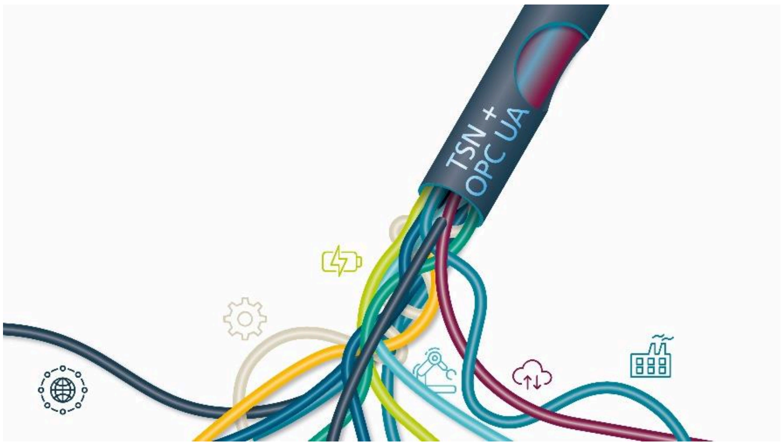
LNI 4.0 Testbed TSN – Whitepaper
OPC UA over TSN



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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 assumed 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.

2 Basics of OPC UA and TSN

TSN is a set of IEEE 802 standards for real-time communication. TSN has been primarily developed for IEEE standard 802.3 Ethernet.

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 supports multiple protocol stacks and different communication models providing a holistic infrastructure from devices and machines to the cloud. In combination with integrated security and semantic information modelling it provides an end-to-end secured semantic interoperability solution independent from vendor and domains.

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 for real-time applications at the field level, including options for both TSN and APL (Advanced Physical Layer for use in hazardous areas in the process industry).

OPC UA provides a flexible and interoperable communication stack and when combined with TSN can meet the strict network requirements for low latency and jitter required by some applications.

TSN is specified by IEEE 802.1 standards, primarily for the IEEE standard 802.3 Ethernet. TSN provides determinism and convergence in the ISO/OSI Layer 2. TSN mechanisms include time synchronization, reliability, traffic shaping, and resource management. The IEC/IEEE 60802 Joint Project defines TSN profiles for industrial automation.

3 Requirements and new combinations for OPC UA over TSN

TSN provides features that are required for industrial communication networks and support the realization of industrial requirements like 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 beside the information interoperability in the shopfloor.

3.2 New combinations

TSN and OPC UA with PubSub will create a lot of new solution opportunities and new combinations. A few combinations are listed here by high-level titles:

- 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
- and so on …

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 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. 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.

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 feedback loops between the standardisation bodies and involved parties. 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

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