LNI 4.0 TSN Testbed and Demonstrator

Time-Sensitive Networking (TSN) overview document

LNI 4.0

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1 Executive Summary

The aim of this document is to provide an overview of the activities of LNI 4.0 in relation to TSN (Time-Sensitive Networks).

LNI 4.0 underlines the importance of TSN technologies to accelerate the changes in the industrial communication ecosystems for industrial automation, explains the procedures of the TSN Testbed, and how the cooperation with the standardisation organisations as IEEE is operationalised. The LNI 4.0 TSN Testbed focus since day one on various independent (non-) real-time applications and use cases running on a dynamic network with multiple administrative domains at the same time. The testbed operationalises this goal as follows:

- Validation of extensions to the IEEE 802.1 standard family as the core of the LNI 4.0 TSN Testbed activities.
- Industrial inter-domain stream establishment with distributed or centralized domain control.
- Evaluation of a simple approaches for production lines, fostering stepwise collaboration between automation system integrators and machine builders.

The LNI 4.0 testbed operates plugfests since 2017 with small, medium and large companies providing TSN technologies. The plugfest is the realisation of the above mentioned testbed goals. It delivers valuable feedback to the companies as well as the standardisation organisations like IEEE. Also information update on standardisation developments are discussed and exchanged in the LNI 4.0 community.

The LNI 4.0 TSN testbed demonstrator is a baseline implementation of the use cases of the testbed members. It is presented at fairs and subject to continuous improvements.

2 LNI 4.0 TSN Testbed

2.1 Who

The non-profit and pre-competitive, i.e., neutral German association Labs Network Industrie 4.0 e.V. (LNI 4.0) was founded in 2015 from the German Plattform Industrie 4.0 to transfer and test Industrie 4.0

solutions to industrial SME (small and medium sized enterprises). LNI 4.0 operates several neutral testbeds jointly with its members and SME since 2017.

2.2 Why

The digital transformation will not occur in a short period of time since the industrial automation components and products have decades-long lifecycles. In addition, it is a global challenge and manufacturing is part of global supply chains and international equipment providers. There are industrial automation challenges at the shop floor with various components. The innovation of equipment is focused on application and technology needs. Standard development for the interaction of components is also an incremental process and may not address specific needs in the first version. There is a need to expedite the changes in the ecosystems but the processes to roll out enhancements in collaboration with different components are rather slow.

LNI 4.0 has the goal to act as a catalyst to expedite this process with its international partners.

2.3 What

The TSN testbed of LNI 4.0 was established in 2017. The use cases of small and medium enterprises (SME) are the base for this LNI 4.0 TSN testbed. Organizing LNI 4.0 plugfests allow the international experts to test their components with other development products based on the basic underlying standards and review as well as feedback pre-competitively the draft standards of the standardisation organisations.

The task of the LNI 4.0 TSN testbed is to be the binding element between the international standardization bodies and the SME, with their expertise in developing value-adding solutions to the larger manufacturing industry.

This means, conveying latest standard development information from the meetings to the TSN Testbed members, and in the other direction, to feedback enhancement ideas and requests for additional, yet missing features to the standardization bodies.

IEEE TSN standards were identified as bringing benefits to the industrial automation world. Its realtime-features allow to add realtime-capabilities to the well-known Ethernet as being used in machine-machine communication. And hence, bring new value to machine-to-machine communication and the network architecture of complete production plants. The main concept is to use a single network but isolate the traffic of different types and systems. The risk for each individual applications to be disturbed by other applications on same network can be reduced in this way.

2.4 How

The first step is to cooperate with the Standards Development Organizations (SDOs) such as IEEE and IEC. For this purpose, LNI 4.0 has liaison contracts with the major relevant SDOs like the IEEE 802.1 working group.

This yields early sample implementations and provides feedback to the standardisation organisation like IEEE and IEC. The suitability of the standards for end application incorporating SMEs remains in the centre of the activities of the LNI 4.0 TSN testbed.

The industrial fair demonstrator is an important application example that creates the feedback loops between the standardisation bodies and the larger stake holder circles. The LNI 4.0 testbed demonstrator will implement technologies that are covered by this document. The testbed supports the overall target that the TSN standards are adapted by the same.

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3 Technological Use Cases

The TSN standards enable a vast amount of possible use cases where lot of them require a different selection of features. The LNI 4.0 choose to focus on the Use case of a production line (see Figure 1). The main criteria of this use case is a TSN Network connecting different machines from various vendors.

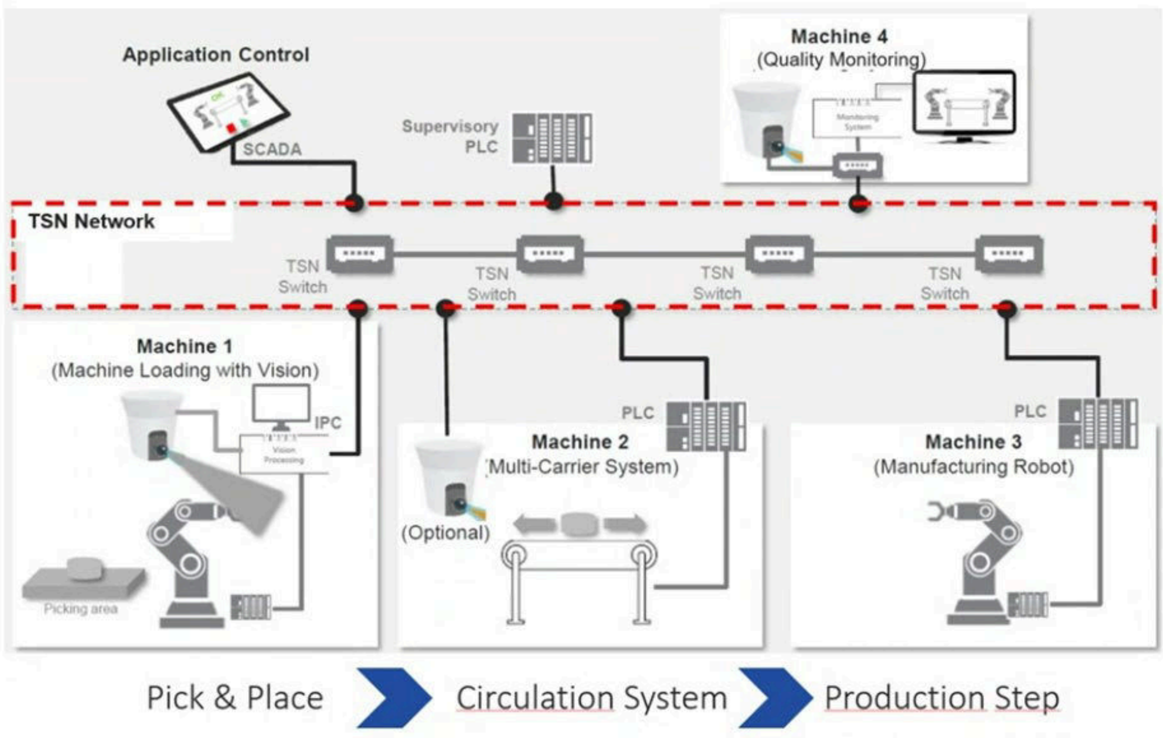

Figure 1 Production Lines Use case

This use case typically comes with following requirements:

- OT personal is in charge of production
  - Avoid extra cost for specialists, e.g., network operator
- Production rate must be met
  - Begin design with sequence of actions with time constraints
- Stepwise commissioning of machines to be supported
  - Start with partial network in operation
- Downtime must be minimized to increase Overall Equipment Effectiveness
  - Limit the effects of failures, avoid side effects caused by components not needed in production
  - Minimize dependencies between connected machines

Upcoming requirements which are addressed by TSN:

- Multiple applications must be supported on a single network

- Integrate formerly dedicated connections:
  Eliminate discrete cabling, additional interfaces, installation, and associated error sources
- Make machine data accessible for Smart Manufacturing:
  Avoid to re-program machines to get access to useful data

In order to achieve those new requirements, the LNI 4.0 does provide a guidance for time-sensitive applications:

Each network uses existing well-established standards. In the context of TSN there are additional options to be selected. The LNI 4.0 chose the reservation protocol drafted 802.1Qdd [9] which is based on MSRP, a distributed stream reservation protocol defined in Q standard for quite some time.

In 802.1Qdd draft there are so called Resources Allocation Classes (RA-Class) for streams. Each RA-Class includes a mathematical model for the dimensioning of required bandwidth, per-hop max latency and network resources. Based on the use case and the Qdd draft an RA-Class has been designed which enables Qdd to be used more efficiently. In this context LNI 4.0 contributes towards Qdd to make the RA-Class Template mechanism more flexible.

Emphasized are the following characteristics to be considered by applications:

- Stepwise commissioning & production line failures:
  Network fragments work autonomously and can join automatically
- Dynamic E2E stream allocation for "plug & produce":
  Applications can establish or remove streams from the network via UNI inside the designed "guard rails" at runtime
- Exposure of stream diagnostics via UNI:
  Applications can adapt to the actual network status through E2E stream diagnostics
- Leverage existing production line networking technology for real time:
  Streams use any given active network topology even shared with non-real time, no need for trafic engineering.
- No need for topology discovery and explicit path computing: In line or ring topologies, loop prevention protocols like RSTP or IEC62439 MRP are sufficient.
- Support for Minimum Viable Solutions:
  Enhancing the existing protocol stack by a single stream reservation protocol used by all time-sensitive applications on a converged network is a lightweight approach which meets the application requirements.

4 Plugfest

LNI 4.0 is a pre-competitive and non-profit association that operates its testbeds completely neutral. This also applies to all LNI 4.0 TSN plugfests that happen once per quarter (see Figure 1). The plugfests focus on the following topics:

- SME requirements collection and feedback,
- Convey latest results of standardization meetings and activities to SMEs
- plugging of IEEE and IEC/IEEE standards in their latest draft versions,
- aggregating of feedback to the SDOs based on the plugfest results, and
- preparation of standardization presentations for SDO and TSN events.

All these activities follow the goal to support the adaption of TSN by the industrial automation market.

The TSN testbed is conceived as a continuous plugfest. It is based on the reference specification targeted by the TSN test bed, specifically, IEEE 802, with a focus on the technical use cases described in chapter 3. Plugfest specifically means that the involved testbed partners continuously try out their (pre-market) products with one another. The Federal Ministry Industrie 4.0 Digital Center in Augsburg hosts the testbed and all plugfests. It provides a factory building and all industrial technical equipment to implement the use cases.

Figure 1: Typical setup of a plugfest of the LNI 4.0 TSN testbed in Augsburg. Companies and organisations connect their devices applying the TSN base standards.

5 Demonstrator

The LNI 4.0 TSN demonstrator shall showcase the potentials and benefits of TSN features applied in industrial automation networking. TSN real-time features and the separation of different traffic types are the focus. The demonstrator uses different traffic types of resp. application protocols streamed and managed by TSN features between the individual systems/machines. Using the same infrastructure while separating different communication types nevertheless allows a plug & produce on the networking level.

5.1 Flexibility of “plug & produce”

Two robots and a carrier system of different vendors are installed as separate modules. A camera system takes on the task of overall module control (see Figures 2 and 3).

One module at a time can be attached to the carrier system to execute industrial communication scenario. When the modules are exchanged, the reconfiguration of the system shall happen automatically without manual intervention.

Figure 2: LNI 4.0 TSN demonstrator

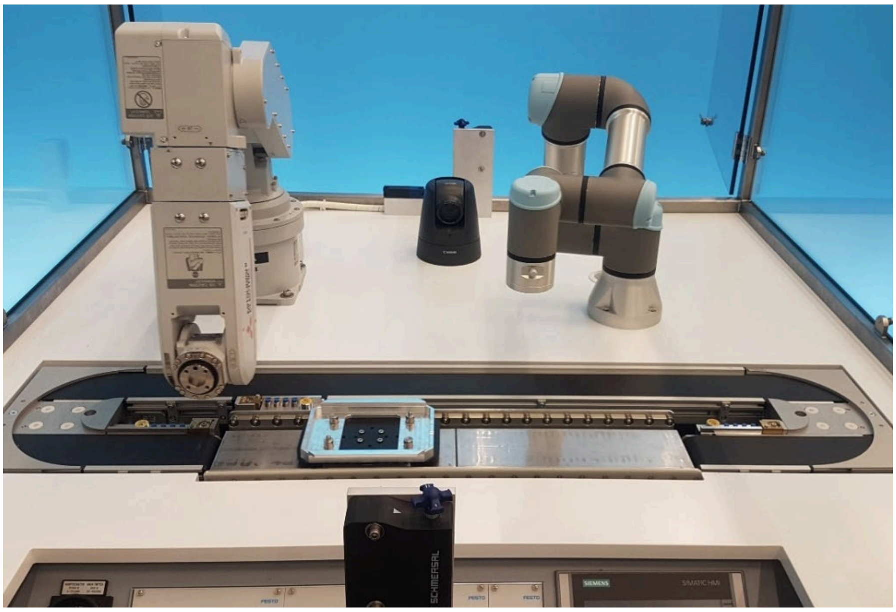

Figure 3: LNI 4.0 TSN demonstrator robot and carrier setup

5.2 First realization

In the current demonstrator the two robots are fixed attached to the carrier system and are not removable. The carrier moves left and right along the linear section (blue arrow in Fig. 4). The speed of the carrier is therefore not constant. The control task is that the robots shall be capable to handle changes in speed of the carrier. The robots are not interacting with the control system of the carrier while following the movement of the carrier. To visualize the precise movements for human inspection, two laser pointers are attached to the two robots pointing at the carrier. The dome camera mounted above the robots acts as an extra data provider, to show the robustness of the communication.

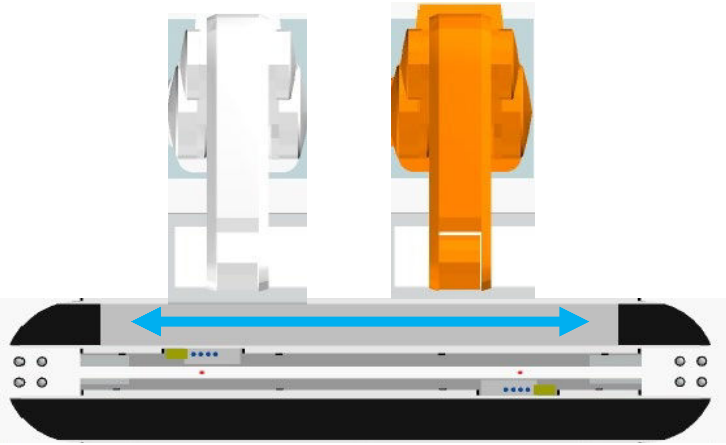

Figure 4: LNI 4.0 TSN demonstrator setup

5.3 Communication Architecture

The communication architecture of the current realisation of the demonstrator is designed in such a way that it communicates in a one to any communication relation. This will be also possible in TSN. Specifically, the industrial communication is setup as shown in Fig. 5:

1. The carrier system is the control master of the system.
    a. It gets commands from its internal panel which is connected via a separate local network and the internal PLC interface. Therefore, all commands can be transmitted even when the load on the TSN network is heavy.
    b. A TSN CP 1543-1 is used. In later iterations of the demonstrator TSN or OPC_UA Pub/Sub can be activated.
    c. The carrier system sends the current position of the carrier via UDP Multicast frame to the TSN domain. The switch publishes this frame to all connected ports.
2. Both robots follow the position published by the carrier system.
3. The industrial TSN camera system captures and displays images of the laser pointer attached on the robot arm pointing at the carrier system. It measures the carrier position using image processing.
4. A video camera monitors the demonstrator for visualization.

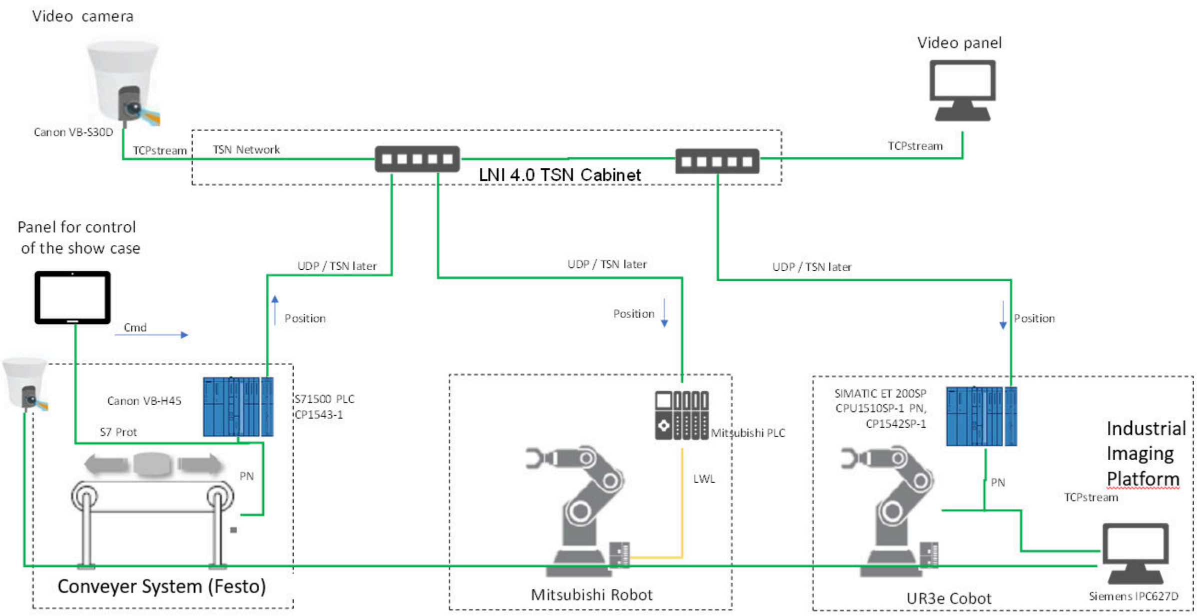

Figure 5: Communication Architecture

6 Outlook

In close cooperation with IEC and IEEE, the standards which are in the focus and are the starting point of the TSN test bed, namely IEC IEEE 60802 and IEEE 802.1 standards family, will be further discussed and test-wise implemented. Feedback will be provided to the standardization bodies. Latest updates generated by those will be conveyed to the SMEs in the test bed. Therefore, providing know-how and experience, and continuing to signal strongly that besides other fields, like internet, telecommunication, audio-video, also the industrial automation market is participating in the benefits of the TSN extensions of the IEEE 802 standard series. Driving the standardization work in the direction of ultimately generating standards that can also be meaningfully applied to industrial automation and its target of production environment is key of the test bed. And this targets to add another key element to the future of lean, smart, sustainable, and ultimately production equipment, and contributing to generate prosperity, economically and environmentally for a better future for us, and the generations to come.

7 References

[1] German Federal Ministry for Economics and Climate Action, https://www.bundesregierung.de/breg-de/themen/digitaler-aufbruch/digitalstrategie-2072884

[2] https://www.aip.org/fyi/2023/nist-budget-fy22-outcomes-and-fy23-request

[3] https://1.ieee802.org/tsn/

[4] https://1.ieee802.org/tsn/iec-ieee-60802/

[5] https://opcfoundation.org/about/opc-technologies/opc-ua/

[6] TSN and OPC UA – Deterministic Communication, Alexander Ziegler / Siemens / LNI 4.0 / 19.11.2021

[7] “Whitepaper_OPC UA_over_TSN_for_LNI_D1.6.2.pdf” Andreas Meisinger / Siemens / LNI 4.0

[8] LNI 4.0 Testbed TSN – Whitepaper OPC UA over TSN, P. Zimmermann, A. Meisinger, D. Rohrmus, A. Simon, K. Weber, S. Hoppe, A. Allmendinger, C. Gündoğan, S. Bhattacharjee, F. Walzer, M. Francis, 2023, https://lni40.de/wp-content/uploads/2023/04/LNI-4.0-Testbed-TSN-Whitepaper-OPC-UA-over-TSN.pdf

[9] https://1.ieee802.org/tsn/802-1qdd/

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