GTI 5G Native Deterministic Technology for New Industrialization White Paper

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Editor	Zhenning Huang(CMCC), Wanming Ma(CMCC), Bohan Yang(CMCC), Long Zhang(CMCC), Chenhui Du(CMCC), Fengbo Yang(CMCC), Qingdong Hou(CMCC), Zerui Ma(CMCC), Shuai Ma(CMCC), Bin Wei(CMCC)
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Executive Summary

The new industrialization serves as a crucial engine for accelerating the development of economy and society. The construction of a robust manufacturing country requires organic integration with the development of the digital economy and information industrialization, and the new generation of information and communication technologies, represented by 5G, provides a key digital infrastructure base for the transformation of the manufacturing industry into digital intelligence.

This white paper presents the deterministic demand for key application scenarios based on the comprehensive analysis of 5G enabled digital factory. In addition, this white paper proposes the core concept of "Native supply of deterministic capability; Extreme service for deterministic performance; and Global guarantee for deterministic reliability". It constructs a technology system covering 3 categories and 12 innovative capabilities.

Finally, the white paper summarized and forecast the future evolution of 5G native deterministic technology and industry development. We hope that industries can work together to drive technological evolution and business maturity.

Abbreviations

Abbreviations	Explanation
3GPP	3rd Generation Partnership Project
5G	5th Generation Mobile Network
AGV	Automated Guided Vehicle
BBU	BaseBand Unit
BFD	Bidirectional Forwarding Detection
BWP	BandWidth Part
CQI/MCS	Channel Quality Indicator/ Modulation and Coding Scheme
DCI	Downlink Control Information
DNN	Data Network Name
DPI	Deep Packet Inspection
eMBB	enhanced Mobile BroadBand
GBR	Guaranteed Bit Rate
GPS	Global Positioning System
FRER	Frame Replication and Elimination for Reliability
IEEE	Institute of Electrical and Electronics Engineers
I/O	Input/Output
IP	Internet Protocol
IRT	Isochronous Real Time communication
IT	Information Technology
LAN	Local Area Network
MES	Manufacturing Execution System
MTN	Metro Transport Network
Multi-TRP	Multiple Transmit/Receive Point
OPC UA	OLE for Process Control Unified Architecture
OT	Operational Technology
PDCP	Packet Data Convergence Protocol
PLC	Programmable Logic Controller
pRRU	pico Remote Radio Unit
PTP	Precision Time Protocol
QoS	Quality of Service
RB	Resource Block
RedCap	5G Reduced Capability
RHUB	Remote radio unit Hub
RRU	Remote Radio Unit
RS	Reed-Solomon
RT	Real Time communication
SCADA	Supervisory Control And Data Acquisition
SDK	Software Development Kit

SIB	System Information Block
TCP	Transmission Control Protocol
TSN	Time Sensitive Network
UE	User Equipment
UPF	User Plane Function
VN	Virtual Network
WMS	WMS Warehouse Management System

1 Scenario Requirements Analysis

The comprehensive empowerment of 5G digital factory requires the realization of the "two-layer, three-tier" architecture for the industrial network, which entails full connectivity and services. This covers the two-layer network of IT (Information Technology) and OT (Operational Technology) in the factory. Additionally, it involves interconnection among devices in three management levels of factory, workshop, and production line. Specifically, different application scenarios at different levels have different requirements for 5G deterministic in terms of network coverage, communication performance and operational security.

1.1 Factory-Level Application Scenarios

Factory-level applications generally refer to production-assisted applications for facility management, logistics management, personnel management, safety management and informatization services for industrial factory, such as video/environmental monitoring, data collection, remote diagnosis, etc. Factory-level applications have strong demand for extensive coverage, convenient networking, highly available access, and other capabilities, which need to support network protocols such as OPC UA, TCP/IP, etc.

In terms of network coverage, factory-level applications need to support the processing of factory level data traffic and establish data communication between workshops. Taking video/environmental monitoring as an example, through 5G networks, real-time monitoring of personnel/data status and equipment performance can be achieved, while intervening control, abnormality warnings, remote diagnosis, and other operations can be performed, which contributes to improve production efficiency and ensure production quality and safety. This requires a 5G network capable of achieving extensive coverage from production floors to warehouses and from office areas to outdoor environments, ensuring seamless connectivity of various mobile devices and sensors.

In terms of communication performance, factory-level applications carry a variety of data streams such as sensors, surveillance video, communications, etc., which generally require a certain degree of low-latency and low-jitter connectivity. Taking data collection as an example, collecting data from various resources within and between production lines through 5G could be conducted, including equipment status, power, gas, water, etc. These data can be transmitted to the central data center in real time via 5G to optimize scheduling, achieve predictive maintenance, and reduce costs and resource wastage. Typically, the latency is required to be around 100 milliseconds, with jitter controlled in the second range and reliability of 99.9%.

In terms of operational security, to ensure the continuity of production and management as well as reduce the risk of potential production interruptions, 5G is required to provide high availability capabilities. Taking the construction of an information management system as an example, 5G can enable more efficient integration of management data, equipment and resources. Efficient information management not only improves the operational efficiency of the industrial factory, but also provides powerful tools for data analysis and prediction. Therefore, the high availability of the 5G network is essential to support the above key business scenarios, ensuring efficient, stable and reliable operation of information interaction tasks.

1.2 Workshop-Level Application Scenarios

Workshop-level applications generally refer to production management and collaborative control applications between controllers, between local/remote monitoring systems and controllers, and between operation systems and controllers in the production workshop. For example, control management applications such as vision inspection and AGV collaboration in workshops, as well as information management applications such as SCADA/MES/WMS/APC systems and vehicle material location, usually need to support communication protocols such as OPC UA, Modbus TCP, and Ethernet/IP.

In terms of network coverage, workshop-level applications need to support the closed loop of industrial production signaling in the workshop, which significantly increases the privacy requirements of 5G networks. Taking the production management with PLC northbound connectivity in the workshop as an example, real-time updating and convenient adjustment of production plan and scheduling can be achieved through 5G-based industrial software. Such data is not only the planning basis of enterprise production activities, but also covers the core elements of enterprise production organization, operation status, production process, etc., which is an important enterprise asset. 5G network should be able to provide a safe and reliable networking environment to ensure that the production data can be locally processed without data leakage.

In terms of communication performance, workshop-level applications have higher requirements for latency and bandwidth. Taking production line cooperative control as an example, 5G is required to support high-resolution video streaming, large-scale equipment data transmission, and convenient real-time communication between machines. The flexible networking of 5G is required to realize a high-degree automation of workshop level applications and enable the production process highly efficient, in order to improve the accuracy and productivity of the production line and reduce the production interruptions. 5G is required to provide deterministic latency and bandwidth guarantees.

In terms of operational security, to maintain stable communications between production equipment and avoid production interruptions, the availability of 5G network should be ensured in most cases. Only minimal interruptions are allowed, where reliability range is typically required from 99.9% to 99.99%. In the case of remote control, for example, based on the deterministic latency and jitter capabilities provided by 5G, deterministic high-reliability capabilities are superimposed to improve the efficiency and safety of remote control, thus enabling remote operation and monitoring of equipment such as iron transport trucks in steel mills, gantry cranes in harbors and excavators in mines.

1.3 Line-Level Application Scenarios

Production-line level applications generally refer to the production line field detection sensors, actuators and industrial controllers and other single production link, business unit applications. For example, the southbound control services between line-level PLC and I/O devices, inverters, and valve island, as well as the east/west control services between the production line PLC and the main equipment PLC, or between the main equipment PLC and subordinate PLCs, usually require communication network with ultra-low latency, bounded jitter, ultra-high reliability and other deterministic capabilities. At the same time, Profinet/RT/IRT, CC-Link IE TSN, EtherNet/IP and other industrial control protocols should be supported.

In terms of network coverage, line-level applications are faced with connection problems such as diversified industrial protocols and multi-level ring networks. For example, the inverter, valve island and other equipment control can achieve the wireless and convenient connection of drag chain, slip ring and other scenarios via 5G network. Further simplifying the multi-group, multi-layer industrial production ring network, meeting the real-time, high-speed, reliable interaction of the production line control, data acquisition, quality inspection can be conducted. 5G should provide a network foundation that satisfies the requirements of interconnection and convenient integration among the elements of "human, machine, material, method and ring" at the production-line level.

In terms of communication performance, line-level applications have extreme deterministic demands on 5G networks, with exceptionally stringent requirements for latency, jitter, time synchronization, bandwidth, etc., including support for high-speed, high-precision production-line operations and ensuring instant collaboration between devices. Taking safety control as an example, in order to safeguard the safety of personnel and equipment during the production process, detect potential risks and take countermeasures in a timely manner, it is necessary to ensure that the 5G network communication between the safety PLC and the safety I/O (e.g., safety relays, emergency stop buttons, and light curtain monitoring systems) strictly controls minor fluctuations, with a network reliability of up to 99.999%.

In terms of operational security, to maintain stable communication between the controllers/actuators of the production-line equipment and ensure the continuity and safety of production actions, the data transmission between the control system and the equipment must be real-time and stable. At the same time, strict security measures are required to safeguard the control logic and key data of the industrial control system. Taking motion control as an example, in addition to guaranteeing high-performance communication through 5G low latency, bounded jitter, and high-precision time synchronization, 5G is also required to provide deterministic and highly reliable capabilities to guarantee the positioning accuracy, operational continuity, and safety of motion control. In this way, the stability and reliability of the entire link of servomotor motion control, CIPMotion, safety PLC control, safety IO control, and common IO control, and general IO control can be realized.

2 Core Concepts and Technology Systems

2.1 Core Concepts

In order to provide industrial enterprises with first-class deterministic 5G enterprise network services, this white paper proposes the core concept "Native supply of deterministic capability, Extreme service for deterministic performance, and Global guarantee for deterministic reliability" as following:

- **Native supply of deterministic capability:** Through the optimization and adjustment of the 5G network architecture and the enhancement of 5G network capabilities, native provision of end-to-end deterministic service capabilities, such as network integration, extreme communication, and operation guarantee, minimizes or even eliminates the need to put forward adaptation requirements for external industrial networks, and realizes lightweight and plug-in deployment;

- **Extreme service for deterministic performance:** Promote the evolution of 5G communication performance in an all-round way, make up for the short board of extreme low latency and bounded low jitter, and lengthen the long board of communication large bandwidth and spatial wide coverage, forge the new board of low power consumption of equipment and high security of network, and provide the extreme performance service that meets the core production link of industrial manufacturing;

- **Global guarantee for deterministic reliability:** Use the global perspective to build the deterministic, reliable, and security capability of 5G network to adapt industrial networks, systematically provide multi-dimensional and multi-level reliability guarantee means and security protection measures to ensure the stable operation of industrial production and the security of the communication network as well as industrial data.

2.2 Technological System

In order to realize the three core concepts identified for 5G native deterministic network, it is necessary to run through the entire life cycle and process services of the 5G enabled digital factory. Therefore, this white paper proposes a technological system that covers 12 key technologies for the three major directions:

- **Deterministic networking:** In the network construction and interconnection stage, a 5G and industrial convergence network with deterministic coverage, deterministic isolation and precise routing is constructed through reasonable network planning. That is to say, to build a "foundation" of direct and ubiquitous infrastructure, to build a "wall" of service deterministic isolation, and to open a "window" of precise routing.
- **Deterministic communication: I**n the service provision stage, for scenarios at different levels of the industry, it provides diversified technical means such as deterministic bandwidth, high-

precision time synchronization, ultra-low latency and bounded jitter, and low-power consumption, so as to realize the provision of deterministic services at different levels of the graded hierarchy.

- **Deterministic guarantee:** In the network guarantee stage, systematic thinking is adopted to comprehensively improve the reliability and security of the 5G communication system, realizing accurate reception at the command level, continuous service at the service level, security protection at the network level, and disaster prevention and destruction resistance at the system level, so as to meet the uninterrupted demand for 7*24 services in industrial production.

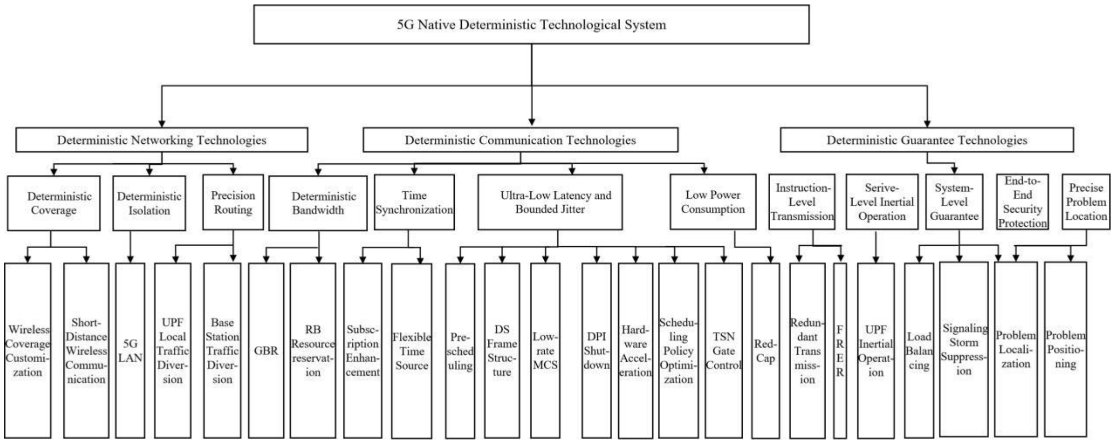

Figure 1-1 5G Native Deterministic Technological System

3 Key 5G Native Deterministic Technologies

3.1 Deterministic Networking Technologies

■ **Deterministic Coverage**

Robust coverage is a fundamental requirement for the integration of 5G into industrial production. In the dynamic environment of flexible manufacturing, it is crucial to meet the deterministic coverage capability, allowing devices to connect from any location. Industrial environments are diverse and complex, with frequent transitions between indoor and outdoor settings, irregular obstructions such as pipelines and goods. The key focus is on addressing large-scale continuous coverage across the entire area and fine-grained blind spot enhancement.

The native deterministic coverage of 5G can be achieved through two methods: wireless coverage customization and short-distance wireless communication. For large-scale coverage across the entire industrial factory and high uplink requirements, deterministic coverage can be ensured by adjusting wireless configurations, redundant coverage with pRRU, and cross-linking with RHUB, based on wireless network planning and the actual environment. For fine-grained blind spot enhancement, a 5G+SparkLink fusion communication approach can be employed. We utilize SparkLink technology's advanced frame structure, Polar/RS channel coding and decoding, to provide point-to-point wireless communication for industrial control terminals within a small area (usually less than 100 meters). By doing this, the overall system's reliability, precise synchronization, concurrency, and resistance to sudden interference have been enhanced.

■ **Deterministic Isolation**

Industrial networks are typically divided into IT network domains and OT network domains. OT networks can be further segmented into independent subnets based on different service lines to ensure mutual isolation between different services, effectively preventing attacks, and ensuring secure data exchange between networks. For example, in traditional manufacturing enterprises, most industrial equipment operates at the network layer 2, connected to the OT network domain through wired means. The IT network domain, responsible for enterprise operations and management, is usually an IP-based network that does not support layer 2 Ethernet protocol stack and is naturally isolated from the OT network domain.

When 5G networks serve interconnection in industrial networks, they have the advantage of direct connection and simplified networking. However, it is necessary to use appropriate technical means to meet the isolation requirements of different industrial network domains. The native evolution of 5G networks supports 5G-LAN technology, which can organize terminals with different communication requirements and service logic into the same LAN by dividing 5G VN groups, achieving broadcast, multicast group communication within VN groups, and mutual isolation between VN groups.

We have innovatively designed 5G-LAN error tolerance and streamlined group management mechanisms, reducing resource consumption of network slices and DNN while further enhancing network reliability and management convenience.

- **Precision Routing**

With the increasing demand for flexibility in production lines, the links between devices are no longer fixed. Production lines can be customized, and communication nodes can be dynamically updated. In addition, the increasing demand for intelligence in production lines requires more frequent interaction between OT networks and IT networks. Therefore, 5G networks need real-time and flexible capabilities for service flow precision routing.

Precision routing can be achieved through UPF's local traffic classifier and base station's traffic classifier technologies. UPF's local traffic classifier is typically implemented by sinking UPF to locally unload traffic and forwarding user plane data to the edge cloud or enterprise intranet for nearby processing. This keeps data in the industrial factory and can enable UPF to build an integrated platform for edge computing services. Base station's traffic classifier is a beneficial complement to UPF's local traffic classifier, providing a low-cost solution to meet the security isolation requirements of data not leaving the premises, particularly suitable for small and medium-sized factory where sinking UPF may be difficult.

Building on this foundation, we has innovatively designed a seamless roaming solution for multi-park interconnection scenarios, allowing terminal devices routing and roaming across different parks without any modifications.

3.2 Deterministic Communication Technologies

- **Deterministic Bandwidth**

Industrial production processes are complex, and there are significant differences in service models, requiring networks to have tiered deterministic bandwidth assurance capabilities. For video surveillance and visual quality inspection services, it is necessary to ensure transmission quality and prevent video buffering. For remote work and video conference, the quality and smoothness of video calls must be met. For control-oriented tasks in the core of production, the priority should be given to ensuring the bandwidth for control commands and data.

To meet the differentiated bandwidth guarantee requirements for different services, we comprehensively utilizes technologies such as GBR, RB resource reservation, GBR+RB resource reservation, etc., to finely prioritize network scheduling. This enables the provision of tiered deterministic bandwidth guarantee capabilities, achieving differentiated bandwidth services for critical businesses and meeting multi-dimensional and various demands of the industry.

Table 3-1 Tiered Deterministic Bandwidth Assurance System

Assurance Level	Assurance Technology	Assurance Effect	Application Scenario

Level 1	GBR	Provides minimum rate guarantee for a single user.	Special scenarios where a single user has minimum rate guarantee requirements.
Level 2	RB Resource Reservation	1. Provides deterministic resource guarantee for a group of users without guaranteeing the rate for a single user. 2. Provides certain isolation, unaffected by other services and network congestion.	Special scenarios where a specific group of users has high requirements for isolation, bandwidth, etc.
Level 3	GBR+RB Resource Reservation	1. In the presence of a large number of GBR users, provides minimum rate guarantee for specific GBR users. 2. Provides isolation through resource reservation, shielding the impact of other services. Besides, provides the highest tier guarantee of minimum rate through GBR.	Special scenarios with a large number of GBR users, requiring isolation and bandwidth guarantee for specific GBR users.

■ **High-Precision Time Synchronization**

High-precision time synchronization is crucial for ensuring the consistency of industrial control task scheduling and is widely used in core industrial production processes such as motion control, fine control, and feedback control. Service transmissions for synchronous motion control have absolute time requirements to ensure simultaneous execution of control commands on different devices. Fine control and feedback control require clock synchronization combined with flow scheduling to ensure service transmission.

5G base stations obtain nanosecond-level timing from sources such as Beidou/GPS satellites， and provide timing to user equipment (UE) through the SIB9 protocol, timing is also provided to User Plane Function (UPF) through the Precision Time Protocol (PTP) transport network. This achieves sub-microsecond-level high-precision time synchronization between UE, base stations, and UPF. To support timing for industrial applications and the transmission of clock source information, 5G promotes support for protocols such as B-Code, IEEE 1588V2, IEEE 802.1AS, as well as various clock synchronization modes such as unidirectional, bidirectional, and transparent, to meet diverse requirements for time synchronization in different industrial networking.

We have innovatively proposed technical solutions such as enhanced information subscriptions and flexible clock source selection, which have been written in 3GPP for ensuring extreme timing accuracy.

■ **Ultra-Low Latency and Bounded Jitter**

Latency and jitter are crucial factors affecting industrial core production control. Industrial control tasks have strict timing requirements for command sending and reception. If a certain number of delayed command packets exceed the threshold, it can lead to a service outage.

To enhance the ultra-low latency and bounded jitter performance of the 5G network, we have implemented technical enhancements and performance optimizations at each stage of wireless, transmission, and core networks. This achieves millisecond-level ultimate latency assurance and microsecond-level jitter control across the entire 5G end-to-end network. On the wireless side, innovative mechanisms such as pre-scheduling, Mini-Slot, DS frame structure, slot repetition, and low-rate MCS are used to reduce waiting and data transmission latency. Network and business cross-layer, cross-domain perception and negotiation are achieved through network-business coordination, ensuring bounded latency jitter and precise and efficient use of air interface resources. In the transmission network, MTN hard channel isolation is used to reduce device forwarding latency, and in the core network, methods such as DPI shutdown, hardware acceleration, scheduling strategy optimization, core binding RT-PATCH, and TSN precise gate control are employed to reduce user-plane processing latency.

- **Low Power Consumption**

The high cost and high power consumption resulting from the high performance of 5G terminals pose significant challenges for enabling smart factories with 5G. To facilitate the rapid expansion and extensive application of 5G in the industry, we are actively promoting industry-supported RedCap technology. Through techniques such as initial exclusive BWP, low-cost measurement, terminal identification, and access control, RedCap technology reduces the power consumption and costs of terminals and networks. Compared to 5G eMBB, RedCap technology reduces terminal complexity by 60%, lowers terminal power consumption by 20%, and has a price comparable to 4G for the same scale. Compared to 4G, it offers advantages such as large capacity, superior coverage, low latency, strong isolation, and optimal adaptation. The system capacity can be increased by 18 times, latency can be reduced by 70%, effectively meeting the requirements for large-scale applications in smart factories.

3.3 Deterministic Guarantee Technologies

- **Accurate Transmission and Reception**

The loss, disorder, or delayed delivery of industrial control system instructions beyond a certain threshold can result in the shutdown of the entire system, even the entire production line. This can lead to safety incidents in critical scenarios such as remote mining underground, steel rolling line control, where precise transmission and reception of control instructions are crucial.

To enhance the accuracy of industrial control instruction transmission and reception, we continuously innovate and strengthen the 5G end-to-end network forwarding mechanism. On the wireless side, technologies such as redundancy transmission in physical layer, small-load DCI formats, low-rate CQI/MCS tables, Multi-TRP, etc., are employed to improve the fault tolerance of modulation and demodulation. In addition, PDCP replication technology is introduced at the PDCP layer to increase data redundancy, thereby improving the reliability of air interface data transmission. On the core network side and terminal side, cooperation is utilized, employing the FRER protocol for redundant packet transmission through dual links to achieve dual reception. This further enhances the stability of industrial communication.

- **Inertial Operation**

Service processes in the core production stages of industry often require uninterrupted 7*24 operations, demanding high availability from the communication network. High availability means the network should exhibit inertial operation, providing the ability to continue normal services even in various abnormal situations.

For smart factories, 5G networks are typically deployed using a dedicated public network approach, which involves the 5G core network control plane deployed in the operator's region and the user plane deployed in the factory. The control plane region and the factory are generally located at a considerable distance from each other. Any transmission faults between the factory and the larger region can directly lead to the disconnection of wireless base stations and UPF in the factory, causing a complete interruption of all services that is difficult to restore.

To enhance the availability of 5G, we innovatively introduced inertial operation technology, providing emergency access services for factory services. In the event of a link failure between the factory and the 5GC network, the technology ensures that factory operations are not affected by the fault. For services already active in the network, an inertial operation mechanism is employed to continue service provision, ensuring that users stay connected, and services remain uninterrupted. For newly initiated services, the control plane of the 5G network in the factory smoothly transitions from the main 5GC to the factory site, enabling emergency control functions embedded in the edge-deployed UPF. Once the link fault with the larger region network is resolved, relevant service management is automatically handed back to the 5GC network, achieving seamless reversion.

■ **System-Level Restoration**

In contrast to consumer-oriented internet applications, industries primarily focused on industrial internet demand very high disaster recovery capabilities of the 5G network. Business interruptions caused by network failures could result in substantial losses or even result in safety incidents.

As the types and scales of applications empowered by 5G in smart factory settings continue to increase, there is a growing need to establish system-level disaster recovery capabilities for 5G networks. We have proposed a five-dimensional assurance approach from the link layer to the network system layer, enhancing the reliability and robustness of the 5G network on a global scale.

✓ Link Layer: Mechanisms such as link detection and dual-path protection are implemented to detect anomalies in real-time and enable switch links in real-time.

✓ Virtualization Layer: Mechanisms like cross-layer linkage reliability coordination and single-arm BFD with millisecond-level fault detection to enhance the network's ability to handle infrastructure failures.

✓ Functional Module Layer: Techniques such as capability gray upgrade, UPF hot backup, BBU dual-core assurance, and RRU redundant coverage enhance the robustness of network element services.

- ✓ Network Element Layer: Technologies such as signaling storm suppression, hot migration under schedule, and dual-active plane for disaster recovery enhance network element resilience and rapid recovery capabilities.

- ✓ Network System Layer: Technologies like load sharing and system bypass are introduced to avoid systemic failures caused by single network element failure.

- ■ **End-to-End Security Protection**

The application of 5G technology results in the physical overlap of industrial production networks and communication networks in the working environment. Therefore, it is essential to strengthen the security protection capabilities of devices in complex production environments. In terms of data link, the overlap of control, data acquisition, and IT communication data is increasingly prominent, involving the intertwining of OT control devices such as SCADA and production field devices like PLC. Thus, the ability to encrypt and protect data needs improvement. The industrial control domain also faces overlapping communication paths of IT and OT control protocols, control software, etc. Therefore, the security control capabilities of devices in terms of decentralization and domain separation need strengthening. Additionally, the open nature of 5G networks introduces security risks to industrial production applications, demanding higher security reinforcement capabilities for applications.

For the security requirements of smart factories, we have proposed a five-fold determined security protection system, establishing end-to-end security measures covering devices, networks, data, control, and applications:

- ✓ Device Security: Ensures the security protection and integrity of network devices and manages product security throughout the life cycle.

- ✓ Control Security: Includes intrusion prevention measures, identity authentication control, and assurance of the integrity of control protocols.

- ✓ Network Security: Provides equipment subdivision, firewall protection and other mechanisms to meet communication performance requirements within the 5G domain and between the 5G and industrial network domains.

- ✓ Application Security: Provides capabilities such as identity authentication, access control, and interface security protection.

- ✓ Data Security: Provides encryption protection, secure transmission assurance, and comprehensive information system security auditing.

- ■ **Precise Problem Localization**

In actual industrial production processes, fluctuations in end-to-end links such as terminals, networks, and applications can impact business operations. Precise localization of network issues and rapid recovery are crucial when faults occur. We introduces the "Localization-Positioning" abnormal latency localization system, facilitating rapid identification of the root cause of network issues and aiding in the quick recovery of network faults.

In the localization phase, two main segmentation delay measurement schemes, namely 5G network external delay localization scheme and 5G network internal delay localization scheme, are employed to gradually locate delay problem network elements. The 5G network external delay localization scheme primarily uses technologies such as SDK/probe to identify whether the delay problem node is in the 5G network or the business network. The 5G network internal delay localization scheme, utilizing QoS Monitoring technology, measures and records segment delays such as 5G UE-UPF, 5G UE-5G gNB, and 5G gNB-UPF. This localization method identifies whether the delay problem is caused by the wireless network or the transmission network, further pinpointing the problem node. Building upon this, an innovative air interface timestamp scheme is introduced, adding timestamps to data packets to enable network elements to read time information for more accurate delay statistics.

In the positioning phase, we have innovatively proposed a second-level localization indicator system and localization scheme based on periodic state statistics and key information reporting triggered by abnormal conditions. Four major categories with 36 specific air interface latency problem root causes and corresponding solutions are provided, facilitating rapid localization and resolution of issues. This system efficiently forms a closed-loop analysis and handling capability for problems, shortening fault recovery time and ensuring high deterministic network performance for the industry.

4 Conclusion

To enhance the deterministic service capabilities of 5G network and promote further integration with smart manufacturing, we hope to collaborate with partners closely, drive progress mutually, strengthen technological breakthroughs, break down cross-industry barriers, promote application innovation and contribute jointly to new industrialization.

1. Emphasizing Technological Breakthroughs and Independent Innovation:
The fields of CT (Communication Technology), IT (Information Technology), and OT (Operational Technology) are evolving rapidly. The automation, informatization and intelligent technologies are continuously developing. 5G intrinsic deterministic technology will consistently address the application demands of smart manufacturing. While maintaining current solution's stability, we will continuously incorporate new standards and solutions. We are committed to high-level innovation to comprehensively drive the development of smart manufacturing, supporting the evolution of the new industrial landscape with higher quality requirements and strategic initiative.

2. Breaking Cross-Industry Barriers and Focusing on Convergent Innovation and Collaborative Development:
The collaboration between industrial manufacturing and communication networks is accelerating. Through means such as resource sharing and complementary strengths, we aim to break down technological barriers. We need a shared vision for the integration of 5G into production and the transformation of production. Encouraging innovation and collaboration across different domains, establishing unified standards, and promoting the deep integration of innovation and industrial chains will expedite the structured upgrading of industries.

3. Advancing Application Innovation and Prioritizing Demand-led Initiatives and Benchmark Demonstrations:
Strengthening the traction of demand and scenario, we will implement the multi-level application of 5G intrinsic deterministic technology in factories, workshops, and production lines. Through practical applications, we aim to drive the standardization of 5G intrinsic determinism, facilitate the transformation of achievements, construct new exemplary scenarios, establish benchmark projects, and accelerate the rapid dissemination and large-scale replication of solutions and application experiences. This approach aims to stimulate the industry's dynamics and vitality, foster the development of the real economy, and drive the optimization and upgrading of industries.