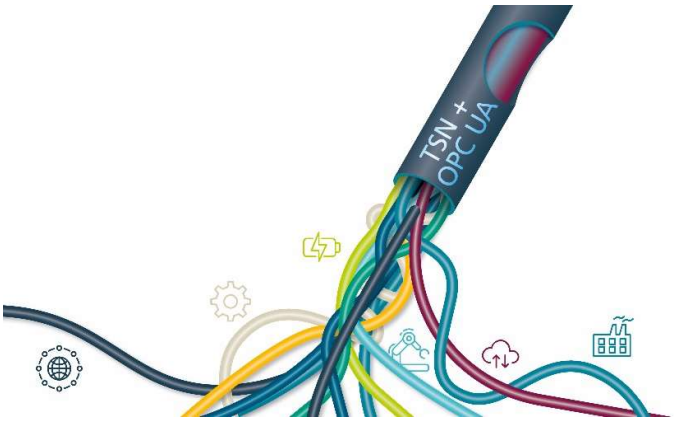
LNI 4.0 Testbed TSN – Whitepaper
OPC UA over TSN



LNI 4.0

17 April 2023

In cooperation with:

STANDARDIZATION COUNCIL INDUSTRIE 4.0

OPC FOUNDATION

Editorial responsibility:

Labs Network Industrie 4.0 e.V.
Französische Str. 33a-c
10117 Berlin, Germany
E-Mail: info@lni40.de

Issue date: 17 April 2023
This publication as well as further publications from the cooperation can be obtained from:
<https://lni40.de/> <https://opcfoundation.org/>

1 Manufacturing automation improvements needed to address global challenges

Over the recent years, global threats repeatedly challenged the stability of the socio-ecological system. Unprecedented events, such as the pandemic outbreaks, geo-political conflicts, and natural hazards serves as a motivation to reconsider entire value chains.

The fourth industrial revolution aims to achieve this via the adoption of innovative, sustainable, and interoperable technologies to evolve legacy processes in today's manufacturing. In addition to a change in processes, a change in products is equally important. A large number of devices are needed to offer the variety of production – an immense effort that cannot be done in a short period of time. We need a transition period and a transfer in which we need a high level of interoperability between existing, invested systems (brownfield) and new components.

The interoperability requirements mandate standardization efforts as expressed by German Federal Ministry for Economics and Climate Action (BMWK) [1]. The U.S. National Institute of Standards and Technology's (NIST) Budget is increased significantly [2] and China released a National Standardization Development Action Plan [3] last year to handle this challenge.

The interaction of components is a key factor of interoperability. Standardization efforts can play an important role in the interconnection of manufacturing equipment: Time Sensitive Networking (TSN) [4], IEC/IEEE 60802 TSN Profile for Industrial Automation [5], and OPC UA [6].

The use cases for OPC UA and TSN are twofold: application-based and technology-based.

1.1 Business use case and applications

OPC UA and TSN enable system integrations and developments in heterogeneous situations (industrial devices, communication protocols, and vendors). These situations occur almost naturally in factories and plants that have a long production history and face the need to integrate machines or skills over long periods. Reasons are often changing situations, investment, or de-investment decisions. TSN is designed to make plain Ethernet deterministic. OPC UA offers a wide variety of so-called companion standards as toolbox for system integration.

1.2 Technological use case

The technological use case is the change from Client-Server best-effort communication to a continuous stream of data. Real-time industrial use cases require end-to-end determinism that current TCP/IP deployment in combination with conventional Ethernet does not cover. A dual protocol shop-floor application, such as OPC UA over TSN, is required, one for collecting data and one for controlling devices. Therefore, OPC UA requires the stream based PubSub extension as base technology to enable the industrial control demands at the shopfloor. OPC UA PubSub communication is designed in a way to support cloud-based data exchange as well. TSN is required to isolate time-critical streams from best-effort (Client-Server) communication and make this type of communication deterministic.

Labs Network Industrie 4.0 e.V., Französische Str. 33a-c, 10117 Berlin

2 Basics of OPC UA and TSN

TSN is a set of IEEE 802 networking standards for real-time communication in combination with Ethernet developed by IEEE in the last 10 years.

The intention is to bridge the OT and IT worlds from a networking perspective to bring smart manufacturing and Industrie 4.0 to life. TSN enables bounded end-to-end latency, extremely low delay-variation (jitter) and high availability in an IEEE 802 network. The TSN application areas include converged Ethernet networks with real-time control streams exemplary for automotive, aerospace, mobile network fronthaul and industrial control applications.

OPC UA (Unified Architecture) is a manufacturer and platform independent service-oriented architecture for industrial communication. OPC UA allows multi-vendor interoperability, supports multiple protocol stacks and different communication models providing a holistic infrastructure from devices and machines to the cloud.

The OPC UA architecture has mappings to several communication protocols like TCP/IP, UDP/IP, Ethernet (Layer 2), WebSockets, MQTT, etc. These protocols in combination with conventional Ethernet do not have real-time capabilities. The Field Level Communications (FLC) initiative of the OPC Foundation was launched in 2018 to establish OPC UA as industrial interoperability solution also at the field level. To this end, extensions to the OPC UA framework are being specified that standardize the semantics and behaviour of controllers and field devices from different manufacturers, both for discrete manufacturing and for the process industry. The initiative has released a first set of the specifications in November 2022, named OPC UA Field eXchange (FX).

OPC UA FX is defining different mappings to underlying communication protocols (UDP/IP and Ethernet) and physical layers, including TSN for real-time applications at the field level and APL (Advanced Physical Layer) to bring Ethernet to the field even in hazardous areas in the process industry.

OPC UA over TSN can fulfil the strict network requirements while providing a flexible and interoperable communication stack. The OPC UA stream discovery and QoS mapping mechanisms contribute to the recent discovery and QoS mapping approaches. By this OPC UA over TSN enables reliable, low-latency, real-time industrial communication. OPC UA PubSub is suitable for centralized, hybrid as well as distributed TSN network and configuration models.

TSN is specified by the IEEE 802.1 standards family group. TSN extends the existing Ethernet standards by providing standard Ethernet determinism and convergence in the ISO/OSI Layer 2. The layer 2 mechanisms are time synchronization, scheduling, resilience, traffic shaping and resource reservation along paths.

3 Requirements and new components for OPC UA over TSN

TSN provides features that are required for industrial communication networks and support the realization of industrial requirements like build-in security, high availability and reliability, maintainability, and bounded latency:

- Meeting low latency and latency variation requirements concerning data transmission.
- Efficient exchange of stream data periodically.
- Time synchronization for communication and application.
- High availability meeting application requirements.

3.1 Business view

From a business view the integrated and standardized technologies meet the necessary business requirements like the avoidance of a vendor lock in effect or the build-in cyber-security beside the information interoperability in the shopfloor.

4 What is the role of LNI 4.0?

The non-profit and pre-competitive, i.e. neutral German association Labs Network Industrie 4.0 (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. The TSN testbed of LNI 4.0 was established in 2017. The use cases, originating from requirements of small and medium enterprises, are the base for LNI 4.0 testbeds.

The digital transformation will not occur in a short period of time. There are quite a few challenges especially at the shop floor with various components. The innovation of equipment is focused on 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 needed changes in our ecosystems but the current processes to roll out enhancements in collaboration of different components tend to slow down.

LNI 4.0 has the goal to act as a catalyst to expedite this process. The first step is to cooperate with the Standards Development Organizations (SDOs) such as IEC, IEEE and the OPC Foundation. Organizing Plug-Fests allow the experts to test their components with other development products and review as well as feedback pre-competitively the draft standards of the standardisation organisations.

TSN and OPC UA with PubSub will create a lot of new opportunities but also new combinations

- OPC UA PubSub with TCP/IP traffic
- OPC UA PubSub over TSN with TCP/IP traffic
- TSN combined with other protocols with TCP/IP traffic
- OPC UA PubSub over TSN and TSN combined with other protocols with TCP/IP traffic
- OPC UA PubSub Cloud interaction and over TSN and TSN combined with other protocols with TCP/IP traffic
- and so on …

The Task of the LNI 4.0 testbed is to find a way to cope with the different situations from the networking perspective as well as for end devices. The main concept is to use a single network but isolate the different traffic types. The impact of individual applications on other applications can be reduced in this way.

This yields early sample implementations and provides feedback to the standardisation organisation like IEEE and IEC. The end application focus of LNI 4.0 testbeds remains in the centre of the activities. The industrial fair demonstrators are important application examples that create the necessary sounding boards to close the feedback loops with the OPC Foundation and the standardisation bodies. The LNI 4.0 testbed demonstrator will implement technologies that are covered by this document like multi-vendor TSN and OPC UA. The testbed supports the overall target that the TSN standards are adapted by the markets.

5 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://www.china-briefing.com/news/china-standards-2035-strategy-recent-developments-and-their-implications-foreign-companies/#:~:text=The%20China%20Standards%202035%20strategy%20empowers%20Chinese%20enterprises%20to%20participate,come%20with%20licenses%20and%20royalties

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

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

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

Labs Network Industrie 4.0 e.V., Französische Str. 33a-c, 10117 Berlin

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

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

6 Authors and Contributors

Patrick Zimmermann, Fraunhofer

Dr. Dominik Rohrmus, LNI 4.0

Anja Simon, LNI 4.0

Stefan Hoppe, OPC Foundation

Dr. Karl Weber, Beckhoff

Andreas Meisinger, LNI 4.0 and Siemens

Dr. Cenk Gündoğan, Huawei

Sushmit Bhattacharjee, Huawei

Frank Walzer, TI

Alexander Allmendinger, Ingenieurbüro Allmendinger

Melvin Francis, BE.services