White Paper

Abstracting Configuration Complexity of Time-Sensitive Networking to Accelerate Mass Adoption

Time-Sensitive Networking (TSN) enhances standard Ethernet with determinism and synchronization, making it suitable for use across converged infrastructure networks. TSN operates in Layer 2 of the OSI model, making it a data link technology that can be adapted for use with different network configurations and higher-level protocols. But as TSN continues to evolve, organizations looking to capitalize on its benefits today must enlist technical experts who understand its nuances and how to deploy it for specific use case requirements.

Most users are only concerned that TSN delivers the features necessary to create, deploy, and manage new deterministic applications and services. While highly specialized experts can accomplish this, needing one just to configure TSN endpoints and applications is a barrier to adoption. For TSN to reach critical mass, industry needs an abstraction layer that simplifies the configuration of time-sensitive applications and endpoints to make TSN accessible to all.

This paper considers ways to abstract the complexity of TSN applications and endpoints through a single pane of glass—the TenAsys TSN RTOS, INtime®. From there, the potential of TSN in a software-defined manufacturing facility comprised of workload-consolidated virtual PLCs (vPLCs) is reviewed. The paper concludes by demonstrating how today's complex mix of industrial hardware and networking technologies can be consolidated and unified to help industry realize the benefits of true IT/OT convergence.

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The IEEE's efforts to converge operational endpoints and IT infrastructure over a universal time-sensitive Ethernet standard—Time-Sensitive Networking (TSN)—are now more than 10 years old. TSN improves network determinism, synchronization, and reliability; reduces costs; and consolidates the wide selection of Ethernet-based fieldbus networks for automation companies. But to date TSN has only been adopted by a few organizations as a spot replacement for legacy fieldbuses—never mind as industry's answer for ubiquitous converged networking.

Since the IEEE TSN task group formed, multiple extensions to the base TSN data link standards have emerged that make it suitable for use with higher layer protocols like PROFINET, CC-Link IE, OPC UA FX, and others. On one hand, the new flavors are a testament to TSN's viability as a next-generation, real-time converged networking solution. On the other, they cause confusion, primarily because the TSN standard allows higher layer protocols to dictate how lower layer protocols are configured and operate.

Put simply, TSN configuration requirements can vary from protocol to protocol and use case to use case, so implementing them requires an expert—hardly the single, unifying technology that was promised.

For TSN to achieve the critical mass industry has been waiting on for more than a decade, users must be able to access it without understanding its nuances; they must be empowered to leverage TSN's determinism, data transparency, cost, and other enabling characteristics in their applications without being TSN experts themselves. With it, today's OT environments will be transformed from rigid, hardware-centric environments into dynamic, software-defined ecosystems driven by deterministic virtual PLCs (vPLCs) and capable of IT/OT convergence.

To get there, endpoint and application developers working with TSN need an IT/OT network abstraction layer like what can be realized with the TenAsys INtime® RTOS.

ABSTRACTING NETWORK COMPLEXITY TO SCALE TIME-SENSITIVE NETWORKS

As there's currently no unified method for configuring TSN endpoints, they must be configured manually. Today, this means you need a specialist to build a TSN endpoint. A specialist is also required just to create TSN-aware applications because, of course, these applications must be developed with the subtleties of the underlying network in mind.

TSN-enabled hardware that could reduce some of the endpoint configuration and application development complexity is slowly reaching the market in the form of infrastructure like switches and controllers. For example, the Intel® Ethernet Controller i225 supports TSN features such as time synchronization (IEEE 802.1AS), time-based and credit-based shapers (IEEE 802.1Qbv and Qav), frame preemption (Qbu), and precision streaming.

But even with a controller like the i225, developers must tune endpoints to support the deterministic requirements of TSN applications. This immediately narrows the field of available development solutions; for example, configuring IT-centric operating systems like Linux to support real-time TSN applications requires complex workarounds that should be avoided if at all possible.

Starting with building blocks that were developed from the ground up for real-time performance is the preferred approach.

For instance, the built-in communication system of TenAsys' INtime RTOS was designed to manage deterministic traffic flows and can be utilized out of the box. INtime supports TSN protocol stacks; includes a High-Performance Ethernet (HPE) interface for most real-time Ethernet protocols; contains drivers for Ethernet controllers (including the Intel® i210, i225, and others); and allows for the creation of explicitly partitioned operating environments with dedicated resources that ease real-time application development on multicore processors.

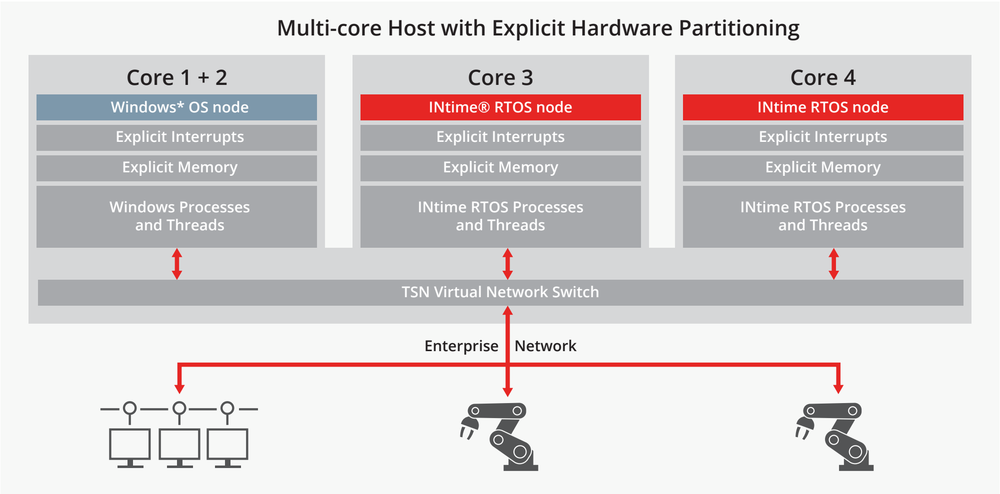

Figure 1. The TenAsys INtime® RTOS reduces the complexity of TSN deployments by partitioning applications and workloads into isolated environments on multicore processors. This allows the underlying network and driver configurations to be abstracted from application developers.

Depicted in Figure 1, the embedded virtualization capabilities of INtime software allow it to allocate compute, memory, and communications resources to specific processes. For TSN applications, this means the RTOS can guarantee different levels of determinism to different streams or classes of multi-protocol traffic. In other words, INtime can be configured as a "virtual network switch" that allocates virtual network resources as needed to different connections interfacing with an application—even across multiple virtual endpoints on multiple nodes.

Given that TSN is, by definition, a technology that involves multiple nodes, the ability to function as a virtual switch is critical. When paired with the RTOS's support for TSN sub-standards regarding traffic shaping, configuration, reliability, and time synchronization (including the Precision Time Protocol (PTP) often used to provide unified timing for devices on a TSN network), it permits applications running in an INtime partition to use external timing sources as a reference for scheduling local real-time processes. From there, real-time tasks can be orchestrated between workloads running in separate partitions thanks to INtime's asymmetric multiprocessing (AMP) architecture and global objects-based (GOBS-based) inter-process communications (IPC) mechanisms.

From a development perspective, INtime serves as an abstraction layer for workloads running inside its partitions. When viewed as an endpoint manager, this means INtime can translate specific application requirements into hardware and driver configurations. As a result, the average developer doesn't need to understand all the intricacies of TSN components, traffic queues, timing offsets, etc. to make use of the networking standard. Instead, INtime's application development tools and utilities function as a network configuration interface that allows workloads running on INtime to be implemented at the application layer or directly on top of the TSN network below—whatever the use case requires.

MULTI-PROTOCOL TSN ACCELERATES SOFTWARE-DEFINED MANUFACTURING

The flexibility and usability of a TSN enablement platform like INtime transforms the growing diversity of TSN-powered application-layer protocols from an interoperability challenge into an opportunity for deployment optimization. An example of the opportunity is apparent in automation environments, which are increasingly software-defined.

Rather than the current practice of deploying a discrete, dedicated hardware appliance for every control function on a factory floor, software-defined manufacturing environments like those described by the SDM4FZI project will depend heavily on virtualized control solutions like vPLCs. In parallel, software like the INtime® Distributed RTOS will allow vPLCs and other virtualized control functions to be implemented as workloads that run agnostically inside explicit partitions with dedicated resources (Figure 2).

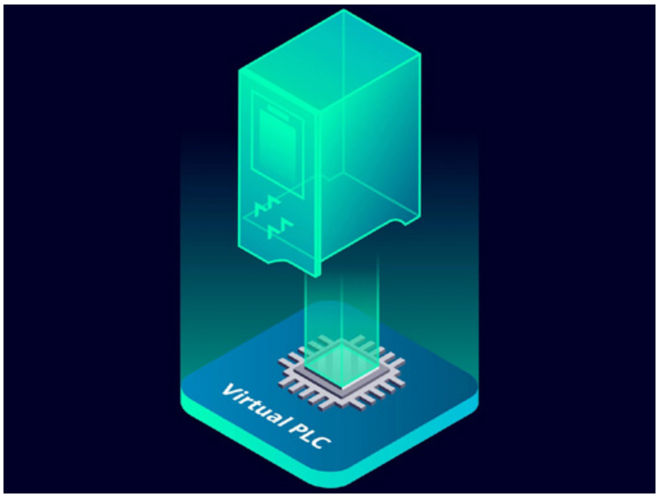

Figure 2. Virtual PLCs (vPLCs) like the Siemens SIMATIC S7-1500 can be implemented as workloads on partitioned multicore processors, paving the way for industrial PCs to operate as multi-function automation controllers. (Source: Siemens Blog)

The primary advantage of this approach is that many INtime vPLC partitions can run side-by-side on a multicore industrial PC. So instead of deploying or managing tens, hundreds, or thousands of discrete hardware controllers, plant operators can consolidate all their real-time control tasks onto a few high-performance multi-function automation controllers.

In the not-so-distant future, TSN links will connect these multi-function controllers to each other and to devices operating at the field level, such as robotic arms, actuators, and industrial sensors. Applications distributed over multiple logical control nodes will be synchronized, orchestrated, and managed by the TSN-aware INtime Distributed RTOS, ensuring the end-to-end continuity of real-time jobs and improving factory yields and uptime.

But beyond controller-to-controller and field-to-controller communications, these job-centric workflows can use TSN to deterministically integrate other systems like edge analytics servers or supervisory control and data acquisition (SCADA) systems. The result is incremental progress towards comprehensive IT/OT convergence, where real-time predictive maintenance and autonomous process optimization are suddenly accessible.

Through a single pane of glass, INtime provides the software foundation needed to realize such use cases by supporting multiple TSN traffic types and protocols over a single Ethernet wire (Figure 3). For example, an industrial PC controller running one or more instances of INtime could:

- Synchronously communicate with other distributed, multi-function industrial PC controllers using PTP over TSN
- Have partitioned vPLCs communicate with and control robotic arms, belts, and actuators via PROFINET over TSN
- Link to SCADA servers via CC-Link IE
- Relay operational data to edge analytics servers through OPC UA FX

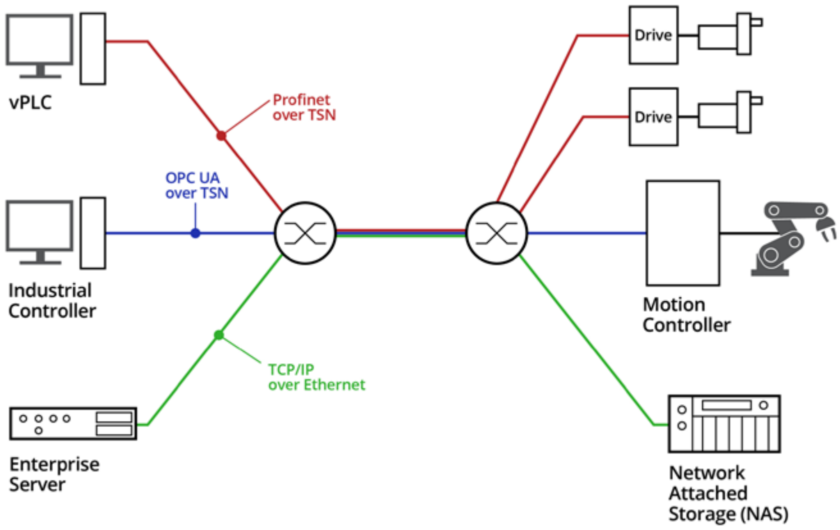

Figure 3. INtime®'s broad TSN protocol support allows heterogeneous application-layer protocols to converge on the same infrastructure and even in the same application.

TENASYS INTIME®: QUICK-START TSN

Like other networking technologies, TSN is an application enabler. By delivering improvements in network determinism, synchronization, interoperability, reliability, and cost, TSN facilitates the creation of new use cases and the enhancement of existing ones in ways the automation industry hasn't experienced in decades. Moreover, it sets the stage for a software-defined future where the OT total cost of ownership (TCO) is reduced dramatically by deploying, managing, and maintaining workloads remotely—all over real-time Ethernet that spans from edge to enterprise.

But without reducing barriers to access, TSN will never become unified and ubiquitous enough to realize the possibilities of true IT/OT convergence.

TenAsys INtime software is a quick-start TSN solution that supports a variety of industrial application protocols, different network configurations, and abstracts the complexity of deploying TSN endpoints. And with an architecture that can scale to support deterministic Wi-Fi, 5G over TSN, and integration with software-defined networking (SDN), it's also prepared for the TSN installations of tomorrow.

Help us build critical mass for TSN. Visit TenAsys.com for more information.

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