Overview of communication TSN technology for Smart Manufacturing including relevant standards

A publication by the Technical Expert Group on Network Communications and Edge Computing

IMS 国家智能制造标准化总体组
National Intelligent Manufacturing Standardisation Administration Group

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PLATTFORM INDUSTRIE 4.0

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NATIONAL INTELLIGENT MANUFACTURING STANDARDISATION ADMINISTRATION GROUP
The National Intelligent Manufacturing Standardisation Administration Group (IMSG) was established to promote and accelerate the progress of intelligent manufacturing in China under the leadership of the Standardisation Administration of China (SAC) and Ministry of Industry and Information Technology (MIIT). It is responsible for carrying out practical work on intelligent manufacturing standardisation, including participation in international standard-setting on intelligent manufacturing as well as organising exchange and cooperation on international standards.

STANDARDIZATION COUNCIL INDUSTRIE 4.0
The Standardization Council Industrie 4.0 (SCI 4.0) was founded at the Hannover Messe 2016 as a German standardisation hub by Bitkom, DIN, DKE, VDMA and ZVEI. The initiative aims to initiate standards for digital production and to coordinate these standards nationally and internationally. SCI 4.0 orchestrates implementation of the standardisation strategy of the German Platform Industrie 4.0, which includes coordination with standardisation organisations (SDOs) and international partners as well as interlocking with pilot projects. The aim of this coordinated approach is to ensure that standards exploiting the potential of Industrie 4.0 are developed in a coordinated manner. SCI 4.0 is supported by DKE and the German Federal Ministry for Economic Affairs and Energy (BMWi).

PLATTFORM INDUSTRIE 4.0
The Plattform Industrie 4.0 is the central network in Germany for advancing the digital transformation in production. More than 350 stakeholders from more than 150 organisations are actively involved in the Plattform, in close cooperation between politics, business, science, trade unions and associations. As one of the largest international and national networks, the Plattform supports German companies in implementing Industrie 4.0, especially by making existing Industrie 4.0 practical examples known to companies and bringing them into the mainstream. In addition, it provides important impetus, with concrete recommendations for action in over 200 specialist publications and refers to support services and test environments. The Plattform's numerous international collaborations underline its strong role in international discussions on the topic of Industrie 4.0.
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GLOBAL PROJECT QUALITY INFRASTRUCTURE
The German Federal Ministry for Economic Affairs and Energy (BMWi) established the Global Project Quality Infrastructure (GPQI) to promote the development of well-functioning and internationally coherent quality infrastructures. GPQI supports political and technical dialogue and implements bilaterally agreed activities in collaboration with all relevant stakeholders. The project aims to reduce technical barriers to trade and enhance product safety through bilateral political and technical dialogue on quality infrastructure (QI) with some of Germany's key trading partners.

Contents

1. Introduction to TEG Netcom committee

Sino-German standardisation cooperation on I4.0 / IM initiated the study on communication technologies of interest to this Sino-German collaboration. A few potential topics were identified, such as wireless communication, co-existence management, Wireless Industrial Application (WIA) and Time-Sensitive Networking (TSN) profiling for industrial automation.

The Technical Expert Group (TEG) Network Communication (NetCom) was created to drive I4.0 / IM communication-related subjects as mentioned above. It also reviewed the IEC NP for TSN profiling for industrial automation, which resulted in project IEC 61784-6. In addition, it raised for discussion in international standardisation the aspects of spectrum and co-existence management. Although TEG NetCom started out with a focus on WIA and TSN areas, it was agreed to extend its scope to include wireline communications and edge technologies.

TEG NetCom also harmonised requirements for the TSN profile for industrial automation by contributing to IEC SC65C/PT61784-6. Further collaboration on the use cases and reference architectures was discussed by TEG NetCom. It was agreed that China would submit use cases and objectives to IEC/IEEE 60802 TSN profile for Industrial Automation (TSN-IA) with proposed German updates. As a result, the collaborative submission of IEC/IEEE 60802 TSN-IA can be considered one of the major deliverables by TEG NetCom. In addition to the specification work, both China and Germany have also driven TSN-IA testbeds, which were successfully completed. The results of these testbeds have been presented within TEG NetCom. This collaboration took place between December 2017 and September 2019, when the TSN-IA testbed was completed.

One should note the critical value of TSN for industrial automation. TSN allows determinism to be maintained with the confidence of being able to satisfy the requirements of less demanding traffic sharing the medium. The meaning of convergence in TSN is the successful convergence of critical control, non-critical control and data streams on a single network. The infrastructure elements (bridges) can be used seamlessly by different fieldbuses. TSN standardisation activities are carried out in IEEE 802.1 and IEEE 802.3. The drafting of an IA profile in IEC/IEEE 60802 initiated new projects in IEEE 802.1. While IEEE 802 standards address a very wide range of networking scenarios, it is noted that users and vendors need guidelines for the selection and use of IEEE 802 standards and features in order to be able to deploy converged interoperable networks to simultaneously support operations technology traffic and other traffic. This is the goal of IEC/IEEE 60802.

For this reason, TEG NetCom continued to collaborate on the submission of contributions to the IEC/IEEE 60802 joint project 'TSN profile for industrial automation (IA)', 60802, which followed both the IEC and IEEE processes. Two different teams were identified which collaborated intensively with each other, i.e. IEC SC65C/MT9/PT60802 (TSN) and IEEE 802.1 TG TSN and resulted in the IEC/IEEE 60802 joint project. The IEC/IEEE 60802 joint project is chaired by Mr Ludwig Winkel, who assumes responsibility for both positions: convenor of IEC SC65C/WG18 (formerly IEC SC65C/MT9/PT60802) and chair of IEEE 802.1 60802 JP in the IEEE 802.1 TSN TG.

The TSN profile for IA demonstrates the successful collaboration between Chinese and German industry experts within the IEC/IEEE 60802 project. It demonstrates the value of TEG NetCom in its joint contributions to IEC/IEEE 60802 for the benefit of international collaboration.

2. What is TSN?

2.1 TSN is a committee name of IEEE 802.1 dealing with Time-Sensitive Networking

Time-Sensitive Networking (TSN) is the committee name of the IEEE 802.1 Task Group, which deals with creating a toolset for deterministic services through IEEE 802 networks for:

- guaranteed packet transport
- low packet loss
- bounded low latency
- low packet delay variation

These standards and their amendments are:

IEEE Std 802.1AB™, IEEE Standard for local and metropolitan area networks: Station and Media AccessControl Connectivity Discovery, available at www.ieee.org

IEEE Std 802.1AC™, IEEE Standard for local and metropolitan area networks – Media Access Control (MAC) service definition, available at www.ieee.org

IEEE Std 802.1AS™, IEEE Standard for information technology – telecommunications and information exchange between systems – IEEE standard for local and metropolitan area networks – Timing and Synchronisation for Time-Sensitive Applications in Bridged Local Area Networks, available at www.ieee.org

IEEE Std 802.1CB™, IEEE Standard for local and metropolitan area networks – Frame Replication and Elimination for Reliability, available at www.ieee.org

IEEE Std 802.1Q™, IEEE Standard for local and metropolitan area networks – Media Access Control (MAC) Bridges and Virtual Bridged Local Area Networks, available at www.ieee.org

The so-called TSN standards form part of those standards that build a toolbox to support selection for time-sensitive networking in a certain domain. The IEEE 802.1 Time-Sensitive Networking TG maintains a website, available at https://1.ieee802.org/tsn/

Additional standards and amendments to existing standards that are under development can be obtained at https://1.ieee802.org/tsn/

These standards of IEEE 802.1 use IEEE Std 802.3™ IEEE Standard for Ethernet for the Physical Layer and MAC Layer.[1]

2.2 What are TSN specific enhancements?

A major topic is timing and synchronisation in IEEE Std 802.1AS-2020.

This is a profile of IEEE 1588 with amendments relevant for Ethernet-based bridged networks. A new amendment for IEEE Std 802.1AS is for Hot Standby of the synchronisation elements in IEEE P802.1ASdm. Other amendments to the profile of Industrial Automation are on the way.

For bounded low latency we have the following amendments: [2]

- Credit Based Shaper [802.1Qav]
- Frame preemption [802.3br & 802.1Qbu]
- Scheduled Traffic [802.1Qbv]
- Cyclic Queuing and Forwarding [802.1Qch]
- Asynchronous Traffic Shaping [802.1Qcr]
- QoS Provisions [P802.1DC]

[1] https://standards.ieee.org/standard/802_3-2018.html
[2] NOTE: P placed before an ID indicates ongoing project.

For high availability we have the following amendments:

- Frame Replication and Elimination [802.1CB]
- Path Control and Reservation [802.1Qca]
- Per-Stream Filtering and Policing [802.1Qci]
- Reliability for time sync [802.1AS-2020]

For dedicated resources and API we have the following amendments:

- Stream Reservation Protocol [802.1Qat]
- TSN configuration [802.1Qcc]
- Basic Bridge YANG [802.1Qcp]
- YANG for CFM [P802.1Qcx]
- YANG for LLDP [P802.1ABcu]
- YANG for Qbv, Qbu, and Qci [P802.1Qcw]
- YANG & MIB for FRER [P802.1CBcv]
- Extended Stream Identification [P802.1CBdb]
- Link-local Registration Protocol [P802.1CS]
- Resource Allocation Protocol [P802.1Qdd]
- Configuration Enhancements [P802.1Qdj]
- LLDPv2 [P802.1ABdh]

2.3 Profiles for TSN

2.3.1 AVB (IEEE 802.1BA)

This standard IEEE Std 802.1BA defines profiles that select features, options, configurations, defaults, protocols and procedures of bridges, stations and LANs that are necessary to build networks capable of transporting time-sensitive audio and/or video data streams.

The successful support of time-sensitive audio and/or video data streams in a bridged LAN requires the selection of specific features and options that are specified in a number of different standards, some of which are standards developed in IEEE 802 and others. [3]

2.3.2 Fronthaul (IEEE 802.1CM)

The standard IEEE Std 802.1CM defines profiles for Time-Sensitive Networking for Fronthaul. This standard defines profiles that select features, options, configurations, defaults, protocols and procedures of bridges, stations and LANs that are necessary to build networks capable of transporting fronthaul streams which are time sensitive. [4]

Fronthaul provides connectivity between functional blocks of a cellular base station (BS). The fronthaul flows between these functional blocks have stringent quality of service requirements. The successful support of fronthaul flows in a bridged network requires the selection of specific features and options that are specified in a number of different standards, some developed by IEEE 802 and others (in particular, those that relate to functionality in OSI layer 3 and above). [5]

2.3.3 Industrial Automation (IEC/IEEE 60802)

This standard IEC/IEEE 60802 defines Time-Sensitive Networking profiles for industrial automation. The profiles select features, options, configurations, defaults, protocols and procedures of bridges, end stations and LANs to build industrial automation networks.

These profiles meet the industrial automation market objective of converging Operations Technology (OT) and Information Technology (IT) networks by defining a common, standardised network infrastructure. This objective is accomplished by taking advantage of the improvements that Time-Sensitive Networking provides to IEEE 802.1 and IEEE 802.3 standard Ethernet networks by providing guaranteed data transport with bounded low latency, low latency variation, zero congestion loss for critical traffic and high availability.

These profiles help the convergence of industrial communication networks by only referring to IEEE Std 802.3 and IEEE 802.1 standards to build the lower layers of the communication stack and their management. Furthermore, these profiles allow the co-existence of different data streams between end stations, including data streams

[3] For more details see committee page of IEEE 802.1 at: https://standards.ieee.org/standard/802.1BA-2011

[4] NOTE: Stream and flow are used as synonyms in this document.

[5] For more details see committee page of IEEE 802.1 at https://1.ieee802.org/tsn/802-1cm-2018/

as defined in IEC 61784-2, which have different performance characteristics and functional capabilities according to the diverse application requirements. It is understood that some of the Communication Profile Families in IEC 61784-2 need to be modified to ensure compliance with the IEC/IEEE 60802 profile. Such modifications are out of scope for the IEC/IEEE 60802 profile.

IEEE Std 802.3 Ethernet extended with IEEE 802.1 Time-Sensitive Networking technology provides features required in the field area of industrial communication networks, such as: [6]

- meeting low latency and latency variation requirements concerning data transmission;
- efficient exchange of data records on a frequent time period;
- reliable communications with calculable downtime;
- high availability meeting application requirements.

2.3.4 Automotive (IEEE P802.1DG)

This draft standard P802.1DG defines Time-Sensitive Networking profile for Automotive In-Vehicle Ethernet Communications.

This standard specifies profiles for secure, highly reliable, deterministic latency, automotive in-vehicle bridged IEEE 802.3 Ethernet networks based on IEEE 802.1 Time-Sensitive Networking (TSN) standards and IEEE 802.1 security standards.

This standard provides profiles for designers and implementers of deterministic IEEE 802.3 Ethernet networks that support the entire range of in-vehicle applications, including those requiring security, high availability and reliability, maintainability and bounded latency.

The automotive segment does not have a standards-based profile for IEEE 802.1 Time-Sensitive Networking standards, as usage can vary widely based on the networking scenarios. The lack of a profile makes defining the automotive manufacturers' requirements and implementation of those requirements by suppliers more difficult and costly. Thus, in order to be able to deploy secure highly reliable converged networks, there is a need to standardise the selection and use of IEEE 802 standards and features.

Stakeholders for the standard are developers, providers, automotive manufacturers, and suppliers, as well as users of networking services and components for automotive Ethernet-networked equipment. These components may include bridges, end stations, network interface cards and integrated circuits. [7]

2.3.5 Aerospace (IEEE P802.1DP/SAE AS6675)

This draft standard P802.1DP/SAE AS6675 defines the Time-Sensitive Networking profile for Aerospace Onboard Ethernet Communications in a joint project of IEEE 802 and SAE Avionics Networks AS-1 A.

This standard specifies profiles for aerospace onboard bridged IEEE 802.3 Ethernet networks based on IEEE 802.1 Time-Sensitive Networking and IEEE 802.1 security standards to provide secure, highly reliable and deterministic communications. The profiles select features, options, configurations, defaults, protocols and procedures of bridges, end stations and LANs to build aerospace onboard networks.

This standard provides profiles for designers, implementers, integrators and certification agencies of deterministic IEEE 802.3 Ethernet networks that support the entire range of aerospace onboard applications, including those requiring security, high availability and reliability, maintainability and bounded latency.

[6] More Details available at the committee pages of IEEE 802.1 at https://1.ieee802.org/iec-ieee-60802/ and IEC at https://www.iec.ch/ TC 65 / SC 65C / WG 18

[7] For more details see committee page of IEEE 802.1 at https://1.ieee802.org/tsn/802-1dg

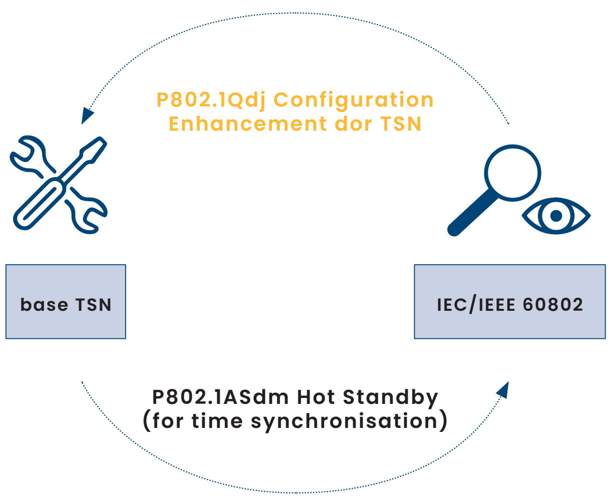
The aerospace segment does not have a standards-based profile for IEEE 802.1 TSN standards, as usage can vary widely based on the networking scenarios. The lack of a profile makes defining the aerospace manufacturers' requirements and implementation of those requirements by suppliers more difficult and costly. Thus, in order to be able to deploy secure highly reliable converged networks and enable certification as a basis for compliance and design assurance, there is a need to standardise the selection and use of IEEE 802 standards and features.

Stakeholders for the standard are developers, integrators, aerospace manufacturers and suppliers, test equipment vendors, certification agencies and users of networking services and components for aerospace Ethernet networked equipment. These components may include bridges, end stations, network interface cards and integrated circuits. [8]

2.3.6 Summary

Cooperation between the IEC/IEEE 60802 joint project and IEEE 802.1 TSN TG continues to be very good. The benefits are mutual; for example, the 60802 joint project identified the need for a configuration enhancement and IEEE 802.1 TSN TG immediately launched the process to start a new project drafting an amendment of IEEE P802.1Qdj. In addition, requirements of the IEC/IEEE 60802 joint project triggered an amendment of IEEE P802.1ASdm for time synchronisation.

Figure 1: Example of good cooperation and mutual benefit



2.4 Industrial Automation IEC/IEEE 60802 joint project

2.4.1 History of the project

Project IEC 61784-6 (Industrial communication networks – Profiles – Part 6: Time-Sensitive Networking profile for industrial use based on IEEE 802.1 and IEEE 802.3) was unanimously approved by SC65C National Committees in June 2017 (see 65C/875/NP and 65C/896/RVN).

Actual work on the project was triggered during an SC65C/MT9/PT meeting in early July 2017, where NC comments on the NP were addressed. A follow-up meeting was held in mid-November 2017.

In the meantime, the PT convenor and IEC SC65C officers were contacted by IEEE 802.1 management, who expressed the interest of their group to have this work done as a joint development project between IEC SC65C and IEEE 802.1. SC65C officers note that this proposal is relevant since the scope of the new work is to define profiles of IEEE 802.1 standards.

As a result of questionnaire 65C/910/Q, SC65C agreed that the approved IEC 61784-6 project (Industrial communication networks – Profiles – Part 6: Time-Sensitive Networking profile for industrial use based on IEEE 802.1 and IEEE 802.3) should be converted into a joint development project between IEC SC65C/MT9 (PT 61784-6) and IEEE 802.1 (TSN TG).

The corresponding PAR (Project Authorisation Request) and CSD (Criteria for Standards Development) documents have been circulated in IEEE 802 for review and consideration for approval at their March 2018 Plenary. The decision whether or not to establish the joint working group will depend on this approval on the IEEE 802 side.

[8] For more details see committee page of IEEE 802.1 at https://1.ieee802.org/tsn/802-1dp/.
[9] For further information see: http://www.iec.ch/about/brochures/pdf/tools/IEC_IEEE_Cooperation.pdf).

The appropriate IEEE PAR procedure was triggered on the IEEE 802.1, and further work will proceed according to the 'IEC Guide to IEC/IEEE cooperation'. [9]

In May 2018 the IEC/IEEE 60802 joint project was jointly agreed in IEC and IEEE.

2.4.2 Use cases

The convergence process from an approved IEC project (IEC 61784-6) to a joint project with IEEE 802.1 took from July 2017 to May 2018, when the IEEE 802.1 PAR was approved and with that a new project number was assigned: IEC/IEEE 60802 as documented in the IEC questionnaire 65C/910/Q and the response from the NCs 65C/917RQ.

In order to converge two organisations with experts having very different technology backgrounds, the convenor proposed the organisation of the work flow to start with a WG internal use case document (the applicability from a system point of view, even if the scope of IEC/IEEE 60802 is limited to some aspects), then to derive from that a WG internal requirement document (the what to standardise), before starting to draft a first CD (the how to realise). The use case document and requirement document are in a phase of V1.x. These are internal documents and it is not yet decided if/when they will be published (interest in combining the use case document with that drafted in IEC TC65 ahg3 and IEC TC65 JWG 21).

Based on the use case and requirement documents, the joint project team believes that it can accelerate the work on the TSN profile to have a CD ready very soon.

The use case document describes use cases for industrial automation, which must be covered in the IEC/IEEE 60802 joint project for specifying the TSN profile for Industrial Automation (TSN-IA). These use cases are intended to guide the specification process: WHAT shall be part of the dual logo International Standard IEC/IEEE 60802. The content of IEC/IEEE 60802 specifies HOW to achieve the use cases. Some use cases are on a system level of an IA system. Even if the scope of IEC/IEEE 60802 does not cover the overall system level, the IEC/IEEE 60802 shall enable or at least not prevent the features described in this use case document.

2.4.3 Requirements

The Requirements document describes requirements for industrial automation based on TSN. These requirements are intended to guide the specification process: What shall be part of the dual logo International Standard IEC/IEEE 60802. The content of IEC/IEEE 60802 specifies how to achieve the requirements. Some requirements are on a system level of an industrial automation system. Even if the scope of IEC/IEEE 60802 does not cover the overall system level, the IEC/IEEE 60802 shall enable or at least not prevent the features described in this requirement document.

The requirements are mainly extracted and derived from:

[1] "Industrial Use Cases",
IEC/IEEE JWG Contributor group [10]

Additional detailed requirements are extracted from contributions:

[2] Contribution
"60802-Steindl-Synchronization" [11]

[10] http://www.ieee802.org/1/files/public/docs2018/60802-industrial-use-cases-0918-v13.pdf

[11] http://www.ieee802.org/1/files/public/docs2018/60802-Steindl-Synchronisation-0718-v02.pdf

[12] http://www.ieee802.org/1/files/public/docs2018/60802-Steindl-Configuration-0718-v02.pdf

[13] http://www.ieee802.org/1/files/public/docs2018/60802-Steindl-NetworkDiagnostics-0718-v01.pdf

[14] http://www.ieee802.org/1/files/public/docs2018/60802-Steindl-DaMacConstraints-0718-v02.pdf

[15] http://www.ieee802.org/1/files/public/docs2018/60802-stanica-qbv-statemachine-0918-v03.pdf V1.2 2018-12-03

Table 1 – Timeline (last updated October 2020) of IEC/IEEE 60802

IEEE 802.1	IEC	Joint Project
TG/WG ballot drafts	**CD/No-CD/CDV:**	**Date:**
TG D1.3	CD 4	July 2021
TG D1.4	CD 5	Oct 2021
WG D2.0	CD 6	early 2022
WG D2.0-2.n	No-CD	-
IEEE SA D3.0	CDV	Mid to late 2022

[3] Contribution
"60802-Steindl-Configuration" [12]
[4] Contribution
"60802-Steindl-NetworkDiagnostics" [13]
[5] Contribution
"60802-Steindl-DaMac-Constraints" [14]
[6] Contribution
"60802-Stanica-Qbv-Statemachine" [15]
Additional information on the requirements is provided in:

[7] Contribution
"60802-Steindl-TimelinessUseCases" [16]
[8] Contribution
"60802-Sato-PA-System-Quantities" [17]

2.4.4 Status of the profile IEC/IEEE 60802

Table 1 represents the timeline (last updated October 2020) showing next steps.

2.4.5 Testbed (Liaison, LNI 4.0 Contributions)

Labs Network Industrie 4.0 (LNI 4.0) is a pre-competitive and non-profit, i.e. neutral German association. LNI 4.0 established an open, neutral and pre-competitive testbed for the validation of extensions of the IEEE 802.1 standard family for TSN based on SME use cases. The extensions make it possible to run heterogeneous real-time applications in a single TSN network. Liaison contracts between the IEEE 802.1 Working Group and the OPC foundation exist. The TSN testbed is conceived as a continuous plugfest. These use cases provide the basis for the architecture, electrics and mechanics used and are reflected in the plugfest demonstrator. Plugfest means that all testbed partners involved continuously try out their (pre-)products with one another. The Federal Ministry Industrie 4.0 Competence Center in Augsburg hosts the testbed and provides a factory building and all industrial technical equipment to implement the use cases.

The IEEE 802.1 standards form the basis of the testbed. TSN is validated as deterministic, real-time Ethernet communication. The testbed also deliberately works with standard templates to be able to validate the different use cases against the IEEE standards and standard projects. These are used to define the technology, the architecture and the network. The key technologies concerned are switches and end devices, time synchronisation, decentralised network configuration, the forwarding of real-time data with bounded latency and the setting up of time-critical data streams. Robots and control components from different manufacturers are networked. There are four or more plugfests happening per year. The testbed cooperates closely with the IIC and Fraunhofer FOKUS TSN testbeds, among others. In China, similar activities have been car-

[16] http://www.ieee802.org/1/files/public/docs2018/60802-Steindl-TimelinessUseCases-0718-v02.pdf

[17] http://www..ieee802.org/1/files/public/docs2018/60802-sato-pa-system-quantities-0718-v01.pdf

ried out for three years involving products such as TSN switches, TSN gateway, TSN chip and terminal equipment. The validation of TSN in a heterogeneous context takes place. In the future the testbed will be open for document validation of the IECEE Conformity Assessment standards.

2.5 TSN application in 5G

2.5.1 Analysis of 5G application scenarios in Industrial Internet

5G network is characterised by large bandwidth, low latency and high reliability, which can satisfy the flexible mobility and differentiation of industrial equipment to process business demand, promote various wireless applications, including augmented reality (AR)/virtual reality (VR) terminal, robot, automatic guided vehicle (AGV) and so on, and help spread flexible production in factories on a large scale. Industrial Internet has brought 5G a wide range of application scenarios, but has also brought unprecedented challenges. For example, some industrial applications may require a network with 1 ms delay, 1 μs jitter, and 99.999999% network transmission quality.

Time-Sensitive Networking (TSN) is one of the key technologies enabling industrial interconnection to achieve low delay, high availability and deterministic transmission. 5G+TSN is an important foundation for future Wireless Industrial Internet and flexible manufacturing. When TSN does data forwarding, it can conduct queue scheduling for different priority business data of Industrial Internet, so as to realise quality differentiation guarantee. There are many types of business traffic on the Industrial Internet, such as video, audio, synchronous real-time control flow, events, configuration and diagnostics, etc. Table 2 is a typical classification example of business traffic on the Industrial Internet. TSN can model and define the characteristics of service flow involved in various industrial applications and on this basis it provides different priority and scheduling mechanisms.

Table 2 Example of classification of industrial Internet traffic

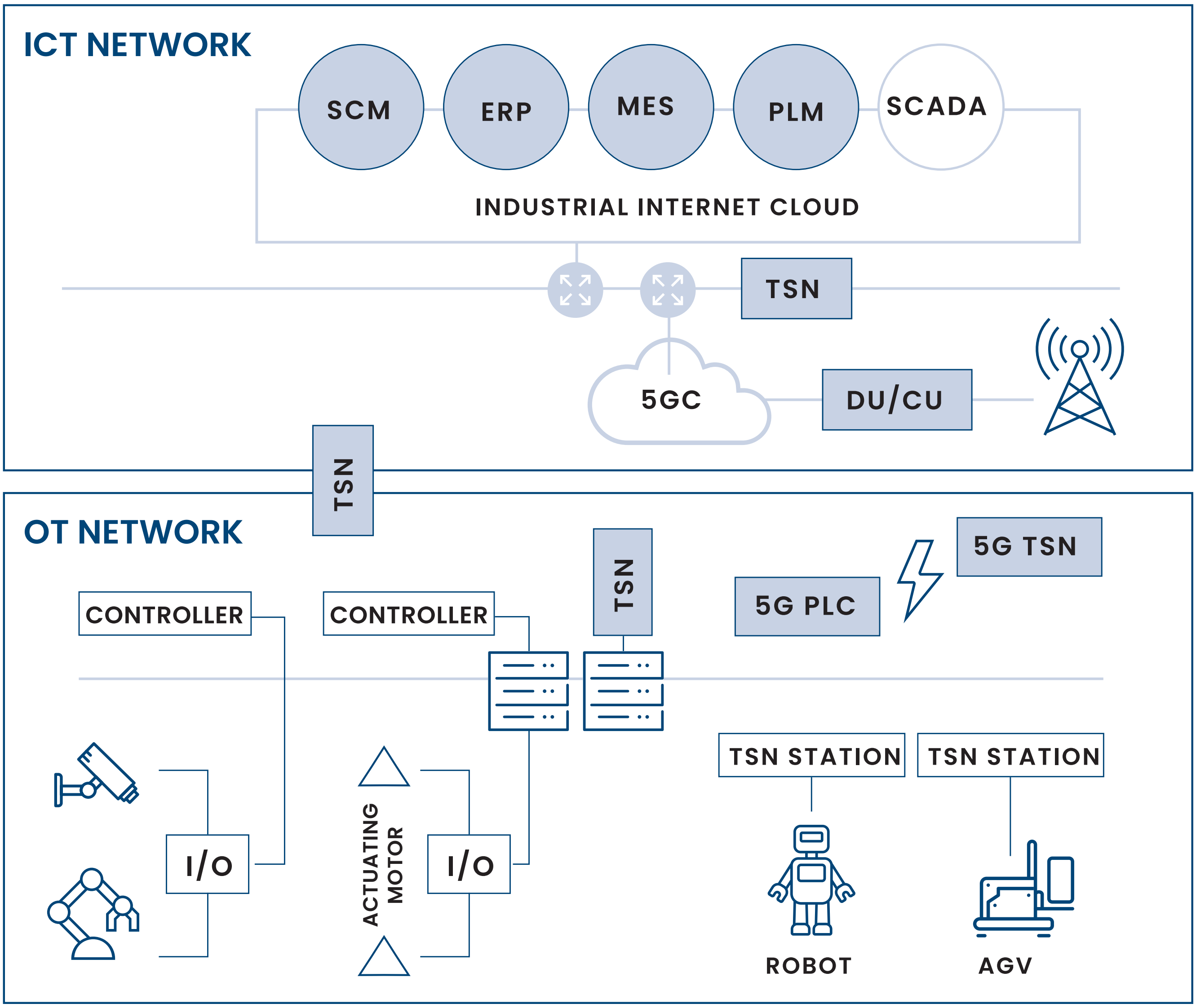
Flow type	Periodicity	Delay requirement	Synchronisation	Transport-guarantee	Allowed the packet loss	Packet size/B
Isocronous Realtime	periodic	<2 ms	yes	time limit	no	fixed 30–100
Cycle	periodic	2–20 ms	no	time delay	1–4 frame	fixed 30–100
Event	qperiodic	not applicable	no	time delay	yes	variable 100–1500
network control	periodic	50 ms–1 s	no	bandwidth	yes	variable 50–500
Configuration & diagnostics	aperiodic	not applicable	no	bandwidth	yes	variable 500–1500
Best Effort	aperiodic	not applicable	no	no	yes	variable 30–1500
Video	periodic	frame rate	no	time delay	yes	variable 1000–1500
Audio	periodic	sampling rate	no	time delay	yes	variable 1000–1500

From Table 2, different traffic flows in the Industrial Internet have different service level agreement (SLA) requirements. According to periodical division, traffic flow can be divided into two types: periodic and aperiodic. Synchronous real-time flow has the highest requirement for time delay, which is mainly used for motion control. Its characteristics are: periodic packet issuing, the period of which is generally less than 2 ms; the length of data sent during each cycle is relatively stable, generally less than 100 B; end-to-end transmission has a time limit requirement, that is to say the data needs to arrive at the destination before a specific absolute time. Event, configuration and diagnostics and best effort classes have no specific delay requirements; audio and video classes are primarily dependent on frame rate and sampling rate; cyclical loops and network control classes have time delay requirements, but are lower than synchronous real-time classes.

2.5.2 Application of 5G TSN in Industrial Internet

The application scenarios of TSN in Industrial Internet can include applications between controllers and field equipment, between controllers and controllers, between information technolo-

Figure 2 – Application of 5G TSN in Industrial Internet



gy (IT) network and operation technology (OT) network, etc, as shown in Figure 2. 5G TSN has the characteristics of both deterministic transmission of TSN and mobility of 5G network. In the Industrial Internet, it can replace part of wired Industrial Ethernet to realise wireless and flexible manufacturing.

Typical application scenarios of 5G TSN include on-site production line equipment control, robot control, AGV control and 5G programmable logic controller (PLC).

- Equipment control in the production line for CNC, three-dimensional warehouses and manufacturing lines: 5G TSN is used to connect the data link between production line equipment and the centralised control centre, so as to realise remote and centralised control of the industrial manufacturing production line with a view to further improving production efficiency.

- Robot control in industrial automation production line: 5G TSN low-delay characteristics are combined with sensor technology to achieve robot and robot arm environment awareness, attitude control, remote operation, automatic control and other functions in order to meet the needs of intelligent production.

- AGV control: In workshops and industrial parks, multiple technologies such as vision, radar and wireless are used for fusion positioning and obstacle judgement; position and motion information are uploaded through the low-delay 5G network to realise automatic obstacle avoidance and mutual cooperation of AGV and improve the automation level on the production line.

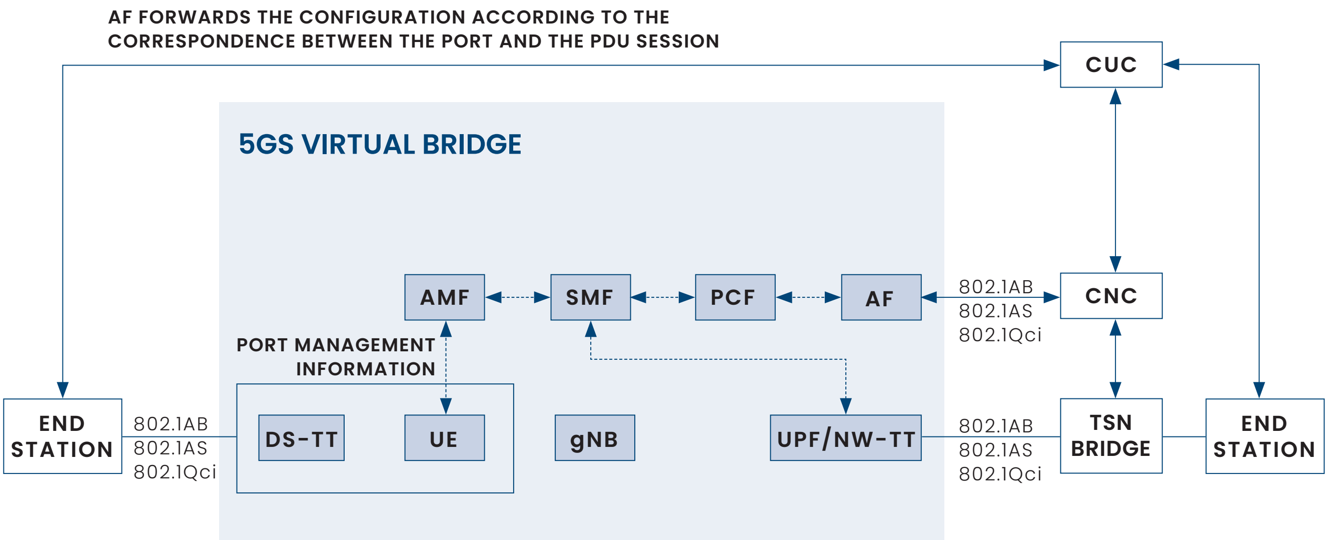
- 5G PLC: In the production process, the 5G network is used to realise system data transmission between PLCs, PLCs and the plant system, while ensuring data security and real-time, it can reduce workshop wiring costs, quickly achieve production line capacity matching and promote flexible manufacturing.

2.5.3 Key technology analysis of 5G and Industrial Internet TSN

2.5.3.1 Integration architecture of 5G and TSN

Currently, the question of how to integrate and deploy 5G and TSN technologies in the Industrial Internet has become a research hotspot for industry, academia and standards organisations. In particular, the 3rd Generation Partnership Programme (3GPP) has started the standardisation

Figure 3 – 5G TSN convergence architecture



of 5G TSN and established the basic fusion architecture. TSN and 5G fusion architecture now mainly adopts bridging technology.

As shown in Figure 3, the 5G TSN convergence architecture is completed in 3GPP R16. In the above architecture, 5GS is regarded as a black box, virtualised as a switch node in TSN network, and adopts the management granularity of each UPF and each virtual switch. In order to reduce the impact on RAN, R16 only supports black box solutions and centralised TSN network models.
On the control plane, the 5GS virtual switch needs to be controlled by the TSN controller. As the information conversion network element between TSN centralised controller CNC and 5GS, AF maps the control instructions of TSN into parameters understood by 5GS, and transforms the information reported by 5GS into the standard format of TSN. It supports 802.1QCC and 802.1AB management interfaces, and communicates information with the TSN system, including 5GS capability and topology reports, traffic forwarding rules, etc.

On the data plane, in order to minimise the impact on 5GS network elements, logic functions NW-TT and DS-TT are superimposed only on the UPF and UE side respectively to support the 802.1 protocol cluster; the protocol conversion between 5GS and TSN system was completed there.

The TSN converter function is used to convert and communicate users and control planes between the TSN and 5G network. The 5G TSN converter includes a device-side TSN converter (DS-TT) and network-side TSN converter (NW-TT), where DS-TT is located on the terminal side and NW-TT is located on the network side. 5G networks are transparent to TSN, providing TSN entry and exit ports via DS-TT and NW-TT. NW-TT/DS-TT supports the 802.1Qbv scheduling mechanism and realises data transmission delay control within 5GS through port information and gated scheduling information transmitted between the 5G network and AF. NW-TT/DS-TT supports 802.1Qci and implements per-stream access control at the ingress.

TSN is a toolbox that enables Time-Sensitive Networking, whereas the 5G network is basically a Best Effort network. Therefore, the difficulty and key point of fusion is how to realise the deterministic network on the uncertain 5G network. 5G and TSN convergence has the following technical challenges:

- Implementation of low latency and low jitter in the 5G network. The 5G TSN includes terminal, wireless, transmission and core network, of which the wireless side is the key to achieving end-to-end determinism. Wireless transmission is easily affected by the environment and the time delay is difficult to guarantee.

- Time synchronisation between 5G and TSN networks. Currently, TSN and 5G networks have their own clock synchronisation mechanism. Time synchronisation is one of the key capability requirements for industrial application scenarios. Industrial Ethernet TSN uses Generalised Precise Time Protocol (GPTP) (IEEE 802.1AS) to achieve time synchronisation. Coordinating clock synchronisation between the 5G network and industrial control system is a problem that needs to be considered.

- 5G TSN UE end-to-end direct communication. In the Industrial Internet, there is direct communication between devices in the field, including cooperative work between mobile robots and AGV cars. Guaranteeing deterministic communication between terminals is also a problem to be considered.

- Industrial Internet deployment environment for 5G TSN. The industrial chain of TSN is relatively long and implementation of TSN in the Industrial Internet will involve the upgrading and transformation of industrial equipment, industrial Ethernet, control systems, etc. In addition, TSN technology is also undergoing development and improvement, scale commercial use will still need some time. Therefore, not all equipment in the actual Industrial Internet environment supports the TSN protocol. Guaranteeing the deterministic transmission of these devices in the initial stage without having to support the complex TSN protocol is a problem that needs further consideration. The integration of TSN and 5G must be promoted step by step and will continue to evolve with the breakthrough of key technologies and the demand changes of application scenarios.

2.5.3.2 Key technologies of 5G TSN

2.5.3.2.1 Low delay and low jitter sensitive communication

5G TSN must reduce jitter and ensure the determinism of delay transmission through some technologies. First, 5G uses Delay Critical GBR, slicing, User Plane Function (UPF) sinking shunt and other technologies to reduce transmission delay. It then combines Time-Sensitive Communication Assistant Information (TSCAI), hold and forward mechanism to eliminate jitter.

- GBR: First of all, according to the characteristics of the Industrial Internet traffic flow, traffic is classified, such as synchronous real-time flow with low periodicity and Best Effort traffic flow with no special requirement on time delay. For Industrial Internet services with high requirements for synchronous real-time streaming (such as Motion Control), a specialised 5G Quality of Service feature (5QI) is recommended. This improves priority of Industrial Internet service in wireless-side scheduling and reduces transmission delay.

- 5G and TSN network slice: For Industrial Internet services with high isolation and low delay, if wireless and 2C (to client) network are shared, use of the reserved slice of physical resource bearer (PRB) is recommended on the wireless side, the hard slice of flexible Ethernet (Flexe) for transmission, and the dedicated UPF for core network. For traffic with particularly high time delay requirements, such as equipment control on a production line in the field, the UPF can sink into the park to reduce time delay caused by the transmission network and use special Industrial Slice in UPF.

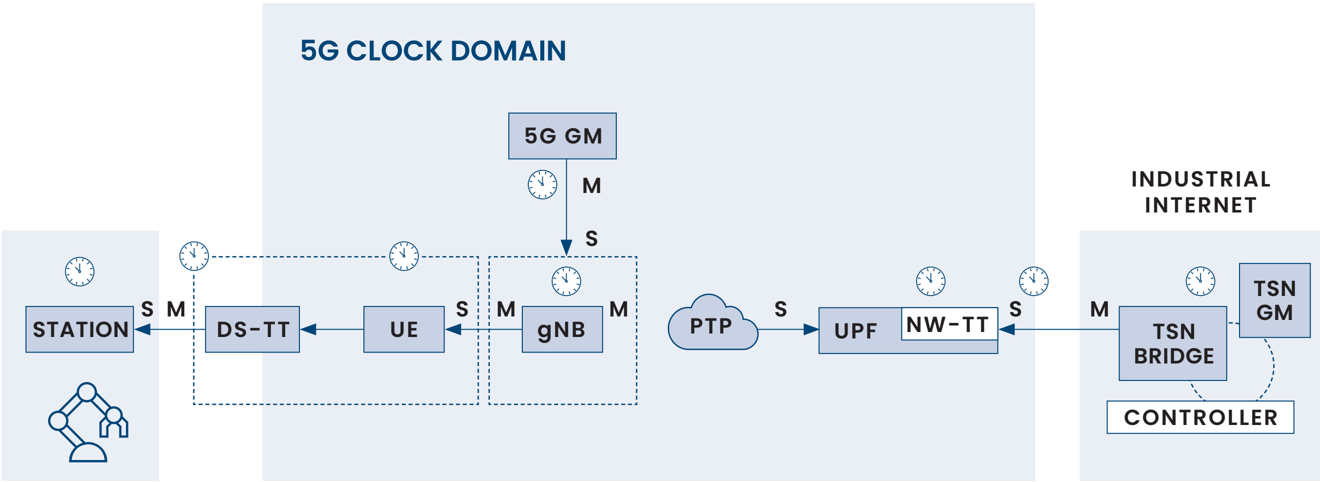
- Periodically determine Quality of Service (QoS): How does 5G TSN solve periodic deterministic QoS? First, 5G TSN uses TSCAI to describe the traffic characteristics of Industrial Internet services, including communication mode (cycle, non-cycle), traffic direction (up, down), traffic arrival time; secondly, DS-TT and NW-TT adopt the scheduling mechanism of hold and forward according to the characteristic information of the traffic and traffic scheduling strategy to reduce delay jitter. 5G TSN supports the hold and forward mechanism of traffic scheduling defined in IEEE802.1 Qbv and its packets can be controlled by opening the gate for data transmission on a predetermined period to control the delay of packets passing through 5G TSN.

2.5.3.2.2 5G syncs with TSN fusion clock

The 5G network and the Industrial Internet have their own master clocks (GM) as shown in Figure 4. Each network element device in the 5G network, including User Equipment (UE), 5G Base Station GNB), UPF, NW-TT and DS-TT, are synchronised with 5G GM (i.e. 5G internal system clock). The entire end-to-end 5G system can be viewed as IEEE802.1AS 'time aware system'; only NW-TT and DS-TT are required to support IEEE802.1AS protocol and keep clock synchronisation with the Industrial Internet, performing all functions related to IEEE802.1AS such as GPTP, timestamp, Best Master Clock Algorithm (BMCA), rateratio, etc. Therefore, DS-TT and NW-TT must support both 5G network and Industrial Internet clocks at the same time, and must calculate deviation between the two clocks.

When Industrial Internet business needs DS-TT and NW-TT to conduct traffic scheduling through gating to eliminate the delay jitter of the 5G network, the message arrival time and cycle time notified to the 5G network will be based on the Industrial Internet clock. Therefore, once the 5G network receives a request for scheduling, the scheduling cycle must first be converted to the time based on the 5G clock before the flow-gated scheduling is carried out.

Figure 4 – 5G TSN syncs with Industrial Internet clock



2.5.3.2.3 Communication of User Equipment (UE) in 5G TSN

In the Industrial Internet, there is often collaboration between industrial equipment and equipment that is mobile, such as AGV collaborative handling, robot collaborative operation, etc. For this reason, terminal and terminal direct deterministic communication is needed. Currently, DS-TT/UE meeting the following conditions can directly communicate with 5G TSN.

- Same data network name (DNN) and single network slice selection auxiliary information (S-NSSAI).
- Network instance of the same UPF. When direct TSN communication between devices in the Industrial Internet is required, slices should be reasonably divided, DNN set and corresponding UPF deployed, as shown in Figure 5.

For UE-UE communication, delay calculation changes to the 5G bridge must be taken into account. Packet Delay Budget (PDB) and UE-DS-TT resident delay of two UEs must be superimposed. The centralised network configuration (CNC) in the Industrial Internet requires a gated scheduling policy for each of the two UEs.

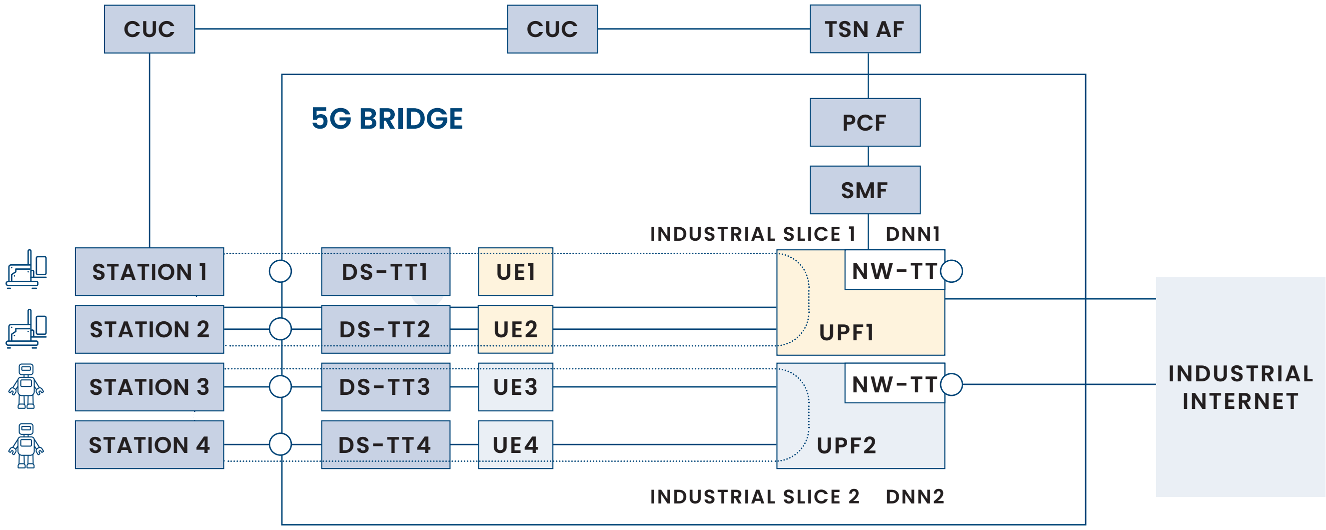
2.5.3.2.4 Endogenous determinacy of 5G TSN

In the application scenarios of Industrial Internet, not all control systems support TSN as shown in Figure 3. For this reason, the question of how to ensure that 5G can still carry out deterministic time-delay transmission without a TSN bridge is a problem that needs to be considered and involves 'endogenous certainty'. Endogenous certainty means that 5G itself guarantees the determination of transmission delay and eliminates jitter.
Problems to be considered for the application of 5G endogenous certainty in the Industrial Internet include: (1) How does the Industrial Internet obtain QoS information from the 5G network? (2) How does the Industrial Internet provide deterministic communication requirements?

First, Industrial Internet applications can be considered through the network exposure function (NEF)/policy control function (PCF) to obtain the delay and jitter between DS-TT/UE, DSTT/UE and NW-TT/UPF.

Second, since there is no CNC for TSN, Industrial Internet applications can construct their own TSN QoS requirements, hold and forward gate control parameters, and provide them to 5G via NEF. With the endogenous certainty of 5G, the Industrial Internet does not need to support the complex TSN protocol in the initial stage.

Figure 5 – UE-to-UE 5G TSN communication



2.5.4 Progress of related standards for 5G TSN

3GPP started research for the Vertical LAN project in July 2018 at the R16 stage, and carried out the research and standardisation for 5G-supporting TSN, 5G LAN and 5G NPN-related technologies for Industrial Internet scenarios. In the R17 phase beginning September 2019, the Industrial IoT project will continue to conduct research to further improve the 5G network system supporting the IEEE TSN protocol, and establish and standardise the deterministic mechanism of the 5G system.

On July 3, 2020, 3GPP announced a freeze on the 5G R16 standard. Compared with the 5G R15 standard, which mainly focuses on EMBB use cases, R16 focuses more on URLLC performance indicators and introduces the TSN mechanism developed by the IEEE 802.1 working group into the standard to enhance latency, jitter and reliability guarantee ability. The 3GPP R17 study is currently in progress and features the following research points:

Research point 1: Uplink time synchronisation

- The TSN master clock source is on the UE side, from which TSN time synchronisation messages are disseminated to TSN devices on the UPF rear end.
- The TSN master clock source is on the UE side, from which TSN time synchronisation messages are disseminated to other TSN devices that hang behind the UE.

Research point 2: UE-to-UE TSN communication

- This mainly studies the influence on the calculation method of 5GS Bridge Delay.
- This mainly studies the influence on QoS parameters and the TSCAI (Time-Sensitive Communication Assistance Information) calculation method.

Research point 3: TSN service capacity opening

- Open TSN service QoS guarantee capability to provide different applications with their own required end-to-end delay, jitter and other QoS guarantees.

- Open time synchronisation capabilities, including time synchronisation capabilities based on TSN clock source and time synchronisation capabilities based on 5G clock source.

Research point 4: the use of time-of-life for deterministic delay applications

- Study how to transmit 'time-of-life' information to SMF via AF and then send it to RAN for scheduling enhancement to solve the problem of continuous packet loss in industrial networks.

2.5.5 Summary for 5G TSN

5G TSN is an important technology for realising the Industrial Internet. On the one hand, delay key GBR, slicing technology, precise timing, flow scheduling and endogenous certainty provide low delay and low jitter deterministic communication for the Industrial Internet and help the wireless and flexible manufacturing of the Industrial Internet. On the other hand, the current industrial chain development of 5G TSN is not mature enough and involves the transformation of terminals, wireless, core network and even transmission. For these reasons, the commercial use of 5G TSN should be promoted gradually. It is expected that the period of research and development and pilot verification of 5G TSN will be from 2020 to 2022; its application will be phased in gradually after 2022.

2.6 Conformity assessment for IEC/IEEE 60802

2.6.1 IECEE (certification process)

2.6.1.1 History (creation of WG35)

2.6.1.1.1 General

Cooperation with IECEE CMC was started in 10/2018. The former CMC TF IN was initiated in line with Decision 58/2019 of the IECEE CMC meeting held in Santiago on 5-6 June 2019. At the IECEE CMC TF IN meeting on 3 October 2019, participants confirmed that the task of TF IN had been fulfilled and recommended the establishment of a new CMC Working Group to be named Services for IEC/IEEE 60802. Based on the successful vote on document IECEE-CMC/2106/DV, the new WG 35 was established in March 2020.

2.6.1.1.2 CMC decision 58/2019 (2019-05) and IECEE-CMC/2106/DV

CMC decision 58/2019 and voting document IECEE-CMC/2106/DV were the basis on which the former CMC TF IN and current CMC WG 35 were created.

Further experts interested in the area of industrial communication protocols and in the field of Time-Sensitive Networks are encouraged to apply for membership of WG 35.

2.6.1.1.3 Decision of IEC SMB and IECEE CMC management on 16 March 2020 on responsibilities for test specifications.

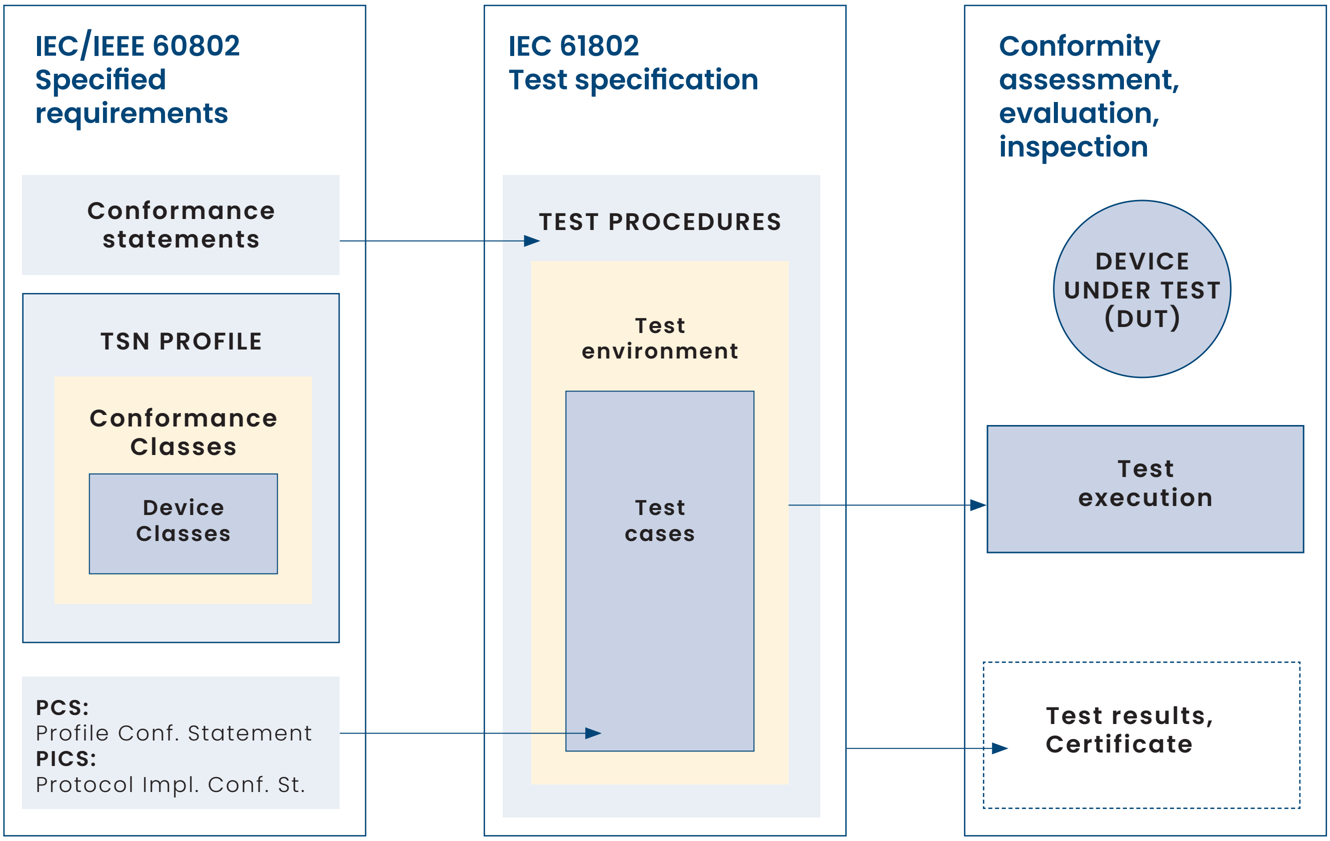
At its meeting in Tampa, Fl. on 26-28 February, the former CMC TF IN submitted a formal request to IEC SMB and to IECEE CMC to clarify responsibility for *where to specify test specifications within the framework of conformity assessments for IEC standards in the area of Industrial Networks: within IEC or within IECEE?*

The IECEE Exec. Secretary, Wolfram Zeitz, informed the TF that similar requests for clarification on responsibilities for test specifications, evaluation methods, test guideline specifications also exist in other areas as cyber security and functional safety.

An IEC/IECEE management group (incl. the chairs of IEC SMB, IECEE CMC, IEC secretariat, IECEE secretariat and IEC CAB) consequently organised a conference call on 16 March 2020 and decided that responsibility for the specification of such test specifications and evaluation methods should lie within IEC.

For IECEE WG 35, the implication of that decision will be that the activity of drafting testing specifications relating to draft IEC/IEEE 60802 (incl. specification of test goals, test setup, test cases, requirements for test equipment) will be moved to IEC SC65C, most likely to a new project team there. IECEE WG 35 plans to hold co-located meetings with that new PT in IEC SC65C from time to time.

Figure 6 – Responsibilities



Activities remaining in IECEE WG 35 include:

- IECEE conformity assessment scheme and work programme for services for IEC/IEEE 60802
- Specification of the certificate structure and contents for IEC/IEEE 60802 certifications
- TRF for IEC/IEEE 60802

Maintenance and updates of the specification Market Impact Analysis/Business Case for new IECEE Service – 'INDA-Communication-60802' (in line with the OD-G-2062 template/structure).
The goal of WG35 is to define a unique approach to conformity assessment for IEC/IEEE 60802 'Time-Sensitive Network profile for industrial automation', and in detail to:

- finalise the draft Market Impact Analysis/Business Case for the establishment of a new IECEE service based on the OD-G-2062 template;
- set up the operational guidance document on how conformity assessment can be handled;
- describe the use of testing tools (instrumentation) and test protocols.

Additional areas of work include conformity assessment elements pertaining to the Time-Sensitive Network profile for industrial automation in conjunction with the IEC/IEEE 60802 standard to address the following:

- cooperation with the IEC/IEEE 60802 joint project to ensure that conformance statements in the Standard contain testable content;
- evaluation of the need for System Level certification for networks using different topologies for an industrial application.

2.6.1.2 Status

Waiting for IEC/IEEE 60802 being published.

2.6.2 IEC (Testing specification)

2.6.2.1 History in IEC

Under the umbrella of IEC SC65C/WG9 and IECEE CMC/WG35, and with the participation of IEEE iCAP, a preparation group (ahG) created a white paper document by November 2019 entitled Business Proposal for the IEC/IEEE 60802 Conformity Assessment (CA) Process. This document provides several options for business models. Option D is the trend of consortia involved in the discussions.

In March 2020, management for the IEC, IEC CAB, IECEE, etc. decided that test specifications are the responsibility of an IEC technical committee not IECEE. IECEE remains responsible for the area of certification

Further meetings were organised (f2f in Tampa as well as remote meetings) to draft the test-spec-outline and NP form. These meetings resulted in the authorisation to Ludwig to finalise edits on the NP and Draft test specification and to forward these to IEC SC65C for circulation to NCs.

2.6.2.2 Status

The German National Committee launched an NP to establish a project to draft the testing specification for IEC/IEEE 60802 in IEC SC65C/WG18. The voting results of the document 65C/1047/NP are listed in RVN 65C/1069/RVN:

- unanimously approved, no comments
- The comments from the voting results proposed to adjust the timeline of the NP to the worst-case scenario with the understanding that the project milestones and the publication dates can be set earlier once contributions will arrive earlier than expected.
- The assigned project number is IEC 61802

There are ongoing discussions as a follow up to the preparation meetings with several consortia representatives concerning how to finance and organise the drafting of the test specification IEC 61802. Goal for this project is the worldwide availability of the test specification to all interested parties for free or a nominal fee. It is expected to get a result until early 2021. Then the host/trustee will be chosen and then the Author.

2.6.3 Responsibilities

Figure 6 shows the responsibilities of the test and certification process.

- IEC SC65C/WG18 and IEEE 802.1 TSN TG is responsible for drafting the IEC/IEEE 60802 profile for industrial automation.
- IEC SC65C/WG18 is responsible for drafting the IEC 61802 test specification for the IEC/IEEE 60802 profile.
- IECEE CMC/WG35 and other interested parties are responsible for certification.

3. TSN Evolution and the future Sino-German contribution

3.Prospects for future development of TSN

3.1.1 Implementation and deployment of TSN in the plant

Although the IEEE 802.1 TSN standard has gradually matured, there are still many problems in the practical deployment of TSN, such as global networking based on TSN devices, global policy configuration, end-to-end TSN network path configuration and the consensus of TSN devices among different manufacturers. Since TSN networks need a global, unified clock source, TSN standards also define the clock source selection algorithm. But in actual network deployment, finding a way to efficiently configure TSN switches to implement global end-to-end delay determinacy and coordinated gate control is one of the keys to large-scale deployment of the TSN network and also the current problem to be urgently solved for TSN standards. At present, TSN equipment in the factory is still at the test stage; there remain many practical problems to be studied and resolved for large-scale application.

In the past, the different Ethernet-based fieldbuses could not share the infrastructure components. Once the IEC/IEEE 60802 profile for IA is finalised, the infrastructure components that support IEC/IEEE 60802 can then be common for the different Ethernet-based fieldbuses. As a large number of infrastructure components are deployed and IEC/IEEE 60802 will not be published before 2023, some of the TSN toolbox standards may be used in the market.

3.1.2 Integration development of 5G and TSN

The integrated application of 5G and TSN is a current research hotspot. Although 3GPP has conducted in-depth analysis and research into the application of 5G in the industry, the latest factory survey shows that the application scenarios and scope of 5G are actually very limited, and that the existing 5G standard is inadequate to support the large-scale application of 5G in the industry.

Although 3GPP R16 provides the preliminary framework for 5G and TSN integration, there is a lack of specific technical implementation details. 3GPP R17 will continue to study ways to achieve deterministic transmission on 5G network through 5G and TSN integration, and in particular ways to guarantee the deployment of URLLC services

3.2 Cooperation and communication with TSN

3.2.1 Cooperation on standards

In recent years, with the development of TSN technology research and product development in China, China Communications Standardisation Association (CCSA) has carried out a lot of TSN standard research, mainly including equipment standards, application standards, safety standards, etc. Under the guidance of GIZ, we hope to make full use of the existing communication platform and carry out exchanges and cooperation on TSN standards with Germany. China also hopes to introduce and promote domestic standards to the international community.

3.2.2 Cooperation on testbed

With the emergence of various new technologies and the integration of technologies, China will consider the construction of new testbeds for 5G and TSN integration, TSN CNC/CUC networking, TSN decentralised configuration, LRP/RAP, TSN+OPC UA and other aspects, and will also carry out exchanges and cooperation with Germany based on the existing communication platform. In the cooperation between German-Chinese test beds for the integrated use of 5G and TSN, a strong reference should be made to the existing activities, e.g. 5G ACIA or 3GPP, in order to avoid double activities for standardisation or, in the worst case, to avoid contradicting results.

3.2.3 Communication of TSN applications

Although the industry has recognised that TSN is the inevitable trend of future factory network development, the deployment and application of the TSN network is still very slow. Of course, part of the reason is the immature development of TSN products, but more importantly there are no killer applications in sight. In China, some enterprises have tried to use TSN technology locally to replace the traditional industrial Ethernet technology, but large-scale application is still a long way off. China and Germany can exchange typical application cases of TSN to promote the application of TSN and the maturity of TSN products.

Annex 1 – Chronicle of meeting highlights

1. Shanghai, 24 November 2015

Investigation of the cooperation Sino/German Intelligent Manufacturing/Industrie 4.0.

Areas identified with a need for standardisation to Industrie 4.0:

- Reference model
- Use cases and methods
- Wireless Communication
- Reliability
- Etc.

In the subgroup Wireless Communication, let by Ludwig Winkel, especially coexistence management was presented.

2. Leipzig, 23 May 2016

Confirmation of intention to cooperate on robotics, intelligent manufacturing, functional safety, IT security solutions, predictive maintenance and wireless industrial applications, etc.

3. Berlin, 29 November 2016

- defined scope and objectives for the wireless industrial applications subgroup

4. Virtual Meeting, 17 March 2017

Ludwig Winkel showed the intended IEC NP for the TSN profile for industrial automation. This IEC NP was planned to become project IEC 61784-6.

5. Qingdao, 26 June 2017

The cooperation route was renamed 'Network communication for industrial applications' and the scope was changed to:

- spectrum considerations and coexistence management are crucial aspects under discussion in international standardisation;
- to create a standardisation roadmap for communications for industry applications
- to find the topics of Sino-German cooperation on edge computing.

Based on the results of the technical cooperation, both sides agreed to strengthen their joint efforts in technical committees and working groups internationally.

6. Frankfurt, 8 September 2017

The Scope and objectives were again changed to:

- Extend the scope of the subgroup to cover wired communication networks and edge computing. The Time-Sensitive Networking was presented by Ludwig Winkel

- harmonise requirements for an industrial automation TSN profile to influence the IEC SC65C/PT1784-6.

7. Hangzhou,
2 December 2017

Actions decided during the meeting: TSN

- Liu Dan to provide the IEC 61784-6 to Chinese experts, together with the MM of the Arlington meeting to review the use cases and objectives.
- China to provide their TSN and reference architecture document, which also includes scenarios, to LW for review.
- report Time-Sensitive Networks (TSN) for industrial automation (IA) domain
- harmonise the use cases and objectives for TSN-IA (input to IEC/IEEE 60802 TSN-IA profile)
- Late April 2018, China will provide feedback; Germany will provide updates when available from February 2018 session of IEC/IEEE
- collaborate on drafting the IEC/IEEE 60802 TSN-IA profile
- define a testbed workflow for IEC/IEEE 60802 TSN-IA profile
- China provides mid-2018 test report (not specific for TSN-IA profile). A plan was established to start working on testbed end of 2018 based on a stable draft of IEC/IEEE 60802 TSN-IA profile.

8. Virtual Meeting
17 April 2018

Topic/area name: Industrial Automation (IA) Networks; Ludwig Winkel

Three closely related topics: 1) Radio spectrum consideration for IA; 2) TSN for IA; 3) Edge computing. All topics are also related to new technologies like 5G, DECT, IEEE 802 Next Generation networks, etc.

9. Heidelberg,
27 April 2018

Presentation by Ludwig Winkel on TSN:

- technical aspects of Time-Sensitive Networks (TSN)
- TSN allows determinism to be maintained with the confidence of being able to satisfy the requirements of less demanding traffic sharing the medium. The meaning of convergence in TSN is the successful convergence of critical control, non-critical control and data streams on a single network.
- activities until May 2018 in IEC and IEEE concerning the TSN Profile for Industrial Automation (IA) joint project.

Next steps:

- drafting the IEC/IEEE 60802 document
- NOTE: Unlike JWGs established between ISO and IEC, IEC/IEEE JWG has to follow the processes of both IEC and IEEE. The organisation will not be affected on either side. [18]
- IEC SC65C/MT9/PT60802 (TSN); Project Team.
- IEEE 802.1 TG joint project for 60802. [19]
- IEEE 802.1 TG joint project for 60802 and 65C/MT9/PT60802 are convened by Ludwig Winkel. IEEE 802.1 intends to nominate an editor in July 2018.

[18] https://www.ieee802.org/1/files/public/docs2018/admin-IEC-IEEE-JWG-cooperation-process-0118.pdf

[19] https://1.ieee802.org/tsn/iec-ieee-60802-tsn-profile-for-indus trial-automation/

10. Beijing,
11 September 2019

TSN standardisation activities are carried out in IEEE 802.1 and IEC/IEEE 60802. IEEE 802 standards address a very wide range of networking scenarios. Users and vendors of interoperable bridged time-sensitive networks for industrial automation need guidelines for the selection and use of IEEE 802 standards and features in order to be able to deploy converged networks to simultaneously support operations technology traffic and other traffic. This is the goal of IEC/IEEE 60802.

11. Summary

The 'Sino/German Intelligent Manufacturing/Industrie 4.0' cooperation agreed to directly support the IEC effort on the TSN profile for industrial communication without creating a white paper setting out what to do in the area of international standards! With the extension to 5G, there is need for a white paper. This document now also describes the TSN standardisation process.

Sino-German Standardisation Cooperation Commission

The central body for standardisation cooperation between the Federal Republic of German and People's Republic of China is the Sino-German Standardisation Cooperation Commission (SGSCC). Under the chairmanship of the Federal Ministry of Economic Affairs and Energy (BMWi) and the Standardisation Administration of the People's Republic of China (SAC) of the State Administration for Market Regulation (SAMR), experts from standardisation organisations work with authorities and companies from both countries on a variety of topics in the commission. These topics include Electromobility, Industrie 4.0, IT security as well as Intelligent and Connected Vehicles.

Sub-Working Group Industrie 4.0 / Intelligent Manufacturing

The Sub-Working Group (SWG) Industrie 4.0 / Intelligent Manufacturing (I4.0 / IM) of SGSCC is the decisive platform for Sino-German exchange on standardisation for Industrie 4.0. Founded in May 2015, it promotes the coordination of common positions in international standardisation bodies. Technical exchange within the SWG enables existing standardisation gaps to be identified and bilateral cooperation in these areas to be promoted.

On a political level, the SWG is led by BMWi on the German side and SAC and the Ministry of Industry and Information Technology (MIIT) on the Chinese side. On a technical level, the work is led by the German Standardization Council Industrie 4.0 (SCI 4.0) and the Chinese National Intelligent Manufacturing Standardisation Administration Group (IMSG). In semi-annual meetings, priority topics are agreed for SWG Industrie 4.0 / IM, which are implemented during the year under the guidance of experts from both countries.

The SWG I4.0 / IM is currently (2021) addressing the following areas of activity in the respective Technical Expert Groups (TEGs):

- Administration Shell/Digital Twin (TEG DT / AAS)
- Artificial Intelligence in industrial applications (TEG AIAI2M)
- IT security (TEG IT-Sec)
- Functional safety (TEG FuSa)
- Predictive Maintenance and Condition Monitoring (TEG PM / CM)
- Use cases and applications (TEG UCA)
- Network communications and edge computing (TEG NetCom)

Related standardisation committees

Working group IEC/SC65C with the title 'Industrial networks' was specifically created within IEC/TC65 'Industrial-process measurement, control and automation' to prepare international standards on wired, optical and wireless industrial networks for industrial-process measurement, control and manufacturing automation, as well as for instrumentation systems used for research, development and testing purposes. The scope includes cabling, interoperability, co-existence and performance evaluation.
IEEE 802 develops and maintains standards specifying data link layer protocols and physical layer protocols to support packet transmission and delivery among netwo rk-layer clients.

(1) Protocols, developed by Working Groups responsible for medium access domain, are specified for transmission of frames within an access domain with sufficient detail to allow multivendor interoperability across the interfaces to the communication medium.

(2) Interoperability is also specified for transmission of frames via a network of such access domains, including bridging specifications developed within the IEEE 802.1 Working Group.

The scope of DKE/K 956 includes the standardisation of industrial communication networks and their applications. This includes the standardisation of classic and Ethernet-based fieldbus systems in wired and radio-based forms, as well as their profiles, including installation profiles. It also includes the standardisation of widely available industrial communication networks and device integration.

DKE/K 956 expresses its support to that activity and for the recommendations of that white paper.

The national TC124/SC10 on Systems and Functional Safety of SAC is the Chinese Committee on Functional Safety and Industry Security, which has released many Chinese standards on functional safety, industrial security and the integration of safety and security.