TSN - Report on the IIC Testbed

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Abstract

This paper will give a report from the Industrial Internet Consortium's (IIC) TSN Manufacturing testbed. The goal of this test bed is to display the value of new Ethernet (IEEE 802) standards, referred to as Time-Sensitive Networks, in a Manufacturing ecosystem of applications. Four ODVA members are participating in the testbed: Bosch Rexroth, Cisco, Innovasic (recently acquired by Analog Devices, Inc.) and Schneider Electric.

The testbed will display the following:

- Combine different critical (e.g. OPC Pub/Sub and ODVA CIP) and best-effort traffic flows on a single network based on IEEE 802.1 Time Sensitive Networking (TSN)
- Demonstrate the real-time capability and vendor interoperability using standard, converged Ethernet
- Evaluate security value of TSN and provide feedback on the secure-ability of initial TSN functions
- Show ability for IIoT to incorporate high performance and latency sensitive applications
- Provide integration points for smart edge-cloud control systems into IIoT infrastructure & application

By the time of the report, the testbed will have conducted at least two plugfests where a variety of vendors have demonstrated varying levels of integration with TSN-based networking technology. This paper will report on the applications used, the level of integration and readiness of TSN based standard technology and report some of the value of TSN to the ODVA community.

Keywords

Industrial Ethernet, Industrial Control, Industrial Internet Consortium, IIC, Motion Control, EtherNet/IP, Time-Sensitive Networking, TSN, software-defined networking, SDN, deterministic Ethernet.

Definition of terms (optional)

Bridge: A system that includes Media Access Control (MAC) Bridge or Virtual Local Area Network (VLAN) Bridge component functionality and that supports a claim of conformance to Clause 5 of IEEE Std 802.1Q-2014 for system behavior. Note: "Bridge" is often used interchangeably with "switch" in TSN discussions.

Centralized Network Configuration (CNC): A centralized component that configures network resources on behalf of TSN applications (users).

Centralized User Configuration (CUC): A centralized component that discovers and configures application (user) resources in end stations. The CUC exchanges information with the CNC to configure TSN features on behalf of its end stations.

End station: A device attached to a local area network (LAN) or metropolitan area network (MAN), which acts as a source of, and/or destination for, traffic carried on the LAN or MAN.

Grandmaster: The time-aware system that contains the best clock, as determined by the best master clock algorithm (BMCA), in the generalized precision time protocol (gPTP) domain.

Listener: The end station that is the destination, receiver, or consumer of a stream.

Stream: A unidirectional flow of data from a Talker to one or more Listeners.

Synchronized time: The synchronized time of an event is the time of that event relative to the grandmaster.

Synchronized time-aware systems: Two time-aware systems are synchronized to a specified precision if they have the same epoch and their measurements of the time of a single event at an arbitrary time differ by no more than a specified amount of time.

Talker: The end station that is the source or producer of a stream.

Time Sensitive Networking – Flexible Manufacturing Testbed

Time Sensitive Networking is an initiative to enhance Ethernet communication, 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 in order to display these new capabilities and the value of TSN. Testbed participants consist of manufacturers of equipment intended for the automation and control systems that make up a large part of the 50 billion things that comprise the IoT. These applications generally require that the pieces, parts and the overall system be very deterministic in nature.

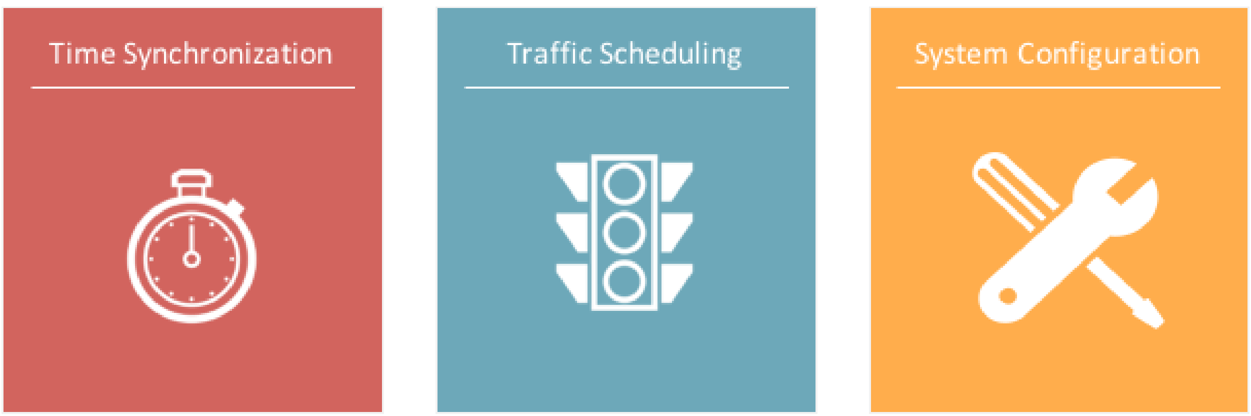
This deterministic performance is mandatory for many control applications in factory automation as well as manufacturing for oil and gas, utilities and transportation. TSN is an enhancement of Ethernet (standards IEEE 802.1 and 802.3 comprise what is generally considered Ethernet) to bring more deterministic capabilities to the network. It is enabling more and more devices, applications and systems to use the standard, open, inter-connected network that is the basic concept and driver of the IoT. Without these enhancements manufacturers of industrial control systems have to use specialized non-IEEE conformant network technology in their products and therefore, they cannot participate in future developments of the IoT. Thus, TSN is viewed as a very important enhancement and upgrade to standard networks in order 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.

Time Sensitive Networking – A Brief Overview of TSN

TSN brings a number of enhancements to Ethernet. Testbed participants have chosen to focus initial efforts on three key TSN enhancements. These particular enhancements are considered key to industrial control systems and are also either published or are nearing publication. 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 synchronized acquisition of sensor signals and activation of output signals 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.



Other TSN enhancements, such as Frame Pre-emption, Ingress Policing and more, will be prioritized and incorporated into the testbed when complete.

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 on establishing time synchronization. Once this was accomplished, devices began to send scheduled traffic over the network. Upcoming plugfests will focus on the centralized, automated configuration aspects of TSN and on application layer standards for interoperable real time control. At that point will comprise a complete TSN ecosystem, albeit with a subset of the TSN standards, and will be able to demonstrate the value proposition of TSN. Participation is open to all IIC members and offers an unparalleled opportunity to explore, understand and apply the TSN standards to real-world applications.

In addition to technical objective, the TSN Testbed is interfacing with a range of tools and applications within the industrial and networking spaces. These tools include programming and configuration tools, as well as the actual operational input and output devices typically found in these environments. The testbed is attempting to emulate the entire process of designing a plant as well as operations of that plant based upon these new capabilities.

The TSN Testbed also provides a unique opportunity to verify TSN functionality and interoperability thanks to the participation of its twelve member companies representing an effective cross-section of functionality. Most of the TSN Testbed participants are from the automation and control markets, but there are also a number of networking technology companies. These organizations have joined together, via 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 paper are Belden/Hirschmann, Bosch Rexroth, B&R Industrial Automation, Cisco, Analog Devices, Inc. (ADI), Intel, KUKA, National Instruments, Schneider Electric, SICK AG, TTTech and Xilinx.

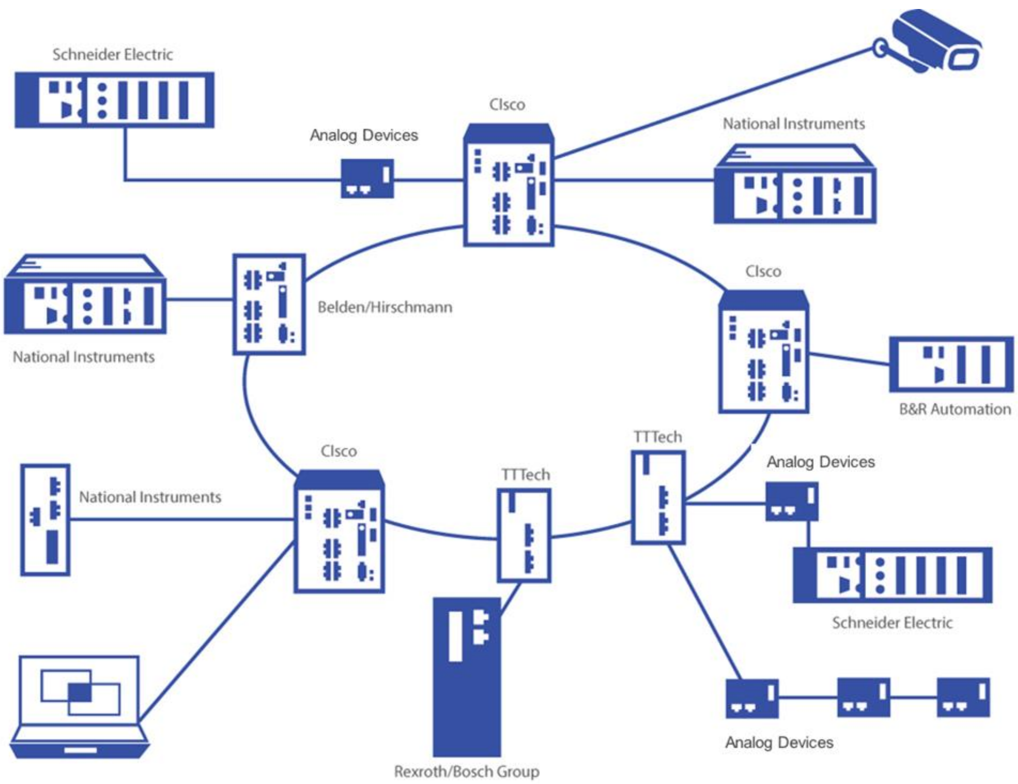


Figure 1 - Current TSN Testbed Topology

Testbed Status

The TSN Testbed partners are currently focused on the technical aspects of TSN communications. 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 spent ensuring that various parts of the TSN standards interoperate. Applications-layer considerations will be included in the testbed as soon as the technical interoperability is ensured.

Testbed Outcomes

The testbed team decided from the beginning that the testbed was to more than a simple “proof of concept”. The goal is to develop a TSN-based ecosystem in which new applications and TSN features can be validated. 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 and thus determine how these products work within a TSN ecosystem. Companies may also validate their progress in larger groups via plugfests.

As a result of these plugfests, all participants gain a valuable sense of how their particular implementations work with these new technologies; what challenges they may encounter, 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 ensure that they and eventually their 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.

Two 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

The first TSN Testbed plugfest occurred on June 20 – 23, 2016 in Austin, Texas at the NI Industrial IoT Lab. Participants include: NI, Cisco, TTTech, GE, Schneider Electric, Kuka, Intel, ADI and Ixia. Depending upon participant readiness, objectives for the plugfest included:

1. Establish end-device synchronization via 802.1AS network based time services
2. Define TSN flows in Central Network Controller and distribute schedule to network infrastructure
3. Communicate I/O traffic via TSN flows
4. Measure and verify TSN performance with available testing tools

All participants with end-devices achieved synchronization and a subset of participants achieved all 4 objectives.

On Oct. 3-5 2016, a second TSN plugfest was held in Austin TX at NI Headquarters.

Participants include: NI, Cisco, TTTech, Belden Hirschmann, BoschRexroth, B&R, Schneider Electric, Intel, ADI and Ixia. Depending upon participant readiness, objectives for the plugfest included:

1. Establish end-device synchronization via 802.1AS network based time services
2. Communicate I/O traffic via TSN flows
3. TSN Gateway traffic from one vendor
4. Measure and verify TSN performance with Ixia testing tools
5. Built a demonstration displayed at IOT SWC (Oct. Barcelona) and SPS Drives (Nov. Nuremberg)

All of these objectives were achieved and successful demonstrations of the testbed were held at the IOT SWC and SPS drives.

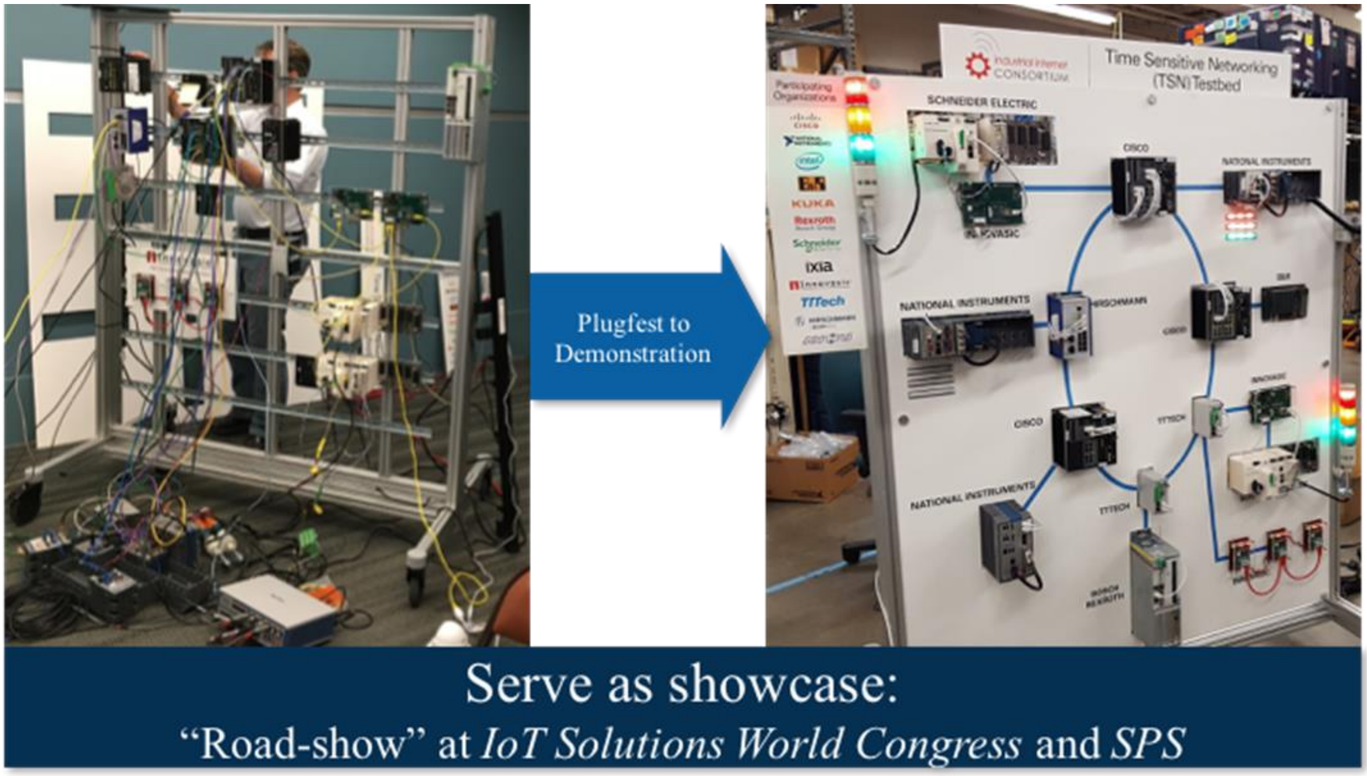


Figure 2 - From Plugfest to Demonstration

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 the TSN 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. Avnu is helping to define measurement conditions and set-up for future conformance testing. 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 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 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.

SDN-inspired Network Configuration

While the participants in the TSN testbed have managed significant progress in a very short time, their work is far from complete. As previously noted, the TSN testbed will evolve to incorporate new use cases, new applications and interoperation of protocols. In the near future, centralized configuration of the time-sensitive features will be achieved, making it possible to coordinate motion control, I/O, controller-to-controller, and machine-to-machine communications seamlessly across the same network backbone. Further, data from any or all of these applications can be made seamlessly available to the user via the network or through the cloud.

To manage traffic schedules and paths (including redundant paths) for data and time-sync, a centralized configuration approach is beneficial. IEEE P802.1Qcc (Stream Reservation Protocol (SRP) Enhancements & Performance Improvements) enhances the existing Stream Reservation Protocol with the addition of a User Network Interface (UNI) which allows for a centralized network configuration (CNC) entity.

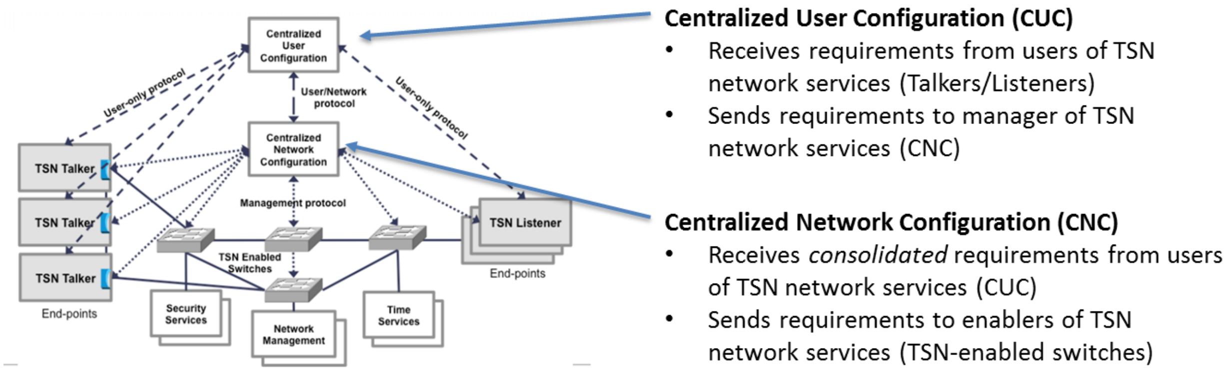


Figure 3 - SDN-inspired Network Configuration

A Centralized User Configuration (CUC) entity communicates to the CNC via a standard API. The CUC may be used to discover end stations, retrieve end station capabilities and user requirements, and configure TSN features in end stations.

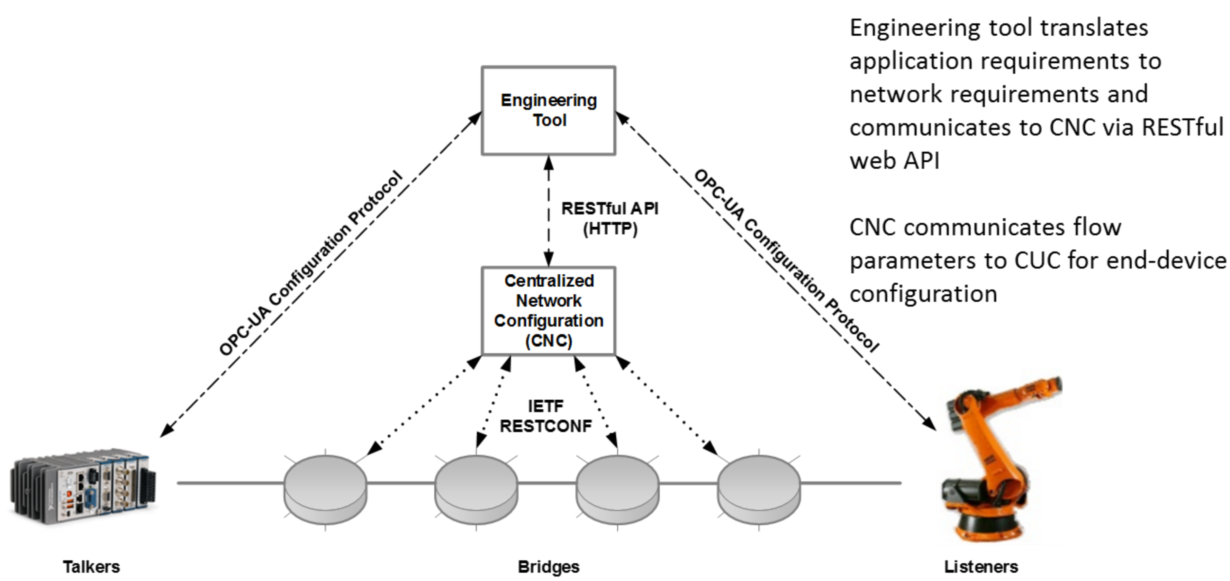


Figure 4 - CNC - Northbound

This CNC can then provide a centralized means for performing network calculus, scheduling and other configuration via a remote management protocol such as NETCONF or RESTCONF.

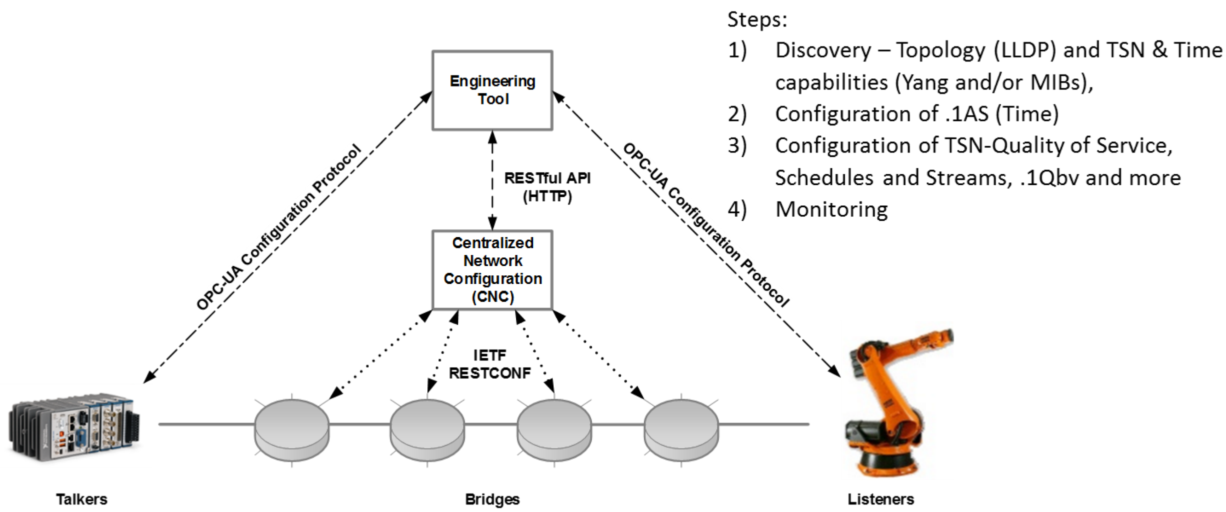


Figure 5 - CNC - Southbound

Conclusions

While progress to date is far from this lofty vision, these are the first vital steps to making that vision a reality. We invite all those interested in shaping that vision to join our efforts to achieve a truly converged network.

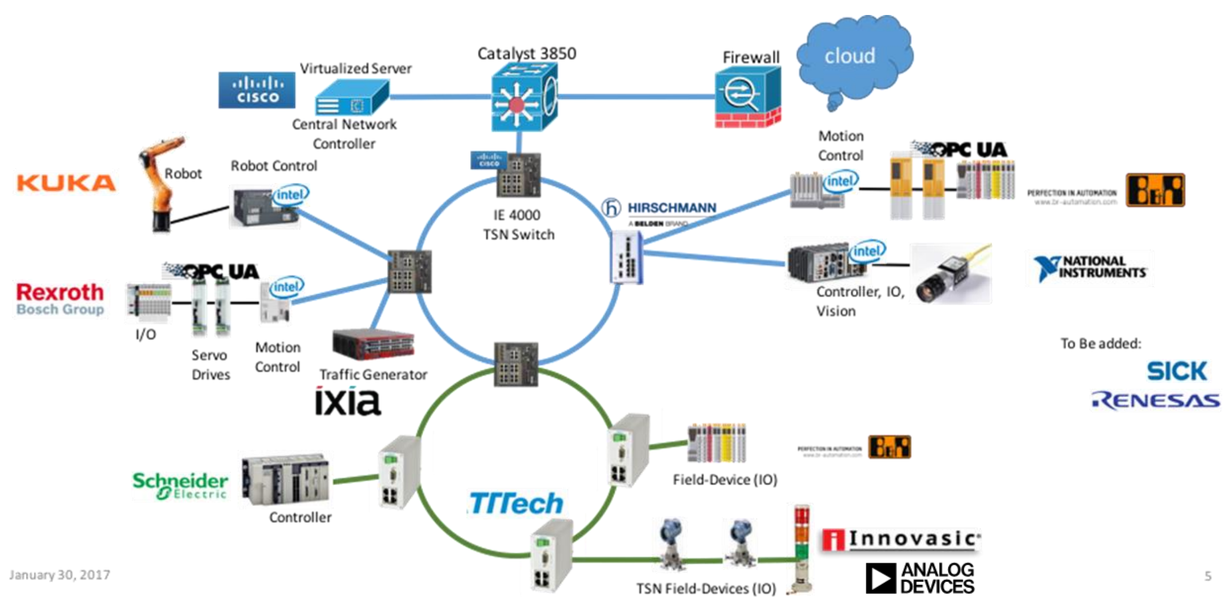


Figure 6 - TSN Testbed of the Future

References

Standard	Description
IEEE 1588-2008	IEEE Standard for a Precision Clock Synchronization Protocol for Networked Measurement and Control Systems https://standards.ieee.org/findstds/standard/802.1AS-2011.html
IEEE 802.1AS-2011	Timing and Synchronization for Time-Sensitive Applications in Bridged Local Area Networks http://standards.ieee.org/getieee802/download/802.1AS-2011.pdf
IEEE 802.1AS-Rev	Timing and Synchronization for Time-Sensitive Applications in Bridged Local Area Networks (*draft*) http://www.ieee802.org/1/pages/802.1AS-rev.html
IEEE 802.1Q-2014, Clause 34	Forwarding and Queuing Enhancements for Time-Sensitive Streams (FQTSS) https://standards.ieee.org/findstds/standard/802.1Q-2014.html
IEEE 802.1Qbv-2015	IEEE Standard for Local and Metropolitan Area Networks -- Bridges and Bridged Networks - Amendment 25: Enhancements for Scheduled Traffic https://standards.ieee.org/findstds/standard/802.1Qbv-2015.html
IEEE 802.1Q-2014, clause 35	Stream Reservation Protocol (SRP) https://standards.ieee.org/findstds/standard/802.1Q-2014.html
IEEE 802.1Qcc	Stream Reservation Protocol (SRP) Enhancements and Performance Improvements (*draft*) http://www.ieee802.org/1/pages/802.1cc.html
IEEE 802.1Qci	Per-Stream Filtering and Policing http://www.ieee802.org/1/pages/802.1ci.html
IEEE 802.1Qcp	Bridges and Bridged Networks Amendment: YANG Data Model (*draft*) http://www.ieee802.org/1/pages/802.1cp.html
IETF RFC 6020	YANG – A Data Modeling Language for the Network Configuration Protocol (NETCONF) https://tools.ietf.org/html/rfc6020
IEEE 802.1AB	IEEE Standard for Local and Metropolitan Area Networks - Station and Media Access Control Connectivity Discovery https://standards.ieee.org/findstds/standard/802.1AB-2016.html
IETF DetNet	Deterministic Networking (DetNet) (*draft*) https://datatracker.ietf.org/wg/detnet/documents/