possible to optimise processes, lowering operational expenses and hence end product costs.

Ultimately, it is possible to improve the performance of plant operations, product quality and the business as a whole. Since many of the process industries' products are ingredients for other industries, these advantages can then have a positive ripple effect through a complete value chain, benefitting customers and end users.

Chapter 7: Water treatment

Clean water is essential to life, but delivering it is particularly challenging. Maintaining security of supply and improving energy efficiency while reducing operating costs are only some of the challenges that water and wastewater treatment companies need to address on a daily basis.

Water treatment is one of the most essential activities on the planet. Life needs water, and this resource also plays a central role in many industrial operations. Due to the importance of water supply and treatment, these activities need to happen non-stop and at low cost to maximise availability and accessibility. They should also take place without impacting end quality, with processes that must operate within strict regulatory guidelines to ensure the safety of supply while protecting the environment.

The water industry is now turning to digitalisation in order to assure its future success and initiatives like “Water 4.0” are examples of this. Processes such as chemical dosing need to be further optimised. Vast supply networks benefit from intelligent data acquisition which in turn raises the issue of handling the huge amounts of data they generate. Cybersecurity is a key topic.

TSN is well placed to help the industry address these kinds of challenges. When it comes to building large scale control and monitoring networks, the ability to combine multiple types of device traffic on a single network architecture will make the task of reducing operating costs easier. Moreover, these deterministic, converged networks with gigabit bandwidth will help to ensure processes are optimised in real-time by getting data out of the processes to edge servers and cloud based supervisory systems more easily and making the application of corrective actions quicker. This also benefits energy efficiency, as immediate adjustments maintain ideal treatment conditions and avoid untimely, energy intensive corrective action. Furthermore, integrating preventative maintenance systems is essential to prevent possible loss of supply and even environmental non-compliance. For brownfield sites, it also offers attractive communication upgrade possibilities for older infrastructure to bring it in line with future initiatives. This will all help to contribute to the security of supply. Well run plants will also improve their environmental credentials by providing optimum water quality at the lowest costs through minimised energy and chemical usage.

There are also other application areas that are outside the scope of traditional treatment plants, such as flood protection and intelligent irrigation. Since these systems are also automated, the potential for them to also benefit from TSN in similar ways exists.

TSN also helps to address cybersecurity by providing a foundation for easier implementation of standards, such as ISA/IEC 62443 [4], and supporting techniques such as zoning, band limitation and filtering, intrusion detection and so on.

Water utilities are now considering how TSN can be integrated into their operations and how this will benefit further application of digitalisation as they move into the future.

Chapter 8: Conclusions

To remain competitive in demanding and fast-paced marketplaces, the adoption of Industry 4.0-oriented applications is becoming a must for companies across industry. In order to harness the ever-increasing volume of information generated by data-driven, smart manufacturing strategies, it is fundamental for businesses to implement robust and future-oriented networks. By doing this, companies are able to fully reap the benefits of digitalisation.

The technology designed to support these needs is TSN, as this enables converged network architectures that combine all OT traffic together into a single stream. This, in turn, can be managed more effectively and shared more easily with the IT level in order to derive actionable insights for optimising processes. Moreover, by implementing TSN on gigabit bandwidth, future capacity for sharing ever increasing amounts of data across the enterprise is assured.

A key solution available now that offers TSN functions and gigabit bandwidth is CC-Link IE TSN, the first open industrial Ethernet to combine these features. It is also backed by leading industrial automation vendors worldwide. Therefore, companies in a wide range of different key industries can already benefit from a wide range of proven, interoperable devices and components to create the systems needed by their facilities to address their digitalisation journeys.

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 twelve 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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