ZTE

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Industrial Internet Oriented 5G TSN Practice and Prospect

Introduction

With the commercial deployment of 5G networks, the Industrial Internet, as an important area of 5G ToB applications, has entered a period of rapid development driven by industry digital transformation and Industry 4.0. As the core field of the Industrial Internet, the production puts forward higher requirements for the real-time and deterministic network connection, including ultra-low latency, ultra-low jitter, and highly reliable transmission links. The integration of 5G and TSN can provide deterministic services with millisecond-level transmission delay and microsecond-level jitter, meeting the real-time requirements of existing major production industries, and has attracted great attention from the industry.

In order to promote the integrated development of 5G and Industrial Internet, ZTE and China Mobile Research Institute, together with industry customers and terminal manufacturers, have conducted in-depth exploration and practice of 5G TSN end-to-end solutions in industrial Internet scenarios. The practice in the power grid differential protection, intelligent PLC real-time control and other aspects have achieved good results and provided strong support for the in-depth development of 5G + industrial Internet.

This white paper aims to promote the industry's understanding of 5G TSN-related standards, architecture, key technologies and development trends, and to provide reference for the technological innovation, experimental verification, and application practice of 5G TSN in the industrial Internet scenario, so as to jointly promote 5G TSN in the field of industrial production, fully empower the industrial Internet and the digital transformation of the industry, and creates a new blue ocean of value.

Written by: ZTE, China Mobile Research Institute

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1 Industrial Internet Ecosystem

1.1. Development Situation of Industrial Internet

Industrial Internet is a new type of infrastructure, application mode and industrial ecosystem deeply integrated by the new generation of information communication technology and industrial economy. It builds a brand-new manufacturing and service system by fully interconnecting people, machines, things and systems. It is the cornerstone of the industrial 4.0 and the key path for upgrading and transformation of manufacturing industry, providing new impetus for the development of digital economy. With the increasing maturity of new generation of information technologies such as 5G, cloud computing, edge computing, big data and artificial intelligence, the development of industrial Internet has been strongly supported. New infrastructure projects in China have been launched, and industrial Internet has become one of the key deployment projects. According to the statistics, the industrial Internet market in China is close to 700 billion yuan in 2020. Around the world, governments and enterprises are attaching great importance to industrial production model innovations triggered by industrial Internet. According to the predictions of relevant organizations, the global industrial Internet market size will exceed USD 1 trillion in 2022 and reach USD 1.2 trillion in 2025.

However, industrial Internet is still in the early stage of development, and still faces many difficulties and challenges. Many problems need to be solved urgently, including data security, cross-field professional training, business model innovation, and standard making. Among them, the effective combination of technologies and requirements is one of the bottlenecks of the industrial Internet development. Each industry has its own unique requirements. It is a global problem on how to combine the standardized communication technologies represented by 5G with diversified industry requirements, make full use of the features of 5G network, including large bandwidth, low latency and high reliability, expand the application scenarios of 5G+ industrial Internet and deepen the integration of 5G and industrial technologies.

1.2. 5G+ Industrial Internet Development Situation

5G is the key empowering technology of industrial Internet, while 5G+ is an important direction for empowering smart factories to be digital, wireless and intelligent. At present, the integration of 5G and industrial Internet has been extended to more than 10 key industries such as aviation, mining, port, metallurgy, automobile, home appliance, energy and electronics. Eight typical application scenarios such as 5G+ UHD video, 5G+ AR, 5G+ VR, 5G+ drone, 5G+ robot, 5G+ remote control, 5G+ machine vision and 5G+ AGV have been initially formed.

Although ultra-low delay services can be guaranteed by network slice and other measures in 5G network, but in industrial scenarios such as production line equipment control, precision instrument manufacturing, robot control, and digital twin, the current 5G technology cannot meet the requirements of E2E high reliability, deterministic low-latency transmission and precise collaboration between heterogeneous systems. Therefore, in order to support the further development of industrial Internet, it is urgent to introduce deterministic commitments and SLA differences to 5G networks.

1.3. 5G and TSN Convergence Requirements and Challenges

TSN (Time Sensitive Network), which is based on the traditional Ethernet, is one of the important technologies for implementing low latency, high reliability and deterministic transmission in industrial interconnection. In addition, TSN is an open Ethernet standard. The equipment supporting TSN from different suppliers can be compatible with each other, thus improving the connectivity and universality of industrial equipment and providing good interconnection and interworking capability. Therefore, the complementary features of 5G and TSN bring them into the vision of the industrial field and standardization organizations. At present, the integration of 5G and TSN includes the following three modes:

- **TSN over 5G uRLLC:** The entire service system is connected to the 5G network as a terminal, implementing the remote deployment of TSN system via uRLLC slice, and guaranteeing determinacy of service transmission in segments.
- **5G Transmission over TSN:** The TSN technology is used to improve the quality of 5G transport network, including fronthaul and backhaul networks, and implement deterministic transmission.
- **5G TSN:** As a TSN logical network bridge, the entire 5G system provides the deterministic forwarding capability via UE-RAN-UPF, thus achieving interconnection between 5G and TSN networks and the E2E deterministic forwarding guarantee across 5G.

The first two 5G and TSN integration modes do not need 5G equipment to support TSN functions, but they do not support TSN E2E integration between 5G and TSN. The third 5G TSN mode, by upgrading the entire 5G system to support TSN-related features (such as traffic scheduling and time synchronization), truly achieves E2E integration between 5G and TSN, instead of ensuring the deterministic transmission of a certain segment or only adopting the TSN technology at the transport layer. To achieve in-depth integration of the 5G TSN solution, the 5G system is faced with a series of technical challenges such as time synchronization mechanism, collaborative traffic scheduling mechanism and highly reliable transmission, so it needs to be further researched and improved in product development and engineering practice.

2 5G TSN Standards and Key Technologies

2.1. 5G TSN and Related Standards

2.1.1. 5G TSN Standard Overview

At present, the main deterministic network standards include three standards IEEE TSN, IETF DetNet (Deterministic Networking) and 3GPP TSC (Time Sensitive Communication). These standards focus on providing bounded delay and jitter, ultra-high transmission reliability and E2E high-precision time synchronization.

5G TSN usually refers to the TSC function defined by 3GPP R16. The 5G network is interconnected with the IEEE TSN network to implement E2E L2 TSN deterministic transmission network. At this time, the entire 5G network serves as a TSN virtual network bridge, the UE side serves as a port of the 5G TSN virtual network bridge, and the UPF serves as another port to connect to the TSN network.

In addition, 5G network can further enhance the deterministic transmission capability without external TSN networks, and interconnect with the IETF DetNet network to enhance E2E L3 deterministic transmission network.

2.1.2. IEEE TSN

TSN is a L2 Ethernet-based deterministic network standard established by IEEE. It provides time sensitive services with deterministic forwarding guarantee with limited latency, jitter and packet loss rate based on the existing 802.1Q. It can be applied in audio/video transmission, industrial control, vehicle-mounted network and smart grid industries.

In July 2004, the IEEE 802.3 research team proposed the technical research of providing precise time synchronization, bounded delay jitter and bandwidth guarantee for the audio and video services in home Ethernet. After that, the research project was migrated from IEEE 802.3 to IEEE 802.1, and the AVB task team was formally established in March 2006. In 2012, AVB was renamed as TSN, indicating that it is not only used for audio and video services, but also for industrial control and other industries with stricter requirements for transmission delay and packet loss rate.

The IEEE TSN standard mainly involves protocols related to time synchronization, delay guarantee, high reliability transmission and resource management (see Figure 1). At present, more than 10 TSN-related standards such as 802.1AS, 802.1Qbv, 802.1Qbu, 802.1Qci, 802.1CB and 802.1Qcc have been released (refer to Table 2). The standards have already been mature. In addition, IEEE is continuously perfecting TSN related protocols so that TSN can better deploy applications and manage various industries, such as TSN Profile for industrial automation/vehicle-mounted Ethernet applications and YANG data model for

802.1Qbv, 802.1Qbu, 802.1Qci, and 802.1AS.

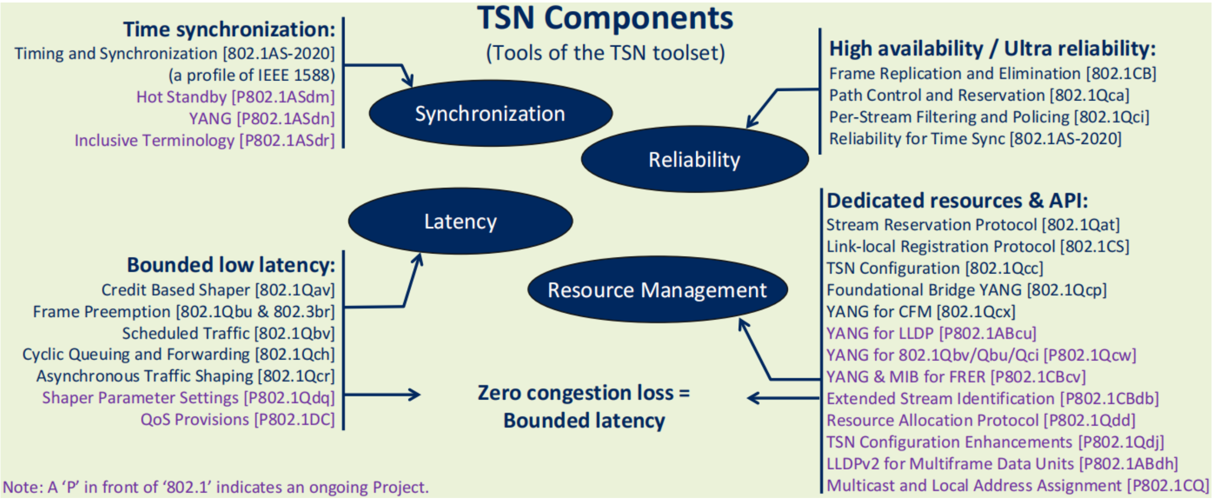

Figure 1 EEE TSN Standard Protocol Stack

2.1.3. IETF DetNet

For DetNet, IETF established its work group in November 2015, focusing on the provision of bounded delay, jitter, packet loss rate and highly reliable transmission capabilities in L2 bridging and L3 routing. The work group not only resolves deterministic transmission of L3, but also provides interoperability with L2 TSN network. DetNet can be applied in professional and home audio/video, vehicle-mounted network, control system and other fields. Unlike the TSN that is mainly used for L2 LAN, DetNet is also used for wide-area private networks, such as campus network.

The content of DetNet research mainly includes the following aspects: **architecture, data plane, control plane, data traffic information model** and **YANG model.** At present, the DetNet standard is still being formulated. More than 10 RFC standards has been released, such as scenarios, architectures and IP/MPLS data plane architectures and traffic models. Other technical standards, such as OAM, control plane and delay queue, are still under research and formulation.

2.1.4. 3GPP TSC

TSC was introduced by 3GPP in the R16 standard released in July 2020. 3GPP TSC is a supplementary and enhanced enhancement to the URLLC function. On the basis of the low-latency and high-reliability transmission provided by the URLLC, the TSC function can further reduce the forwarding scheduling delay for periodical traffic, provide more accurate delay/jitter control and interconnection with the external TSN/DetNet deterministic network to form an E2E deterministic networking.

In a deterministic network, each network forwarding node (such as switch and router) in the network needs to provide the deterministic forwarding capability. If one of the network nodes does not support deterministic forwarding, the network may suffer uncontrollable delay or packet loss due to insufficient forwarding capability of this node, which will cause the service transmission quality of E2E to be affected. This is unbearable. Therefore, in the 3GPP R16 standard, the entire 5G system is regarded as a TSN logical network bridge, providing the deterministic forwarding capability via UE-RAN-UPF, thus implementing the interconnection and interworking between 5G and TSN networks and the E2E deterministic forwarding guarantee across 5G. Therefore, 5G TSC is also often called 5G TSN.

In addition, because it is equivalent to a TSN bridge, the 5G system also needs to support basic protocols related to the TSN network:

- First, the 5G system needs to support the TSN traffic forwarding capability of L2 Ethernet, that is, to support basic functions such as frame format and frame identification and classification rules defined by the 802.1Q protocol.
- In addition, the 5G system also needs to support enhanced scheduling and management functions related to TSN services, including time synchronization protocol 802.1AS, 802.1Qbv protocol based on time gating control scheduling, TSN network management configuration protocol 802.1Qcc, and 802.1AB protocol discovered in network topology management.

2.2. 5G TSN Architecture

In the 3GPP R16 standard, the 5G TSN network complies with the network architecture of the fully integrated centralized model defined in the IEEE 802.1Qcc protocol (see Figure 2). The CUC (Centralized User Configuration) manages requirements of service scenarios, discovery and configuration of terminals (Talker and Listener), and interacts with the CNC (Centralized Network Configuration) to transmit TSN service features and network transmission requirements. The CNC implements the TSN network management functions, including configuration and management functions of bridge devices, In accordance with the capabilities of bridge devices and requirements of service traffic, the CNC plans E2E transmission paths of TSN service traffic and the scheduling policies of all bridge nodes.

Generally, a network bridge needs to have two data forwarding ports and one control plane management interface. Therefore, when the 5G system acts as a TSN logical network bridge, a TT (TSN translator) module is introduced at both the UE side and the UPF side. It is responsible for undertaking the functions of the data forwarding port of the logical network bridge, connecting with other bridges or terminal devices in the TSN network, and introducing the TSN AF NE to interact with the CNC so that the CNC can configure and manage the 5G TSN logical bridge.

Refer to Figure 2 for the overall architecture of a 5N TSN logic network bridge, as shown below:

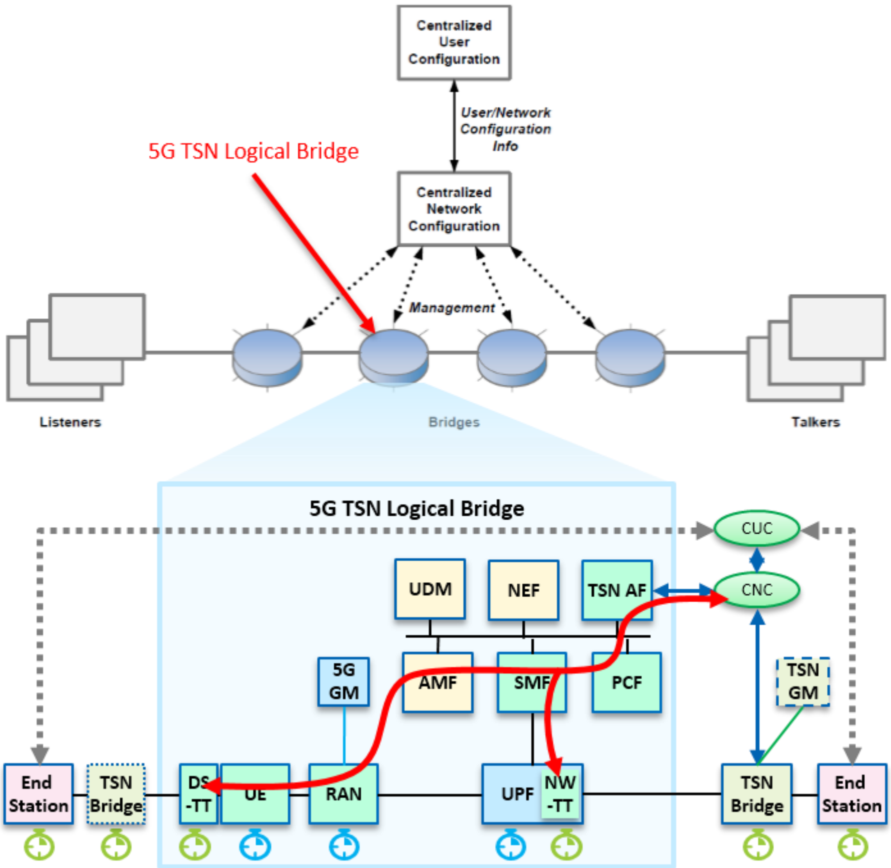

Figure 2 5G TSN E2E Network Architecture

To interconnect between the 5G TSN logical network bridge and the TSN network, the 5G system defines the following three functional modules:

- **DS-TT:** It is the Device-side TSN translator. As a port of the 5G TSN logical network bridge, the DS-TT can be connected to the TSN system at the terminal side. Generally, the DS-TT is integrated with the UE.
- **NW-TT:** It is the Network-side TSN translator. As another port of the 5G TSN logical network bridge, the NW-TT can be connected to the TSN system at the network side. The NW-TT is a functional module of UPF.
- **TSN AF:** It is the TSN Application Function. As the management interface of the 5G TSN logical network bridge, TSN AF can be connected with the CNC controller of the TSN network. In general, the TSN AF can serve as an independent NF NE or be co-located with other NF NEs.

2.3. 5G TSN Key Technologies

2.3.1. High-accuracy Time Synchronization

As 5G applications continue to expand into the ToB field, various control applications are increasingly demanding on 5G system air interface time synchronization. For example, subway, railway, traffic control, and autopilot all need precise time synchronization to achieve synchronization and efficient operation. Moreover, power network control requires strict system synchronization, and the timing accuracy can reach up to 1us.

In s 5G TSN network, there are two different time domains: TSN time domain and 5G time domain. The TSN time domain serves each node of the TSN network, including terminal, bridge, DS-TT and NW-TT. The 5G time domain serves the 5G system, including UE/DS-TT, RAN and UPF/NW-TT. The 5G clock source and the TSN clock source can be independent of each other without interfering with each other. In addition, only the DS-TT and NW-TT need to perceive the time in two different time domains at the same time, while the RAN does not need to perceive the TSN time. See Figure 3:

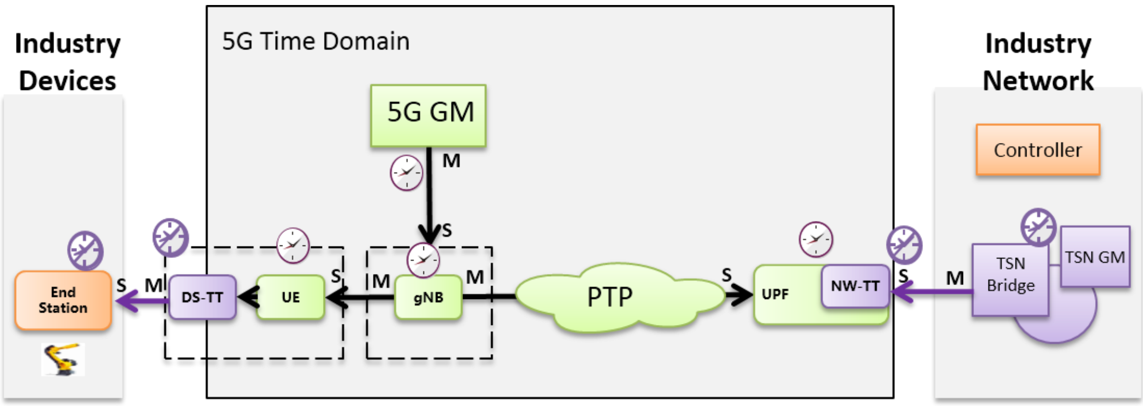

Figure 3 5G TSN Time Synchronization Architecture Diagram

- **5G time synchronization:**

After acquiring the time from 5G GM (such as GPS satellite), the RAN needs to synchronize the time to the UE/DS-TT and UPF/NW-TT to achieve high-accuracy time synchronization within the 5G system. The UE/DS-TT can synchronize the clock with the RAN via the SIB9 system broadcast message or RRC message on the Uu interface. Generally, the UPF/NW-TT can implement time synchronization with the RAN by following the IEEE 1588v2 specification.

- **TSN time synchronization:**

As a TSN bridge, the 5G system is integrated with external TSN networks to support time synchronization. The entire E2E 5G system can be regarded as an IEEE 802.1AS time sensing system. The two TT modules (DS-TT and NW-TT) at the edge of the 5G system should support the time synchronization related message processing function defined by the IEEE 802.1AS protocol.

2.3.2. Accurate Delay Scheduling

The 5G TSN network enhances the scheduling forwarding mechanism to implement accurate uplink/downlink bandwidth guarantee, ultra-low delay and ultra-low jitter forwarding capabilities. First, the 5G TSN network provides E2E accurate time-based resource reservation and scheduling to ensure that all links in the network are smooth.

- **Co-work with the URLLC low delay QoS guarantee mechanism（Delay Critical GBR）**

In terms of the URLLC scenario, the protocol introduces a series of enhancement technologies such as Mini-slot, configured grant, 1D1S frame structure and low bit rate transmission. The algorithm parameters and function switches, such as frame structure and SR period, can be configured together according to service requirements. Through flexible combination of multiple technologies, the air interface delay and reliability transmission capability can be formed.

- **Introduce the TSCAI delay sensitive communication assistance information**

TSCAI (TSC Assistance Information) includes the burst arrival time and periodicity of service data. By leveraging the TSCAI information, together with the algorithm parameters such as configured UL grant, semi-static dispatch, pre-scheduling and SR period, and associated configuration of the function switch, the gNB enables the wireless scheduling behavior to more effectively match the characteristics of the service traffic, thus reducing the wireless transmission delay of the service traffic and improving the wireless scheduling efficiency.

- **Introduce the 802.1Qbv scheduling technology**

The UE/DS-TT and UPF/NW-TT can also learn about the arrival time of packets based on the 802.1Qbv protocol, and reserve sufficient network resources in advance to avoid TSN traffic waiting time caused by network congestion. In addition, the time gate-based forwarding and scheduling mechanism of the 802.1Qbv enables packet forwarding in the specified time window to achieve ultra-low jitter forwarding effect.

- **Introduce the SPN Fine Granularity Unit (FGU) technology**

SPN (Slicing Packet Network) is a new generation of converged bearer network architecture based on slicing Ethernet core with the advantages of low delay, large bandwidth, ultra-high accurate time synchronization and flexible management. It's also compatible with the Ethernet ecological chain and has the characteristics of low cost and easy deployment. SPN FGU technology integrates fine-grained slicing technology into the overall SPN architecture, providing a low-cost, refined, hard-isolated small-grain bearing pipeline, and reducing the granularity of hard slicing from 5Gbps to 10Mbps, to meet the needs of differentiated services such as small bandwidth, high isolation, and high security in scenarios such as 5G+ vertical industry applications and private line services. The introduction of FGU technology in the backhaul network can provide deterministic transmission guarantee for TSN service flow, and achieve the effect of end-to-end deterministic transmission.

2.3.3. High Availability Redundancy Mechanism

Transmission guarantee without packet loss and service interruption are the benchmark capabilities of the deterministic network. In the 5G TSN network, the dual-path redundancy transmission mechanism can be used to prevent network service interruption and data loss caused by network failure and packet loss, such as PDCP replication, dual-N3/N9 tunnel, dual-PDU session, dual-UE redundancy active-active and FRER. In addition, together with redundancy and fault protection mechanism of the equipment, full-service, all-state, all-traffic real-time active/standby capabilities and uninterrupted network service capabilities can be provided, such as active-standby/active-active disaster recovery, and NG-C link disconnection service retention.

2.3.4. Closed-loop Coordination and Management

Deterministic network guarantee cannot be separated from refined management and coordination of network resources. 5G TSN network needs to construct a comprehensive monitoring mechanism from terminals, networks and services.

- Provide E2E slice management to guarantee service SLA.
- Implement on-demand network customization through E2E coordination of terminals, networks and services.
- Percept data such as network status, service experience and dispatching effect, adjust the service dispatching strategy in real time, and construct an E2E closed-loop control of "perception-decision-making-optimization."

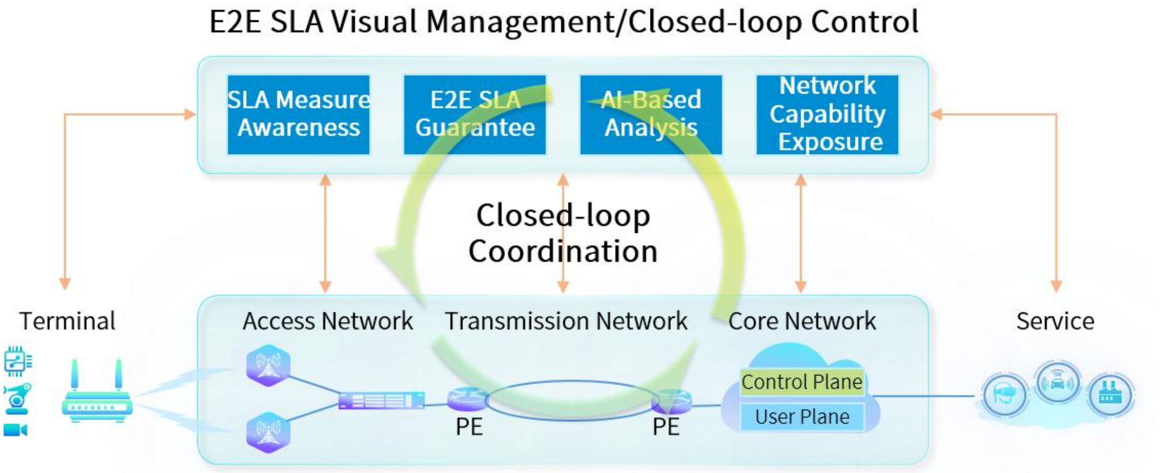

Figure 4 5G TSN Closed-loop Coordination and Management Architecture

First, as the TSN logical network bridge, the 5G system coordinates the CNC management system of the TSN network to report the status, capabilities and networking topology of the 5G network, and receive resource requirements and scheduling strategies of TSN service traffic. When the 5G network status changes or is abnormal, notify the CNC system to adjust the strategies timely.

In addition, to further optimize the network, enhanced capabilities such as E2E SLA measurement perception, network capability exposure, AI analysis and E2E strategy planning can be used to achieve collaborative optimization between TSN terminals and E2E nodes such as services, transmission networks, RANs and UPFs, and to create an optimal E2E network.

3 5G TSN E2E Practice

3.1. Automatic 5G TSN + DTU Power Distribution

3.1.1. Application Scenarios and Requirements

The differential protection technology is widely used in the power distribution field of power grids. In short, differential protection means that when a transmission line is operating properly, the current values at both ends of the transmission line are the same. When the transmission line breaks down, the current values at both ends are different. When the differential current is higher than the pre-set value of the differential protection device, the circuit breaker on each side of the protected device is disconnected from the power supply. Differential protection can shorten the fault duration and improve power supply reliability. The following figure shows the power distribution differential protection scenario in the smart grid.

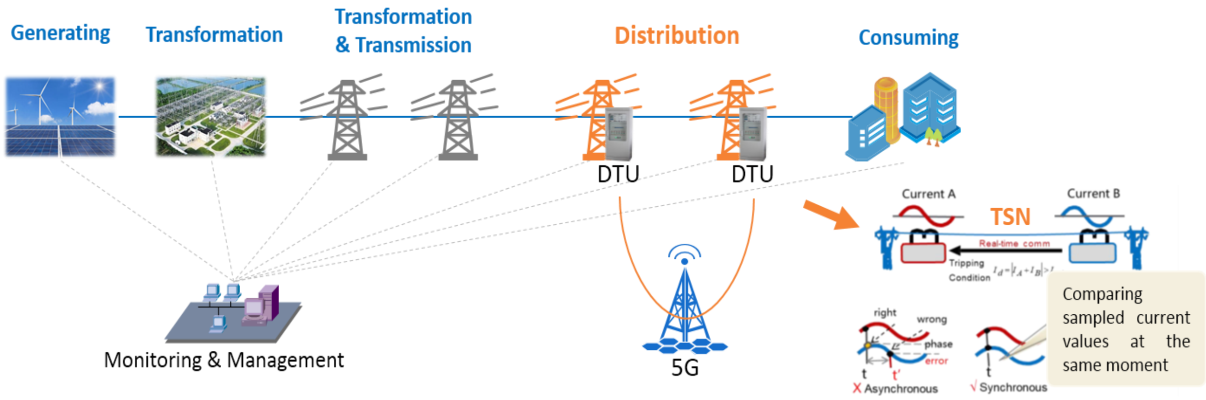

Figure 5 Power Distribution Differential Protection Scenarios in Smart Grid

To ensure accurate determination of differential protection and timely startup, it is necessary to ensure that a group of differential current is sampled at the same time, that is, time synchronization of differential current must be strictly ensured. Therefore, differential protection requires high communication delay and reliability among DTUs (delay: less than 10ms, time synchronization accuracy: less than 10us, reliability: more than 99.999%). To achieve power distribution differential protection, a communication network needs to be deployed among the differential protection devices of adjacent power distribution stations. However, due to the large number of terminals for differential protection and scattered deployment, when dedicated optical fiber lines are used for deployment, the costs are high and it is difficult to meet the increasing access requirements.

The low latency, high reliability and massive connections of 5G network can meet the above requirements. 5G TSN provides precise and reliable network transmission capability to meet the requirements of differential protection for communication delay. Combined with the dedicated network service capability such as 5G LAN, the strict security isolation requirements of the power grid are also satisfied. Therefore, 5G networks are used to replace optical fiber transmission, and 5G private network technologies are used to flexibly deploy terminals, reducing deployment costs and guaranteeing transmission delay. In addition, a large number of differential protection terminals deployed in distributed mode can be accurately controlled and managed. Therefore, China Mobile, together with ZTE and NR Electric, jointly released the industry's first E2E 5G TSN deterministic network, verifying the services such as grid differential protection and achieving good results.

3.1.2. Solution Architecture and Application Effects

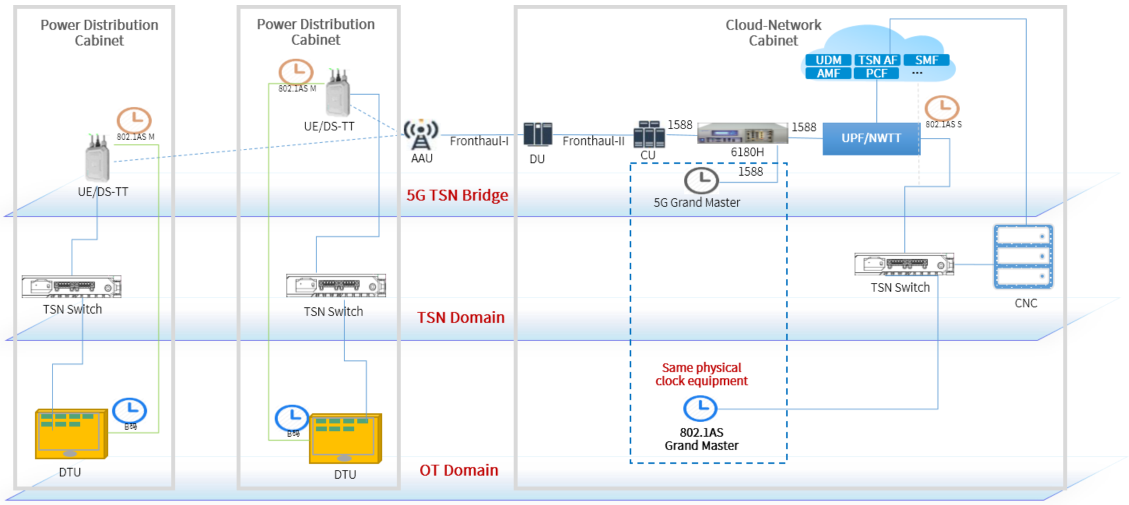

Figure 6 Automatic Power Distribution of 5G TSN + DTU Solution Practice

By reconstructing existing power distribution cabinets, UE/and TSN switches are added to the power distribution cabinet for networking with DTU in the power distribution cabinet. An integrated cloud-network cabinet is deployed at the network side. The cloud-network cabinet integrates 5G Grand Master and 802.1AS Grand Master (deployed with the same physical equipment), BBU (DU + CU), transmission equipment (SPN), core network equipment (AMF/SMF/UDM/PCF/TSN AF), UPF/NW-TT, TSN switch and CNC.

Through network transformation, the timing equipment (GPS input and B code output) originally distributed in the power distribution cabinet is integrated into the cloud-network cabinet for centralized deployment (it can serve as Grand Master of 5G or Grand Master of OT domain), which not only saves investments, but also facilitates centralized management and maintenance of the network.

The innovative UE/DS-TT supports the B code to time the differential protection device DTU. UE/DS-TT obtains the TSN clock with high-precision through 802.1AS, and then gives time to the differential protection device through B code.

CNC is deployed in the cloud-network cabinet to automatically manage and configure TSN switches and 5G TSN bridge.

Time-based precise gate control management is enabled at the UE/DS-TT side to implement bounded transmission of packets and prevent network jitter.

Application effect: By clock timing with high-precision, the timing requirement of the differential protection device is satisfied, and the deviation of the timing accuracy is within 300 nanoseconds. Time-based precision gating management ensures the bounded transmission of DTU service packets and guarantees the network jitter within 1 millisecond. The introduction of 5G TSN deterministic network has effectively supported grid services such as grid differential protection, accelerated deployment of new energy sources such as solar energy and wind energy, finally enabling green grid.

Commercial visions: The practice of 5G TSN in power grid differential protection makes a useful exploration for future large-scale commercialization. The large-scale commercialization requires joint efforts of all parties in the industry chain, including the terminal chip manufacturers to build convergent UE/DSTT products, the network manufacturers to build more integrated TSN products, the OT manufacturers and IT/CT manufacturers to work together to integrate services at the cloud end, which provides a solid foundation for 5G to empower the green grid.

3.2. 5G TSN + PLC Industrial Automation

3.2.1. Application Scenarios and Requirements

As an important element of industrial automation, PLC is a bridge between OT and IT, and its role is not to be underestimated. The PLC connects and controls a variety of devices. It connects and processes data analysis, and transfers it to the upper-layer information system to serve as the control center between the factory and the workshop. At present, well-known enterprises, including Rockwell Automation, Siemens, and Mitsubishi, are embedding more intelligent functions in PLC to turn them into industrial intelligent controllers. However, to enable the PLC to play its due role in industrial Internet and flexible manufacturing, and to further flourish the industrial Internet with the help of 5G, there are a series of challenges:

- Scenarios such as data collection, industrial control, automation and man-machine interaction have strict requirements for network transmission delay and security and reliability.
- The industrial design, auxiliary assembly, video monitoring and maintenance scenarios require an upstream bandwidth of over 800Mbps.
- Most of the current industrial data collection adopts the wired connection mode, which features high cost, long deployment time, inconvenient deployment, slippery ring communication and easy aging, and large handover delay, stability, anti-interference and poor security.
- An industrial enterprise needs to build an industrial private network/virtual private network oriented to industrial Internet. However, due to the limitations of traditional industrial networks (without unified technical standards, they cannot be interconnected on a large scale), they cannot meet the requirements for building private and virtual networks in the industry.

Therefore, China Mobile and ZTE, together with the renowned industrial automation vendors in the industry, collaborate in providing low-latency and low-jitter deterministic connections for the real-time control of intelligent PLC by introducing the 5G TSN network, further proving the application prospect of 5G TSN in the industrial Internet.

3.2.2. Solution Architecture and Application Effect

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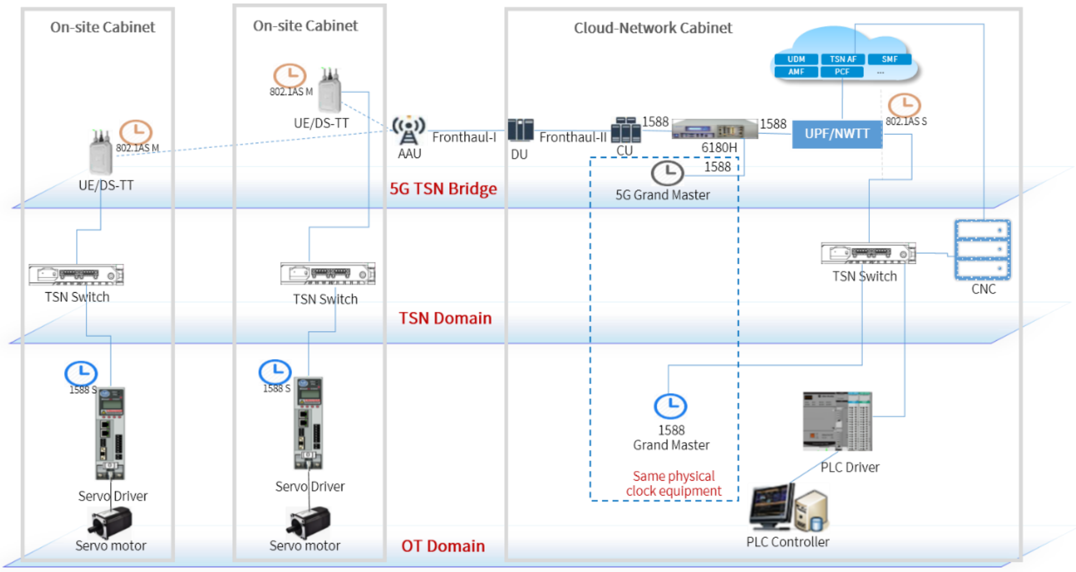

Figure 7 5G TSN + PLC Industrial Automation Solution Practice Architecture

By reconstructing the existing on-site cabinets, UE/DS-TT and TSN switches are added to work together with the servos and drives in the on-site cabinet for on-site motion control of industrial automation.

Integrated cloud-network cabinets are deployed at the network side. 5G Grand Master and 1588 Grand Master (using the same physical equipment), BBU (DU+CU), transmission equipment (SPN), core network equipment (AMF/SMF/UDM/PCF/TSN AF), UPF/NW-TT, TSN switch and CNC.

Through network transformation, the PLC that was originally distributed in the on-site cabinet is deployed to the cloud-network cabinet in a centralized manner. The Grand Master that was distributed in the PLC is also deployed to the cloud network cabinet (which can serve as the Grand Master of 5G or the Grand Master in the OT domain). This not only saves the investment but also facilitates centralized management and maintenance of the network.

The innovative TSN switch supports interworking between 802.1AS and 1588, and meets the precision requirements of EtherNet/IP industrial standard Ethernet for network timing.

CNC is deployed in the cloud cabinet to automatically manage and configure TSN switches and 5G TSN bridge.

Time-based precise gate control management is enabled at the UE/DS-TT and NW-TT sides to implement bounded transmission of packets and prevent jitter in the network.

In addition, in the N3 interface, the SPN Fine Granularity Unit technology (FGU) is enabled to realize the transmission guarantee for the TSN service flow and ensure the end-to-end deterministic transmission guarantee in the 5G system.

Application effect: By high-precision clock timing, the precision timing requirement of EtherNet/IP is satisfied, and the deviation of timing accuracy is within 300 nanoseconds. Time-based precise gate control ensures bounded transmission of CIP/CIP Motion service packets and network jitter within 1 millisecond, verifying the feasibility of real-time motion control through the 5G TSN network.

Commercial prospect: The practice of 5G TSN in PLC movement control has made a useful exploration for future large-scale commercial use. For future large-scale commercial use, all parties in the industry chain, including terminal chip vendors to build integrated UE/DSTT products, network manufacturers to build more integrated TSN products, and OT manufacturers and IT/CT manufacturers to integrate services at the cloud end, providing a solid foundation for 5G to empower flexible manufacturing of industrial Internet.

4. 5G TSN Prospect

4.1. Technology Evolution

At present, in the R17 standard being formulated by 3GPP, the 5G TSC feature adds UE-UE deterministic transmission. At this time, 5G network is an E2E deterministic network, which does not need to interconnect with the external TSN network. In addition, with the capability exposing function, the 5G deterministic service capability can be customized and coordinated by the industry network.

At the same time, clock synchronization is enhanced. Further study is made on the delay compensation (PDC) in the precise timing process to support that the clock synchronization error between UE and UE is less than or equal to 900ns.

For QoS enhancement, R17 introduces the Survival Time parameter in TSCAI. The terminal enters the Survival Time status (ST status) and activates the PDCP duplication solution to ensure that the service QoS meets the Survival Time.

In the future R18 standard, 3GPP is expected to interconnect with the DetNet network and improve the deterministic forwarding capability of L3, so as to provide a larger range of deterministic private network capability. In addition, 3GPP is expected to provide cooperative management between the E2E nodes in the 5G RAN and the transmission network, thus achieving a more ultimate deterministic network.

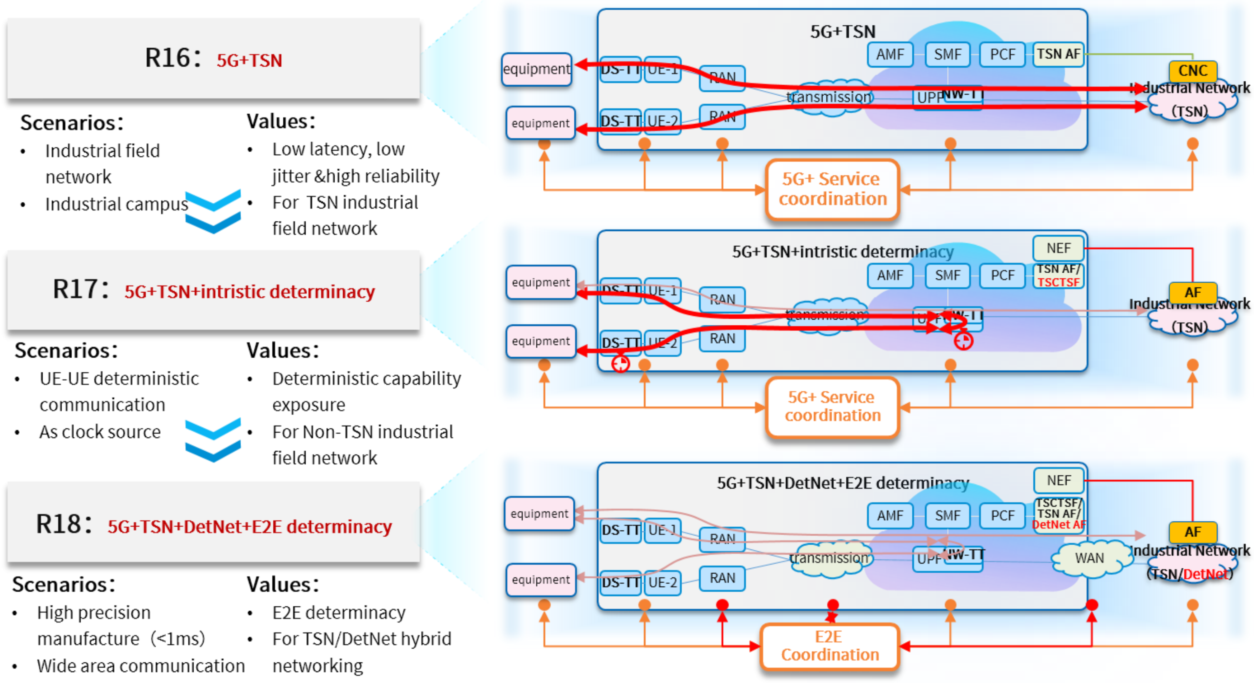

Figure 8 3GPP TSC Technology Evolution

4.2. Industry Collaboration Progress

5G TSN has attracted wide attention in the practice of industrial Internet. Although 5G TSN faces many technical and industrial challenges, the enormous potential that 5G empowers industrial Internet will be fully realized through cross-industry communication, cooperation and innovation.

At present, the China Industrial Internet Industry Alliance has launched the "5G+TSN Joint Test Bed" project, which is a deterministic, highly reliable, intelligent and flexible network access comprehensive verification test platform in the industrial Internet scenario. This project will provide a test environment for the integration of 5G and TSN technologies, and provide technical verification for the innovative applications of the deterministic network in flexible manufacturing, production process control and machine collaboration scenarios.

At the same time, the 5G-ACIA (5G Alliance for Connected Industries and Automation), which includes representatives of traditional automation and manufacturing and leading companies in the information and communication technology industries, is actively promoting the implementation of 5G TSN in the field of industrial production, and releasing the Integration of 5G with time-sensitive networking for the industrial communications white paper.

As the world's leading communication operator, China Mobile is also actively working together with its industrial partners to provide 5G TSN E2E solutions for industrial IoT scenarios. At present, China Mobile is building a 5G+TSN test system to test the E2E service features, network performance, and the functions and performance of the equipment and system in the integration network, including terminals, gateways and platforms, in the typical 5G-TSN integration scenario of the industrial field. Together with the industry partners, China Mobile will promote the demonstration project of integration of 5G+ industrial Internet, to form a virtuous cycle of technology, standard, industry and application to empower intelligent manufacturing of 5G+ industrial Internet and facilitate digital transformation of industries and high-quality development of the real economy.

4.3. Industry Prospect

From chips, switches, industrial terminals to E2E solutions, 5G TSN has begun extensive testing and verification. With the wide deployment of 5G network infrastructure, especially the implementation of 5G private networks for industrial parks, a platform is emerging for 5G TSN to make difference. The flexible deployment and deterministic service experience provided by 5G private network + TSN will effectively deal with the complex and changeable application scenarios of industrial Internet and intelligent manufacturing

At present, leading enterprises in the industry have started to promote the integrated applications of 5G TSN in the industrial field. Qualcomm, Intel, Siemens, Bosch and Mitsubishi have all launched related solutions and concept verification projects. ZTE will also apply the 5G TSN technology in the production practice of the global 5G intelligent manufacturing base in Binjiang, Nanjing, and “make 5G with 5G”. Although it will take time for 5G TSN to be fully implemented in the industrial field, with breakthroughs in key technologies, operators and communication equipment manufacturers' deepening understanding of industry needs, and the continuous enrichment of industry use cases, 5G TSN technology will create great value in the era of the Internet of Everything.

5. References

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