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Research on Integration of 5G and TSN

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Abstract. This paper analyses the TSN technology and its basic standard components. It also analyses the architectures of 5G System and 5G RAN. Base on the two analyses, three technology directions of 5G and TSN integration are studied. Finally, to realize the integration, key technologies are discussed.

Keywords. TSN, 5G, Integration.

1. Introduction

With the advent of the fourth industrial revolution, the industrial field continues to realize industrial upgrading through the path of automation, informatization, digitization and intelligence. New industrial scenarios are defined, and new industrial applications emerge one after another. Industrial Internet is the only way to realize industrial intelligence. It integrates industrial control technology and information communication technology, and makes use of data collection, advanced network, big data, cloud computing, and artificial intelligence, so as to save costs and improve production efficiency for industrial enterprises. However, the traditional industrial network architecture can’t meet the requirements of Industrial Internet. It is imperative to build an industrial network with large bandwidth and high determinism.

For future industrial communications, time-sensitive networking (TSN) and fifth-generation wireless communications (5G) are the main network connecting technologies, i.e. TSN for wired connectivity and 5G for wireless connectivity. In order to fulfil the requirements of large bandwidth, flexible deployment (wireless and wired) and high determinacy in industrial applications, it is necessary to integrate 5G and TSN effectively.

2. TSN

The IEEE 802.1 Audio Video Bridging (AVB) Task Group [1] was formed in 2005 to solve the problem of real-time synchronous data transmission in audio and video networks. With the working scope extending, TSN TG [2] was evolved from the AVB TG in November 2012, including the former Interworking TG. The set of standards made by TSN TG define deterministic mechanisms for the time-sensitive data transmission while staying compatible with traditional Ethernet network.

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2.1. TSN Overview

TSN technology locates in the Data Link Layer of the OSI/RM model. TSN technology components consists of four common standard subsets: time synchronization, bounded low latency, high availability/ultra reliability and dedicated resources, as shown in figure 1.

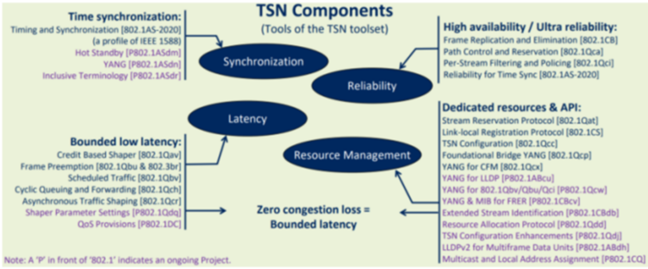

Figure 1. TSN Components [3]

For ease of deployment and interoperability, TSN TSG also provides TSN Profiles to describe the network architecture and composition for a specific use. A TSN Profile selects functions and options from the TSN standard components. The published TSN Profiles are IEEE Std 802.1BA for Audio-Video Bridging networks and IEEE Std 802.1CM TSN for Fronthaul. The underway TSN Profile is IEC/IEEE 60802 TSN Profile for Industrial Automation. Two Profiles are on the horizon: P802.1DF TSN Profile for Service Provider Networks and P802.1DG TSN Profile for Automotive In-Vehicle Ethernet Communications.

2.2. Basic Components

There is no strict time synchronization in traditional IEEE 802.3 Ethernet and IEEE 802.1Q Ethernet bridging. On the contrary, a mutual time reference is needed to synchronize all the devices in the network to realize real-time communication with strict transmission delay boundaries. In TSN standard family, IEEE 802.1AS Timing and Synchronization for Time-Sensitive Applications [4] defines the time synchronization mechanisms. The Generalized Precision Time Protocol profile is defined by selecting among the IEEE 1588 options to apply to Ethernet networks. To further improve time synchronization accuracy, redundancy by supporting multiple time domains is introduced in IEEE802.1AS-2020.

As for scheduling and traffic shaping, traditional IEEE 802.1Q bridging defines Priority Code Point (PCP) field in Ethernet frame to support eight distinct priorities. But it cannot guarantee absolute bounded end-to-end transmission time even with the highest priority. To achieve bounded latency, several scheduling and shaping methods are formulated, such as the credit-based traffic shaper (IEEE 802.1Qav) [5] , time-aware shaper (IEEE 802.1Qbv) [6] , asynchronous shaper (IEEE 802.1Qcr) [7], etc.

3. 5G

3.1. 5G System Architecture

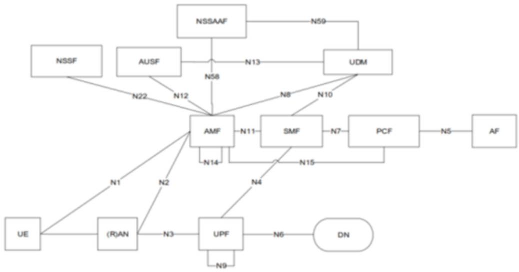

Figure 2. 5G System Architecture using the reference point representation

TS 23.501 [8] defines the 5G system architecture, as shown in figure 2.

The following network functions (NF) are the main constituents of 5G System architecture.

- *User Equipment (UE)*.
- *(Radio) Access Network ((R)AN)* includes NR and other wireless access and wired access.
- *User Plane Function (UPF)* includes the functionalities of packet routing and forwarding for user plane, QoS handling for user plane, traffic usage reporting, TSN Translator (NW-TT), external PDU session point of interconnect to Data Network and so on.
- *Access and Mobility Management Function (AMF)* includes the functionalities of registration management, connection management, mobility management and so on.
- *Session Management Function (SMF)* includes the functionalities of session management (session establishment, modify and release, including tunnel maintain between UPF and AN node), UE IP address allocation and management, charging data collection and support of charging interfaces and so on.
- *Policy Control Function (PCF)* supports unified policy framework to govern network behaviour and provides policy rules to control plane function(s) to enforce them.
- *Unified Data Management (UDM)* includes the functionalities of generation of 3GPP AKA authentication credentials, user identification handling, UE's serving NF registration management and so on.
- *Application Function (AF)* interacts with the 3GPP Core Network in order to provide services such as application influence on traffic routing and accessing network exposure function. According to operator deployment, different connecting mechanism are used to different AFs. Trusted AFs are permitted to connect directly to relevant Network Functions, while non-trusted AFs must connect with relevant Network Functions through NEFs.

- *Network Exposure Function (NEF)* supports the independent functionalities of exposure of capabilities and events, secure provision of information from external application to 3GPP network, translation of internal-external information and so on.

3.2. 5G RAN Architecture

As figure 3 displays, the 5G RAN architecture consists of the following parts.

- AAU(Active Antenna Unit) includes parts of the PHY, RRU and antenna, which is connected by fronthaul with DU.
- DU(Distributed Unit) includes PHY and real-time protocols, which is connected by midhaul with CU.
- CU(Centralized Unit) includes non-real-time protocols and applications, which is connected by backhaul with CN.

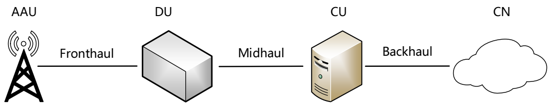

Figure 3. 5G RAN Architecture

4. Technology Directions Of 5G And TSN Integration

The research scope of integration of 5G and TSN mainly refers to the technical integration innovation of 5G system and TSN network system and the collaborative deployment on solutions. Currently, there are three integration technology direction: TSN over uRLLC, 5G Bearer Network over TSN and 5G appearing as TSN bridge.

4.1. TSN Over 5G uRLLC

TSN over 5G uRllC means connecting the existing time-sensitive system, such as industrial control network, vehicle network, to the 5G system. This integration deployment utilizes 5G uRLLC to realize the extension of TSN system.

In this type of solution, as depicted in figure 4, the entire TSN business system is regarded as a 5G UE. A mapping relationship is established to map the TSN traffic classification with the service type of the 5G network system, meanwhile it is necessary to retain the relevant tags of TSN traffic configuration. After the transmission of the 5G network system, the 5G packaging is stripped. The TSN packages enter the TSN business system, deterministic transmission is still performed according to the TSN traffic scheduling type.

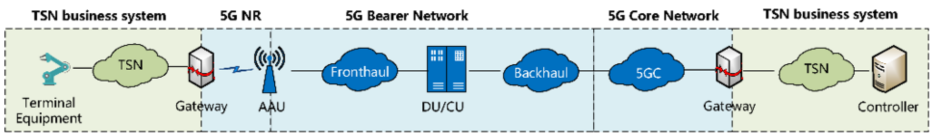

Figure 4. TSN Over 5G uRLLC

4.2. 5G Bearer Network Over TSN

In addition to proposing new air interface standards and new core network architecture, the reconstruction of the 5G bearer network is also an important research direction. The 5G bearer network usually adopts the wired network to carry traffic. TSN network can be utilized to improve the quality of the 5G bearer network, as shown in figure 5.

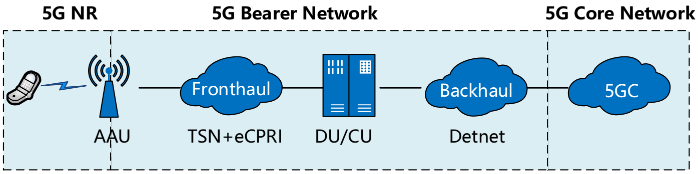

Figure 5. 5G bearer network over TSN

In order to better adapt to the large bandwidth, high reliability, and low latency transmission requirements of 5G networks, Ericsson, Huawei, NEC and Nokia have cooperated to create eCPRI based on CPRI, which is the interface protocol of 5G fronthaul network. The user plane data of the eCPRI interface is transmitted based on Ethernet, which has the advantages of high bandwidth, high scalability, and low equipment cost, and can better match the optical transmission network. It can be said that the 5G fronthaul network with eCPRI as the interface already has the technical prerequisites for integration deployment with TSN. In fact, IEEE has set up two related projects, IEEE 1914 Next Generation Fronthaul Interface [9] and IEEE802.1CM Time-Sensitive Networking for Fronthaul[10].

Since 3G era, the mobile backhaul network usually adopts the packet forwarding technology to carry traffic between the base station and the core network. Typical solutions are represented by IPRAN and PTN. The MPLS label forwarding technology is used to realize the forwarding, scheduling and protection switching of service traffic. The backhaul network in the 5G era will combine SDN and NFV technologies to drive the intelligent evolution of the backhaul network, and also take advantages of TSN technology to realize low-latency and low-jitter service transmission in the backhaul network. Deterministic Networking (DetNet) is a suitable technical solution, which is made by the IETF DetNet Working Group [11] collaborating with IEEE802.1 TSN Working Group.

It is worth noting that when the separation of CU and DU is actually implemented, the transmission distance of the fronthaul may be shortened, and the midhaul network between DU and CU is likely to use packet transmission for transmission. Therefore, the combination of TSN and 5G midhaul network will also be a key focus of integration deployment.

4.3. 5G Appearing as TSN Bridge

Figure 6 depicts that the 5G System can be used as a TSN bridge connecting with external networks, which is defined in 3GPP 23.501. The integration applies the fully centralized configuration model in IEEE Std 802.1Qcc.

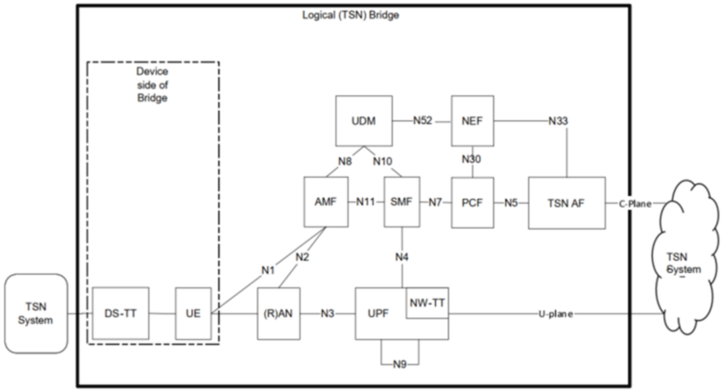

Figure 6. System architecture view with 5GS appearing as TSN bridge

In this logical TSN bridge structure, two TSN translators, Device-side TSN translator (DS-TT) and Network-side TSN translator (NW-TT) are designed as TSN ingress and egress ports to realize the user plane functionalities such as hold and forward functionality and link layer connectivity discovery and reporting. The TSN AF serves as the entity to accomplish the control plane functionality of the integration connection, such as the interaction with the CNC. Via the above three function entities, the 5G System specific procedures and data transmission over the air remain transparent to the TSN network. So the 5G System integrates with TSN network as a bridge.

5. Key Technology of Integration 5G with TSN

5.1. Clock Coordination

In the 5G clock domain, the gNB obtains the clock from the 5G GM (e.g. GPS satellite), it then passes the clock to UE and UPF to achieve high-precision clock synchronization within the 5G system. UE can achieve clock synchronization through the RRC message of the Uu port between UE and gNB, and the UPF can usually use the IEEE 1588 specification to achieve time synchronization with the gNB. In the TSN clock domain, the network elements are synchronized with the TSN GM based on the IEEE 802.1AS specification. It is not difficult to see that the 5G network system and the TSN network system follow two clock domains, and the two clock domains follow the 5G GM clock source and the TSN GM clock source respectively.

To realize the coordination of the clock synchronization mechanism in the integration deployment of 5G an TSN, two problems must be solved: the coordination of the clock source and the coordination of the clock message transmission mechanism. The coordination of clock sources can be processed through normalization or mapping. The clock message transmission mechanism can be implemented by hop-by-hop delivery or tunnel pass-through. It is worth noting that the two gateway devices (DS-TT, NW-TT) at the edge of the 5G and TSN systems are the key functional modules for clock coordination.

5.2. QoS Mapping

The QoS mechanisms of TSN system and 5G network system are independent of each other. In the integration of 5G and TSN, the QoS mechanisms of the two systems need to be aligned with each other, including of QoS mapping and the strategy coordination.

5.2.1. QoS Mapping

QoS mapping between 5G and TSN can be divided into 2 processes. First, TSN AF maps the CNC information to TSN QoS parameters. Then, PCF maps TSN QoS parameters from TSN AF to 5G QoS parameters. TSN AF can configure QoS mapping table locally to query TSN QoS parameters corresponding to PDU sessions. TSN AF can also receive PSFP information and transmission gate scheduling parameters from TSN CNC and map them to TSN QoS information. PCF provides the mapping function from TSN QoS information to 5GS QoS profile, that is, mapping TSN QoS information to appropriate 5G 5QI, GBR, MBR and other parameters. Then, the 5G system can trigger the PDU session modification process according to the QoS strategy decided by the PCF to establish a 5G QoS flow channel and realize the low-latency transmission of the TSN service flow in the 5G system.

5.2.2. Strategy Coordination

The QoS requirements of TSN services are usually passed to the Policy Control Function (PCF) through TSN AF. Then PCF allocates appropriate 5G QoS strategy for services based on service flow requirements. SMF and AMF interact through control plane signaling to obtain the service QoS requirements issued by the PCF. On the one hand, AMF carries it to the RAN through the N2 interface, and on the other hand, SMF carries it to the UPF through the N4 interface. UPF and UE map service flows with different QoS requirements into appropriate PDU sessions and QoS flows, so as to realize the differentiated QoS scheduling of different service flows in the 5G system.

5.3. Resource Coordination

There are obvious differences between 5G and TSN in terms of network architecture, communication mechanism, protocol mechanism, and data format. Only efficient resource coordination can realize flexible heterogeneous network adaptation and seamless cross-network high-reliability bearer. In order to realize the resource coordination between 5G and TSN, the 5G system has carried out corresponding mechanism adaptation and related mechanism enhancement from the system architecture, control plane and user plane.

For the control plane, the main work is to support 5G perception of TSN network, TSN centralized network controller (CNC) perception of 5G system existence, and unified scheduling control. The specific process mainly includes network topology discovery (LLDP), 5G TSN bridge configuration management, and unified scheduling control.

The user plane is mainly aimed at the enhancement of the accurate delay residency and forwarding mechanism of 5G UPF. The realization of TSN's scheduling and forwarding mechanism based on precise time is the core function of 5GS to support TSN functions. DS-TT and NW-TT provide the TSN data stream residency and forwarding mechanism, following the IEEE802.1Qbv standard. In the 5GS system, it is necessary to implement low-latency scheduling to ensure that the data packet arrives at the NW-TT or DS-TT before its scheduled transmission time.

6. Summary

This paper first analyses the TSN technology. The standards components and specific using profiles are studied. Secondly, 5G system architecture and 5G RAN architecture are studied. Then three technology directions of 5G and TSN integration are researched. Finally, three key technologies of the integration are discussed.

To implement the integration deployment, more solution details should be studied. And the specific applications in industrial automation, internet of vehicles, intelligent substation and other scenarios will be researched next.

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