Results, Insights and Best Practices from IIC Testbeds: Time-Sensitive Networking Testbed

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1. INTRODUCTION

This article presents information gathered about the Industrial Internet Consortium's (IIC) Time Sensitive Networking – Flexible Manufacturing Testbed, commonly known as the TSN Testbed. The information and insights described below were captured in an interview of TSN Testbed lead Paul Didier, Manufacturing Solutions Architect in the IoT SW Group at Cisco, conducted by Joseph Fontaine, VP of Testbed Programs at the IIC.

2. TIME SENSITIVE NETWORKING – FLEXIBLE MANUFACTURING TESTBED

Time Sensitive Networking is a new technology that enhances Ethernet, a foundational piece of the Internet of Things (IoT). The IIC's TSN Testbed endeavors to apply new TSN technology in a manufacturing system with a wide range of automation and control vendors, to display the new capabilities and value of TSN. Manufacturers are dealing with automation and control systems that make up a large part of the 50 billion things we are trying to connect, and they usually require the pieces and parts and the overall system to be very deterministic in nature.

This deterministic characteristic is important to many industrial automation and control applications for manufacturing in oil and gas, utilities and transportation. TSN is an enhancement of Ethernet (standards IEEE 802.1 and 802.3 comprise what is generally considered Ethernet) to bring more deterministic capabilities to the network. It is enabling more and more devices, applications and systems to use a standard, open, inter-connected network that is the basic concept and driver of the IoT. If manufacturers do not connect things because they are worried about how the network is going to perform, they cannot implement IoT applications. This technology is viewed as a very important enhancement and upgrade to the standard networks to enable the overall Industrial IoT.

The goals of the TSN Testbed are to:

1) Show TSN's readiness to accelerate the marketplace and
2) Show the business value of accelerating the adoption of this technology.

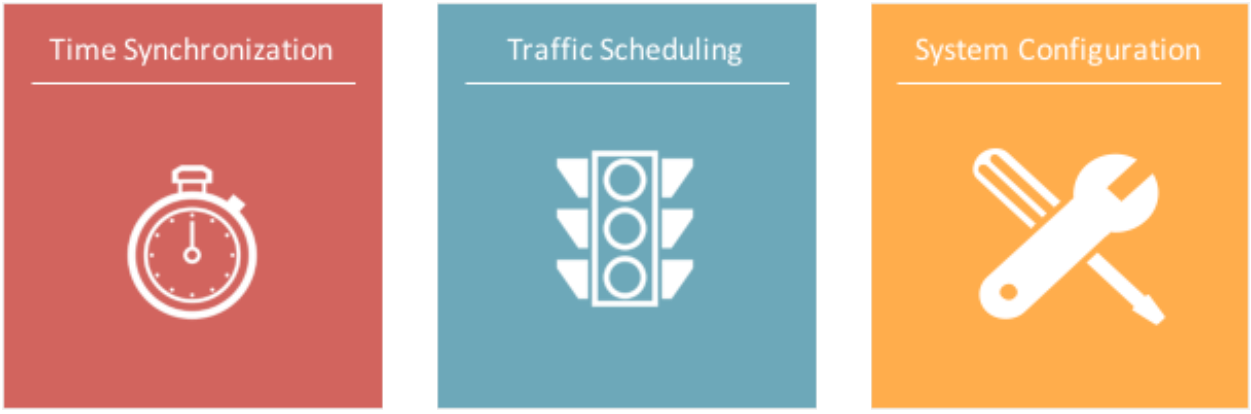
3. TESTBED STATUS

The TSN Testbed partners are currently focused on the technical aspects. They have brought in vendors with infrastructure, devices, switches and test equipment, to conduct rigorous testing. They have also developed successful demonstrations. Significantly, much of the effort has been getting various parts of the TSN-enhanced Ethernet to standard interoperate and work together. The end-devices and applications developed by participating vendors will be built into the testbed as soon as the technical interoperability is successful. The resulting manufacturing applications will show the business value.

4. TIME SENSITIVE NETWORKING – A BRIEF OVERVIEW OF TSN

TSN brings a number of enhancements to Ethernet. TSN comprises a number of enhancements, but three key capabilities form the core of TSN. They include:

1) Time Synchronization – A distributed, precise sense of time is a base requirement for distributed automation and control. It is also a requirement for the deterministic delivery of information needed between the sensors, actuators, controllers that comprise the manufacturing systems as well as the network infrastructure.
2) Sending scheduled Traffic flows – Based on the precise sense of time, the network infrastructure must be capable of forwarding critical automation and control traffic on a timely basis. This is considered an enhancement to the Quality of Service capabilities in most network infrastructure.
3) Central, automated system configuration – Recently, a key trend in networking has been Software-Defined Networking which enables automated, easier configuration. Software-Defined Networking is particularly important for TSN in Manufacturing because it consolidates application requirements, develops paths and schedules for the traffic flows and distributes that to the relevant network infrastructure.



There are other functions that are part of TSN, such as Frame Pre-emption, Ingress Policing and more, but these will be incorporated when complete - they are not required for the basic TSN functionality.

5. TESTBED OBJECTIVES

This testbed is designed to grow and achieve objectives in a progression. The three key capabilities listed above represent the initial technical milestones of the testbed. In initial plugfests, the focus was first on establishing time synchronization. Once this was accomplished, devices began to send scheduled traffic over the network. In our upcoming plugfests, we will focus on the central, automated configuration aspects of TSN. At that point we will be able to demonstrate the business value. Anyone can join and learn lessons through participation that many others have learned through this same progression.

In addition to the technical milestones, the TSN Testbed is looking at interfacing with a range of tools and applications within these spaces, from the programming and configuration tools, down to the actual operational input and output devices typically found in these environments. The testbed is trying to handle the whole process from designing a plant to operations of a plant using these new capabilities.

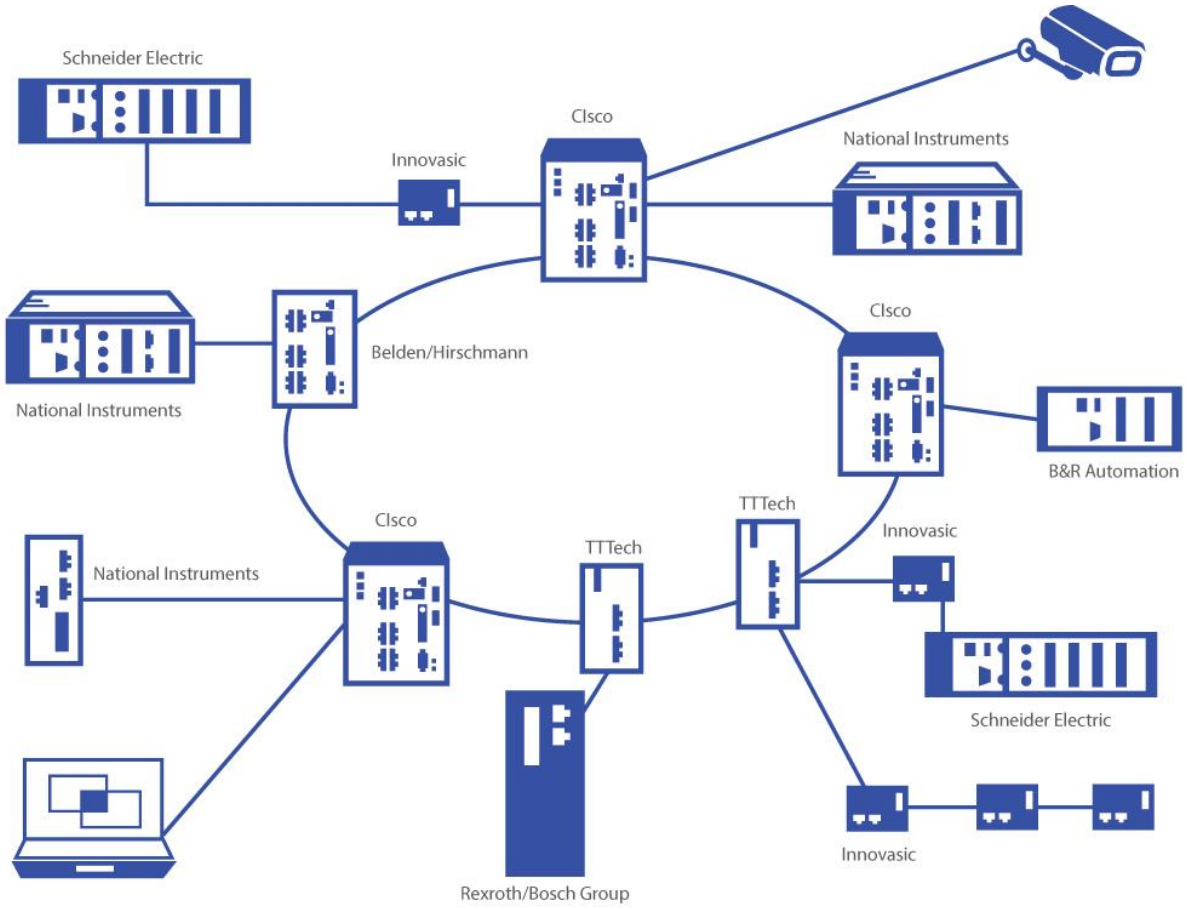
Testbed Lead, Paul Didier, was asked whether standard Transmission Control Protocol (TCP)-based equipment can plug into an Ethernet system for TSN:

"Absolutely. It's a key requirement to be backward compatible. That's the whole point, it's the next version of Internet technologies – Ethernet in particular. You can plug in any device and conventional communication will still work and it will co-exist with this critical automation and control traffic that we'll have going on. That is the key: we are converging this critical control traffic onto a network that is used by a video camera, Voice-over-Internet Protocol (VoIP) phone, or any other TCP/UDP (User Datagram Protocol) device that you may find in the manufacturing facility. It is by no means required to be a TSN device to connect, but clearly the devices that are TSN capable will benefit from more deterministic service."

The TSN Testbed is unique thanks to the participation of twelve major companies representing an effective cross-section of functionality. A typical testbed in the IIC ecosystem commonly includes six or fewer participants. Most TSN Testbed participants are from the automation and control world, but there are also a number of networking and technology companies. All of these organizations are joining together to enable the testbed to address the cultural and technical divide between Information Technology and Operational Technology. IIC members participating in the TSN Testbed at the time of this article are Belden/Hirschmann, Bosch Rexroth, B&R Industrial Automation, Cisco, Innovasic, Intel, KUKA, National Instruments, Renesas Electronics, Schneider Electric, SICK AG, TTTech and Xilinx.

In the manufacturing vertical, it takes time for new technologies to be adopted due to the long lifecycle of systems and equipment. The critical nature of those systems requires careful design and implementation. This testbed is important to the process of proving that TSN is ready for adoption.

A number of technology companies and industrial companies are very interested in the technology. These companies are readying their products and solutions for TSN. TSN requires a fair amount of coordination and synchronization between network infrastructure, switches and routers, as well as end-devices.



TSN Testbed Overview Diagram

6. TESTBED OUTCOMES

The testbed team decided from the beginning this would not be a short-term testbed – throw some technologies at it, get a quick result and proof of concept and walk away from it. A fixed location was established at National Instruments – the NI Industrial IoT Lab – which provided the team with a permanent home for their collaboration. The Lab is available for anyone to test their product or technology to determine how they might work with a TSN set of systems. Companies may validate their progress in larger groups – via plugfests – or independently.

Plugfests are face-to-face events where the participants gather to test their enhanced products and technology. Using the testing tools, participants check their progress and how well their devices are working with other devices and networks. As the plugfests progress, the participants continually add more features and functions to what they imagine can be tested. IIC members and non-members alike can request participation in these plugfests. Ideally, potential participants come and add value, capabilities or something to the overall plugfest that goes beyond simply receiving feedback on a product.

To date, most of the testbed participants have used the TSN Testbed to achieve results to advance their synchronization and scheduled traffic capabilities. Most participants are currently working on communicating critical control traffic and successfully getting certain protocols to run over TSN. The TSN Testbed's significant progress is great news for all of the participants. They have used the work in the TSN Testbed to put a high priority on their investments.

All participants are gaining a valuable sense of how their particular implementations work with this new technology; what challenges they have encountered, where they need to focus development and where they may have misunderstood or require further clarification from the standards and technology elements. All participants – the network infrastructure vendors, the end-device vendors, even the testing tool vendors – have learned what it means to implement TSN, where they can enhance, improve or update their product to interoperate and how it can be done in such a way that the vendors and eventually the customers gain value. These experiences are not just valuable for the participants, but are being fed back to the various standards groups working on TSN.

The most recent TSN Testbed plugfest occurred on January 12 & 13, 2017 in Austin, Texas at the NI Industrial IoT Lab.

Three plugfests have occurred, to date, offering participants opportunities to test, for example:

- Synchronizing devices to a common, precise sense of time delivered over the network
- Establishing TSN flows between various vendors
- Defining TSN flows in Central Network Controllers (CNCs) and distribute schedules to network infrastructure
- Communicating input/output traffic via TSN flows
- Demonstrating TSN's ability to protect critical flows from high-bandwidth traffic
- Connecting via gateway non-TSN traffic into TSN flows
- TSN flow requirements
- CNC to network infrastructure (schedule distribution)
- Data consistency over OPC UA Pub-Sub over TSN

7. INFLUENCING STANDARDS

It is one thing to build a standard and it is another thing to actually implement and use it. The TSN Testbed is accelerating this process by early phase usage of enhancements to the Ethernet standards.

Specifically, the testbed has been influencing two Ethernet standards: IEEE 802.1 and IEEE 802.3. All TSN Testbed work is filtered to Avnu, a standards organization developing the interoperability and certification based on IEEE's TSN. Through Avnu, it is channeled back into IEEE [Institute of Electrical and Electronics Engineers].

Many IIC members participate in both organizations. Additionally, both have formal liaison relationships with the IIC, easing this information flow. The IIC maintains active liaison relationships with standards organizations, open-source organizations, other consortia and alliances (either technology-focused or industry-focused), certification and testing bodies and government entities or agencies. The purpose of these relationships is to generate requirements for new standards from every part of the activities taking place within the IIC. These relationships help eliminate duplication of effort and ensure that new standards and technologies necessary to build and enable the Industrial Internet are brought to market more rapidly.

What other architectures, standards and protocols are potentially influenced by TSN? When TSN gets into the manufacturing area, the TSN Testbed team anticipates the TSN aspects will influence OPC Unified Architecture (OPC-UA), the Object Management Group Data Distribution Services (OMG DDS) standard and the ODVA, among others such as SERCOS International or Profinet International are looking to adopt TSN. Common Industrial Protocol (CIP), SERCOS and Profinet are industrial automation and control protocols often used between Programmable Logic Controllers (PLCs), input/output devices, motors and drives, and robots. They support tight synchronization and tight deterministic systems and can benefit from the capabilities TSN brings.

8. IIC ECOSYSTEM

The IIC approach to testbeds fosters collaboration and helps the TSN initiative increase awareness and drive adoption. Bringing 12 companies together inevitably leads to questions around Non-Disclosure Agreements (NDAs), Intellectual Property, etc. The participants want to ensure no vendor takes any of the results to drive advantages for a small group or for itself. The structure of the IIC helps testbed partners collaborate with enough confidence that sharing or exposing insights and technology is not going to lead to bad press, somebody claiming rights or locking the others out of a marketplace.

According to Paul Didier:

“We are trying to create a bigger, better marketplace for everybody and therefore we should have a willingness to share and work together towards a common goal. It is good to have an ecosystem where we can collaborate with a number of standards organization to get information from and give feedback to. Without being a standards organization ourselves, it’s nice to be able to work with OPC Foundation, with Avnu, IEEE, IETF [Internet Engineering Task Force] and whoever else we need.

“We can get all of the interested parties together, as the standard is being finished, to make sure we can implement it and [achieve interoperability]. We are working with the IEEE and Avnu and giving both organizations feedback on how this is working and where there might be clarifications or changes required as we try to get everything working in a real lab.”

The TSN Testbed applies the IIC's Industrial Internet Reference Architecture (IIRA), with a focus on the connectivity section on the testbed implementations. In fact, the TSN Testbed participants are actively collaborating with the IIRA authors. The findings from the testbed are reflected in the requirements, key functions and capabilities established as a part of the connectivity section in v1.8 of the IIRA. Future testbed phases will involve expansion beyond the connectivity at the edge work happening right now.

Specialized resources are required within the TSN Testbed to manage very precise delivery of information and the synchronization of devices. For example, Ixia joined the testbed—bringing high-quality testing equipment to validate that things work as expected. Ixia develops specialized products for the TSN technology marketplace. In turn, the TSN Testbed helps Ixia develop a market and show the value of its products. In addition, Ixia participates in the plugfests and give the participants valuable feedback on product performance.

The testbed is not actively recruiting partners, but interested companies are invited to learn about it and join. It welcomes partners who can identify a mutual benefit and have the resources available to participate. To get the full benefit out of the testbed, participants should bring equipment – remember, this is an interoperability testbed. The objective is to bring in technology and equipment to determine how well it interoperates with other people's devices, with infrastructure and with the general TSN concept.

9. CHALLENGES AND SURPRISES

With a new technology, it is challenging to figure out why a certain behavior is happening and how to make adjustments. In the spring of 2016, there was a point when the devices were not doing what they were supposed. Their discovery efforts were hindered by the fact that they lacked feedback on their performance. When the testbed team brought Ixia into the plugfest, change was instant and dramatic. With Ixia, the testbed had a resource that gave feedback into why something wasn't working, where an improvement could be made and why behavior was not occurring as expected.

Today, the testbed team is getting the base technology working and interoperable. The next step will be application protocols. One of the big surprises is the understanding that this testbed could scale rather quickly because of the IIC ecosystem. The testbed team grew at least 50% in 2016 and that growth is expected to continue. As they add more participants, and as they scale the concept, there will be challenges along the way. A year from now, Paul Didier expects to revisit this conversation to reflect on a year of more good experiences, more advancement, more players and an outlook of that pace continuing for many years. TSN is an area where there is a great deal of room for ongoing innovation and collaboration. The testbed team has seen distinct value right away.

Paul Didier's advice to any organization starting an IoT project of this caliber is to focus on an area that is going to drive value and advancement for a range of companies. That will attract a

good group of collaborators who are motivated to make changes, to invest time and resources and to create that innovation spark.

10. CURRENT ACTIVITY

The TSN Testbed team has a few use cases in action right now. One use case currently ramping up involves a major robot supplier and a major automation control supplier who seek to use the TSN technology to perform intercommunication between their devices and systems. They will coordinate and control PLCs and the monitoring of the sensor data between robots and PLCs. This use case consists of a combination of receiving highly time-sensitive, synchronized information from sensors and passing control or actuation commands back into that environment to other types of devices (a robot, as example). Previously, these companies would have had to perform this intercommunication between devices and systems with a separate, proprietary networking technology – either not Ethernet or heavily modified Ethernet – that would leave these applications and systems, from an IoT-network perspective, relatively in the dark. The TSN Testbed will be running these with other types of automation and control applications, showing the convergence and eventually showing the ability to run IoT applications in Year Two.

A good example of an established IIC testbed considering the adoption of TSN capabilities within the end-devices and the network is the Communications and Control for Microgrid Applications Testbed. There are some very strong business cases to see the use and adoption of TSN technology in smart grid as well as manufacturing. That testbed will likely take a look at the TSN Testbed soon.

For 2017, the TSN Testbed team has taken an action item to establish a testbed in Europe. Four or five organizations have expressed interest in hosting the TSN Testbed in various locations. By the middle of 2017, the team hopes to have a second instance of the TSN Testbed running in Europe.

For more on the TSN Testbed, please visit the overview and related links found on the TSN Testbed webpage.

11. TESTBED PARTICIPANTS

- Belden/Hirschmann
- Bosch Rexroth
- B&R Industrial Automation
- Cisco
- Innovasic
- Intel
- KUKA
- National Instruments
- Schneider Electric
- SICK AG
- TTTech
- Xilinx
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