GTI Vertical Models and Enterprise Network Requirements White Paper

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WHITE PAPER

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1 Introduction

1.1 Background

With the advent of 5G technologies, mobile networks are further applied in various industries and become one of the foundations for digital transformation and innovation in industries. 5G will further change the society. Compared with the previous-generation 4G network, 5G has not only higher rates, but also new capabilities such as low latency and high reliability to meet industry application requirements. 5G enables applications related to life and production security, such as smart factory, smart campus, autonomous driving, and remote surgery using robot arms. In addition, 5G networks feature large capacity. By combining edge computing, big data, and cloud computing services, 5G networks cannot only connect people, but also things. In this way, 5G networks can be used in scenarios that are difficult to be digitalized before, the number of connections will increase to tens of billions, and the data traffic generated every day will increase exponentially. Information technologies, represented by 5G, will carry out all-round digital reconstruction for all industries in the society, facilitating economic and social digital transformation.

One purpose of designing the 5G network is to enable vertical industries. Different from services provided by operators to traditional users, vertical industry services have differentiated industry characteristics, as well as complex and diversified requirements in specific application scenarios. Operators must understand industry characteristics and explore and discover industry requirements. Therefore, GTI and its partners have sorted out typical application scenarios and key technical requirements of key cases for networks in major industries, such as manufacturing, power grid, transportation, mining, port, warehousing, healthcare, media, education, public safety, and cloud office, extract basic common requirements and for better understanding industry characteristics. With these technical supports, operators can provide services to industrial customers using enterprise networks with different architectures, thereby fully meeting differentiated service quality requirements of different industries for high-speed and low-latency networks, security, isolation, and data privacy and improving the operation efficiency and intelligent decision-making level of traditional vertical industries.

1.2 Objectives

Different industries have different requirements for communications systems, and application scenarios of communications technologies also vary greatly. This document describes the requirements and application scenarios of 5G networks in major industries, summarizes and analyzes common scenarios and requirements, and provides a set of basic capabilities required for 5G networks to meet industry requirements. This document also analyzes and provides suggestions on the characteristics and advantages of enterprise networks and services provided by operators to industrial customers, from the perspective of operators.

This document is composed by participants in the Vertical Models and Requirements Task of the GTI Enterprise Network Solutions (ENS) Program. Some of the content in this document is derived from public content released by some public organizations, including 3GPP and 5G Alliance for Connected Industries and Automation (5G-ACIA), and some is composed by Global TD-LTE Initiative (GTI) participating organizations. The industry requirements are changing. This document will be updated continuously to summarize the industry communication requirements accurately and objectively.

1.3 Terminology

Term	Description
5G	5th generation mobile communication systems
3GPP	3rd Generation Partnership Project
4G/LTE	4th Generation of cellular technology/Long Term Evolution
5G-ACIA	5G Alliance for Connected Industries and Automation
AGV	automated guided vehicle
BSR	buffer status report
CA	carrier aggregation
IIoT	Industrial Internet of Things
IGV	Intelligent Guided Vehicle
IoT	Internet of Things
MEC	Mobile Edge Computing
MNO	Mobile Network Operator
MNVO	Mobile Network Virtual Operator
QoS	Quality of Service
RF	Radio Frequency
SLA	Service Level Agreement
V2X	Vehicle-to-everything (V2X) is based on the vehicle intranet, inter-vehicle network, and vehicle-mounted mobile Internet. It implements wireless communication and information exchange between vehicles and between vehicles and the Internet based on agreed communication protocols and data exchange standards to implement intelligent transportation management and control. It is an extension of the IoT technology in the intelligent transportation system field.
V2V	Vehicle-to-vehicle (V2V) enables interconnection between vehicles, between vehicles and road infrastructure, between vehicles and pedestrians, between

Term	Description
	vehicles and the cloud, and between vehicles and homes through vehicle-mounted self-networking and interconnection between multiple heterogeneous networks.
V2I	Vehicle to Infrastructure
V2P	Vehicle to Pedestrians
V2C	Vehicle to Cloud

2 Key Industry Segments

2.1 Manufacturing

The following content about 5G in manufacturing is extracted from public documents including:

- 5G-ACIA White Paper_5G for Automation in Industry
- 3GPP TR 22.804: Study on Communication for Automation in Vertical Domains
- Ericsson Technology Review - 5G AND SMART MANUFACTURING

And with views and additional contents from GTI members.

The main 3GPP reports related to industrial use cases are as follows:

- Study on Communication for Automation in Vertical Domains (FS_CAV) in Technical Report (TR) 22.804
- Feasibility Study on Business Role Models for Network Slicing (FS_BMNS) in TR 22.830
- Feasibility Study on LAN Support in 5G (FS_5GLAN) in TR 22.821

The TRs were primarily written by 3GPP to understand and summarize the high-level communication needs of the industrial community – which have since been described in the following normative and binding technical specifications (TS):

- Service requirements for cyber-physical control applications in vertical domains, TS 22.104
- Service requirements for the 5G system, TS 22.261

2.1.1 Industry Overview

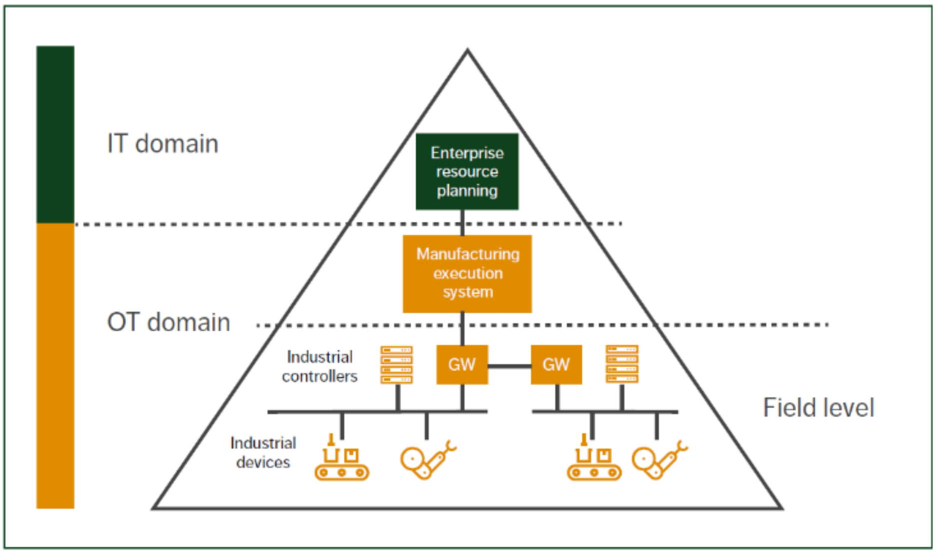
Manufacturing has been identified as one of the most promising new application areas for 5G. Mass production was optimized for producing many of the same in an efficient manner. In the 1980s, the paradigm of mass customization emerged, and the number of varieties offered to the consumer increased significantly. This process had then intensified leading to the latest paradigm, Industry 4.0, where products are highly personalized. Transforming systems previously optimized for mass production and mass customization into truly flexible production systems, where each customer can be served with their personalized version of the product, forces changes on the shop floor to account for smaller batches and more frequent changes in tasks and layout.

Industry 4.0 systems are estimated to require a high level of automation. This is achieved with industrial robots and advanced connected equipment. To enable frequent changes in tasks, robots need to be reprogrammed often to perform a new task. Commanding the robots from a cloud server is seen as a feasible alternative to bring down cost of a single robot and to enable frequent and fast reprogramming.

The goal of Industry 4.0 is to maximize efficiency by creating full transparency across all processes and assets at all times. Achieving this requires communication between goods, production systems, logistics chains, people, and processes throughout a product's complete lifecycle, spanning everything from design, ordering, manufacturing, delivery, and field maintenance to recycling and reuse. The integration of 5G in the manufacturing process has great potential to accelerate the transformation of the manufacturing industry and make smart factories more efficient and productive.

Today's state-of-the-art factories are predominantly built on a hierarchical network design that follows the industrial automation pyramid. The fourth industrial revolution will require a transition from this segmented and hierarchical network design toward a fully connected one. This transition, in combination with the introduction of 5G wireless communication technology, will provide very high flexibility in building and configuring production systems on demand.

The following figure is often referred to as the operational technology (OT) part of the manufacturing plant, comprising both the field level (industrial devices and controllers) and the manufacturing execution system. The top section is the information technology (IT) part, made up of general enterprise resource planning. For connectivity at field level, a variety of fieldbus and industrial Ethernet technologies are typically used. Ethernet and IP are well established communication protocols at higher levels (IT and the top part of OT). The OT network domain is currently dominated (> 90%) by wired technologies and is a heavily fragmented market with technologies such as PROFIBUS, PROFINET, EtherCAT, Sercos and Modbus. Currently deployed wireless solutions (which are typically wireless LAN based using unlicensed spectrum) constitute only a small fraction of the installed base; they mainly play a role for wirelessly connecting sensors where communication requirements are non-critical.



One near-term benefit of leveraging wireless connectivity in factories is the significant reduction in the number of cables used, which reduces cost, since cables are typically very expensive to install, rearrange or replace. In addition, wireless connectivity enables new use cases that cannot be implemented with wired connectivity, such as moving robots, automated guided vehicles (AGVs), and mobility tracking of products in the production process. Wireless connectivity also makes it possible to achieve greater production line layout flexibility and deploy factory equipment more easily. Newest wireless systems such as 5G target in providing ultra-reliable low latency communications (URLLC) with the intention to serve the manufacturing industry and the demanding use cases in factories. This opens a whole new application area for wireless systems.

2.1.2 Typical Scenarios

2.1.2.1 Motion Control

Motion control is one of the most challenging closed-loop control use cases in industry. A motion control system is responsible for controlling moving and/or rotating parts of machines in a clearly-defined way, for example for printing presses, machine tools and packaging equipment. A motion controller periodically sends target set points to one or several actuators (e.g. a linear actuator or a servo drive) that then perform(s) a corresponding action for one or several processes (in this instance, generally the movement or rotation of a specific component). At the same time, sensors determine the current state of the process(es) (e.g. the current position and/or rotational position of one or multiple components) and send the actual (current) values back to the motion controller in a strictly cyclical and deterministic manner.

For example, during each communication cycle, the motion controller sends updated set points to all actuators, and all sensors send their actual (current) values back to the motion controller. At present, motion control systems typically employ wired Industrial Ethernet technologies. Examples of these technologies include Profinet IRT or EtherCAT – which support cycle times of less than 50 μs. In general, motion control has the highest requirements in terms of latency and service availability. The service areas are usually comparatively limited in size, and no interaction with public networks is required.

2.1.2.2 Control-to-Control

Control-to-control (C2C) communication is between industrial controllers (e.g. programmable logic controllers or motion controllers). It is already established for a number of use cases, such as:

- Large items of equipment (e.g. printing presses), where several controllers are employed to cluster machine functions which need to communicate with each other. These controls typically need to be synchronized and exchange real-time data. In general, this use case has very stringent requirements in terms of latency, integrity, and service availability.
- Multiple individual machines performing a shared task (e.g. machines on an assembly line) and that often needs to communicate with each other, i.e. to control and coordinate the handover of components from one machine to another. Today for today's C2C communication include Industrial Ethernet standards such as PROFINET, EtherCAT, OPC UA, and other protocols – which are often based on Fast Ethernet. C2C communication is expected to increase. In particular, there is likely to be a significant rise in the number of participating controllers in any given use case and in the volume of data being exchanged.

2.1.2.3 Mobile Control Panels

Mobile control panels are crucial to interaction between people and production equipment, and to interaction between people and mobile/portable devices. These panels are mainly used for configuring, monitoring, debugging, controlling, and maintaining machines, robots, cranes or entire production lines.

In addition, (safety) control panels are typically equipped with an emergency stop button and an enabling device which an operator can activate when a dangerous situation arises in order to avoid injury to humans or damage to assets. When the emergency stop button is activated, the controlled equipment (and possibly neighboring machines) must immediately be placed in a safe, stationary position. Similarly, with a "dead man's switch", the operator must manually keep the switch in a predefined position. If the operator, for example, inadvertently releases it, the corresponding equipment must again immediately come to rest in a safe, stationary position.

Due to the critical nature of these functions, safety control panels currently usually have a wired connection to the equipment. In a 5G radio scenario, a signal must be periodically sent – and received – in order to verify that the control panel is still connected. The verification cycle time always depends on the corresponding process/equipment. For a fast-moving robot, for example, the cycles are shorter than for a slow-moving linear actuator. The service area is usually limited in size, as each mobile control panel is associated with a single, individual item of equipment.

2.1.2.4 Mobile Robots

Mobile robots and mobile platforms, such as AGVs, are employed widely in diverse use cases in industrial and intra logistics environments. A mobile robot is essentially a programmable machine capable of executing multiple operations, traveling along pre-programmed routes to perform a large variety of tasks.

A mobile robot is able, for example, to move goods, materials, and other objects, and can have a significant range of movement within a given industrial environment. Mobile robot systems are able to perceive their surroundings, i.e. they can sense and react to their environment. AGVs are a sub-group within the mobile robot category. AGVs are driverless vehicles that are steered automatically. They are employed to efficiently move goods and materials within a defined area.

Mobile robots are monitored and controlled by a guidance control system. This control system is required to transmit real-time information to avoid collisions between robots, to assign tasks, and to manage robot traffic. The mobile robots are track-guided by means of markings or wires in the floor, or guided by their own surround sensors, such as cameras or laser scanners.

Mobile robots and AGV systems must frequently interoperate with conveyor assets (cranes, lifts, conveyors, industrial trucks, etc.), and monitoring and control elements (sensors and actuators). They also need to exchange data for reporting, e.g. inventories, goods movements, and throughput, for tracking and monitoring, and for forecasting. Service areas can be very large.

2.1.2.5 Massive Wireless Sensor Networks

Sensor networks are designed to monitor the state or behavior of a particular environment. In the context of manufacturing, wireless sensor networks (WSNs) monitor processes and equipment, and the corresponding parameters. This environment is typically monitored using diverse sensor types, such as microphones, CO_2 sensors, pressure sensors, humidity sensors, and thermometers. These sensors together typically form a distributed monitoring system. The data captured in this way is leveraged to monitor diverse parameters, for example to detect anomalies.

WSNs are highly dynamic in nature, changing significantly over time in terms of the type, number, and position of sensors deployed. The position of sensors may be constrained by the available wireless sensor network hardware. Given that sensors are typically relatively simple devices, the corresponding functionality usually needs to be modeled in a centralized computing infrastructure. In certain instances, functionality may be supported within or shared with the sensor network.

In many scenarios, it is necessary to lay expensive cables to supply electrical power to sensors. Alternatively, the sensors are battery powered. In this latter instance, batteries must be capable of reliably supporting sensor operation, including the communication module, for extended periods, even years.

2.1.2.6 Remote Access and Maintenance

Remote access is the ability to establish contact and communicate with a device from a distant location, and this is often the means for performing remote maintenance. Although industrial networks are isolated from the internet, remote access is already possible, i.e. via peer-to-peer communication links between just two devices, field buses with multiple devices and controllers, LANs or WLANs. However, this requires gateway functionality.

Remote access to device data requires mapping of data formats, addresses, coding, units, and status at each transition in the automation pyramid. This can entail significant engineering effort. Moreover, data mapping implemented in the gateway(s) is relatively static.

An example use case is the inventorization of devices and periodic extraction of configuration data, event logs, version data, and predictive maintenance information. Generically, this is known as asset management. Tools for collecting and displaying data from multiple connected devices are called asset monitors.

A system of this type might operate autonomously (a set of configured periodic checks) or interact with a user ("show me the status of this device"). The remote diagnostics system might be operated by, for instance, a manufacturer for devices deployed in its factory. Or the system might be operated by the device vendor as a service for its customers.

2.1.2.7 Augmented Reality

Augmented reality (AR) is a technology that allows a computer-generated image to be superimposed on a user's view of the physical world, providing a composite view. People will continue to play an important and substantial role in production. But factory-floor workers, for instance, need effective support, i.e. assistance that allows them to rapidly become familiar with and adept at new tasks, and that ensures they can work in an efficient, productive and ergonomic manner. In this respect, head-mounted AR devices with see-through displays are especially attractive since they enable maximum ergonomics, flexibility and mobility, leaving the hands of workers free. However, if AR devices are worn for prolonged periods (e.g. an entire work shift), they need to be lightweight and highly energy-efficient. One way to achieve this is to offload complex processing tasks to the network (e.g. an edge cloud).

AR is expected to play a crucial role in the following use cases:

- Monitoring of processes and production flows
- Delivery of step-by-step instructions for specific tasks, for example for manual assembly
- Ad-hoc support from a remote expert, for example for maintenance or service tasks

2.1.2.8 Closed-loop Process Control

With closed-loop process control, multiple sensors are installed in a production facility, and each sensor performs continuous measurements. The sensor-captured data is transferred to a controller which then decides whether and how to operate actuators. Latency and determinism are crucial.

In closed-loop process control, sensors distributed throughout the production facility continuously measure typical process parameters such as pressure, temperature, flow rate, and pH value. Harnessing the sensor-captured data, the controllers operate actuators such as valves, pumps, and heaters/coolers to manage the production process in an optimized, safe, and reliable way.

In these scenarios, determinism and availability are essential as these processes run continuously over extended periods.

2.1.2.9 Process Monitoring

With process monitoring, multiple sensors are installed in a production facility to grant visibility into processes or environmental conditions, or into inventories. Data is transmitted to displays for observation and/or to databases for logging and trend monitoring. The communication service must support high sensor density, and provide low latency and high service availability. In addition, any battery-driven sensors, including the communication module, must be highly energy-efficient.

2.1.2.10 Plant Asset Management

To keep a plant up and running, it is essential that assets such as pumps, valves, heaters, instruments, etc., are well maintained. Timely recognition of any degradation, and ongoing self-diagnosis, are used to support and plan maintenance work. This calls for sensors that provide visibility into processes or environmental conditions. Remote software updates modify and enhance components in line with changing conditions and advances in technology. In plant asset use cases, positioning is an essential requirement. Latency and service availability are also requirements, but they are less critical than positioning.

2.1.3 Key Technical Requirements

The manufacturing industry has specific 5G requirements that differ significantly from public mobile broadband (MBB) services. These include:

- URLLC

URLLC with ultra-high availability and resilience, which can only be satisfied with a dedicated local network deployment using licensed spectrum. For critical applications, there must be guarantees against uncontrolled interference, which implies that licensed spectrum is necessary. Unlicensed technologies such as Wi-Fi and MulteFire cannot guarantee bounded low latency with high reliability as the load increases. This is due to the use of listen-before-talk back-off, which does not perform well during uncontrolled interference.

- Industrial Ethernet support

The ability to integrate with the existing industrial Ethernet LAN and existing industrial nodes and functions is another fundamental requirement.

The introduction of 5G on the factory shop floor will happen in steps. When 5G is added to existing production systems, the various parts of the system will be moved to 5G connectivity at different stages, depending on the evolution plan of the production system and where the highest benefits of wireless 5G communication can be obtained. Over time, more parts of the shop floor can be migrated to 5G, in part due to the introduction of new capabilities in future 5G releases. Even in greenfield industrial deployments, not all communication will be based on 5G. The need for wireless connectivity may not be prominent for some subsystems, while others may require performance levels (isochronous sub-millisecond latency, for example) that are not currently addressed by 5G.

Consequently, a local industrial 5G deployment will coexist and require integration with wired industrial LANs. To this end, the transport of Ethernet traffic is required. As part of the ongoing industrial transformation, the wired communication segments of industrial networks are expected to evolve toward a common open standard: Ethernet with TSN support. Therefore, a 5G system needs to be able to integrate with a TSN-based industrial Ethernet, for which 3GPP has defined different study and work items in Release 16 of the 5G standards.

TSN is an extension of the IEEE 802.3 Ethernet and is standardized within the TSN task group in IEEE 802.1. A profile for TSN in industrial automation is being developed by the IEC/IEEE 60802 joint project. TSN includes the means to provide deterministic bounded latency without congestion losses for prioritized traffic on an Ethernet network that also transports traffic of lower priority.

TSN features include priority queuing with resource allocation mechanisms, time synchronization between network nodes and reliability mechanisms via redundant traffic flows. 5G enhancements include support of redundant transmission paths, which can be combined with the TSN feature frame replication and elimination for reliability (FRER) that is standardized in IEEE 802.1CB. One of the resource allocation features of TSN for bounding the latency for periodic control traffic is time-aware scheduling (standardized in IEEE 802.1Qbv), for which transmission queues are time-gated in every switch on the data path to create a protected connection.

This requires all Ethernet switches to be time-synchronized according to IEEE P802.1AS-Rev. Features that are being developed in 5G standardization to support time-aware transmission across a mixed TSN-5G network are to time-align the 5G system with the TSN network and provide 5G transmission with deterministic latency.

- Local data, local management, local survivability

On top of URLLC performance and integration with industrial Ethernet networks, many manufacturers also require full control (that is, independent of external parties) of their critical OT domain connectivity in order to fulfill system availability targets. Full control can be expressed as requirements on keeping things local: local data – the ability to keep production related data locally within the factory premises for security and trust reasons. Local management – the ability to monitor and manage the connectivity solution locally. Local survivability – the ability to guarantee the availability of the connectivity solution independently of external factors (for example, shop-floor connectivity must continue uninterrupted even when connectivity to the manufacturing plant is down).

- Local management and real time monitoring

An easy-to-use local management system is required to monitor and manage the end-to-end connectivity, including local network infrastructure and connected devices. The local management use cases include both software management and fault, performance and configuration management. The management system also needs to integrate with other elements of the OT systems and the industry IT systems. A low-latency cloud infrastructure is required both for 5G network functions and industrial applications, and all pieces need to be connected using an integrated local transport infrastructure.

- Positioning

One 5G feature that could have significant importance for manufacturing use cases is positioning. For 3GPP Release 16, the objective is to achieve indoor positioning accuracies below 3 m, but NR deployed in a factory environment has the technology potential to support much more precise positioning.

- Time synchronization between devices

In 3GPP Release 16, a new requirement is being introduced, whereby the 5G system will be able to synchronize devices to a master clock of one or more time domains. One reason for this is that several industrial applications require time-synchronized actions of multiple machines. This can be a collaborative common task performed by multiple industry robots, where the control of the different robots needs to be coordinated in time. NR in Release 16 will supply the capability for a base station to provide precise timing references to devices down to microsecond precision. It will also make it possible to relate this time reference to the reference clocks of one or more time domains used in an industrial system. The time alignment of the 5G system with the external industrial LAN is also a basis to enable TSN time-scheduled communication over a combined 5G-TSN network.

- Security

Security in cellular networks has matured with every generation to enable confidential communication services, user privacy, authentication of users for network access and accountability, and authentication of the network so users know they are connected to a legitimate network. To address new use cases and the evolving threat landscape, 5G includes new security features that benefit industrial deployments. Examples include improved confidentiality of user-plane data achieved by both the encryption and integrity protection of data to prevent eavesdropping and modification as it passes through the 5G system.

Item	Motion control Control to control Mobile control panels Process control	Mobile robots (AGV, etc.)	Wireless sensor network Process monitoring Asset management	Remote access and maintenance	AR Computer vision
Current Connectivity Technology Used	Cable	Wi-Fi	Wi-Fi, LTE	Cable, Wi-Fi, LTE	Wi-Fi
Form of Device	Gateway Module	Gateway Module	Module	Gateway Module	Gateway Module
Pain Point	Expensive cable network deployment and maintenance, no flexibility	Challenge when large number of devices, and when devices move in a large area	Wi-Fi is incapable of supporting massive and secured connectivity	Quality, security, availability of connectivity	Bandwidth limitation, connection quality, user experience
Protocol	Profinet, Ethernet/IP, EtherCAT, Modbus TCP, TSN, etc.	TCP/IP	HART, MQTT, TCP/IP etc.	TCP/IP	TCP/IP
Capacity Requirement	> 50 in 1 workshop	> 100 in 1 workshop	> 100 in 1 workshop	> 10 in 1 workshop	> 50 in 1 workshop
Coverage Requirement	Indoor	Mainly indoor, also outdoor	Mainly indoor, also outdoor	Mainly indoor, also outdoor	Mainly indoor, also outdoor
Mobility Requirement	Slow or not moving	Around 20 to 40 m/s	Depends Normally slow or not moving	Depends Normally slow or not moving	< 5 m/s
Latency Requirement	0.5–20 ms	10–100 ms	50 ms	50 ms	< 20 ms

Bandwidth Requirement	Small bandwidth for control only, normally less than 200 kbps	Small bandwidth needed, normally less than 500 kbps. When video needed from AGV, additional bandwidth needed (10–50 Mbps)	Small bandwidth needed, normally less than 2 Mbps	Flexible bandwidth, normally less than 10 Mbps	Flexible bandwidth (normally less than 100 Mbps), depending on video quality
Traffic Model	Routine for use cases like running motion control and synchronization between nodes Trigger for use cases like remote control when needed.	Trigger for use cases like task management and routine for use cases like status monitoring	Normally routine, sometimes trigger when needed, depending on the device type and use case	Routine for use cases like status monitoring. Trigger for situations like remote access.	Trigger for use cases like AR or routine for use cases like quality inspection using computer vision
Positioning Requirement	No	Yes Mainly indoor, but also outdoor	Sometimes yes Mainly indoor, but also outdoor	Sometimes yes Mainly indoor, but also outdoor	Sometimes yes Mainly indoor, but also outdoor
Voice Requirement	No	No	No	Sometimes yes	Sometimes yes
Reliability Requirement	99.9999%	More than 99.9%	99.999%	99.9%	99.9%
Security Requirement	Anti-attack, strong authentication, anti-interference, data privacy, self-survivability, stability and reliability, etc.				
Deployment Model Requirement	On-premise enterprise network or dedicated UPF	On-premise enterprise network or dedicated UPF	On-premise enterprise network, dedicated UPF, or public network, depending on application scenarios and requirements		
Business Model Requirement	Customers need to own or control the network system assets when local systems are deployed. Strong SLA is needed for enterprise network services or public network services.				

	System integration services and managed operation services may be required.

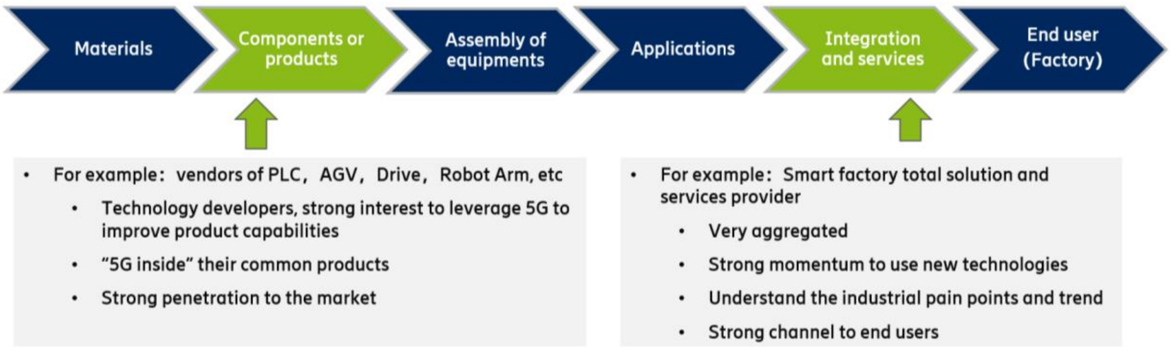
2.1.4 Industrial Value Chain Analysis

The industrial value chain of manufacturing involves materials, components, and products, assembly, application, integration and service, and end users (factories).

Among these aspects, components, and products are more universal and feature converged industry chains. Related vendors have a strong innovation awareness and they are the main target partners of 5G. Through cooperation with these partners, 5G can be built in or compatible with related modules and products in the manufacturing industry, achieving the goal of 5G implementation in the manufacturing industry.

In addition, integration and service providers are the main driving force for factory transformation. They have a first-line understanding of factories and manufacturing, and understand manufacturing pain points and the specific problems that 5G can resolve. They are also the channels for selling 5G products and services to final factory customers. These enterprises are also the key objects of 5G cooperation.

End users are beneficiaries of 5G products and services. Different types of manufacturing customers have different characteristics. At the initial stage of 5G deployment, cooperation with customers with large production scale and high automation requirements is recommended.



2.2 Energy/Grid

2.2.1 Industry Overview

The power communication network is the "nerve system" of a smart grid. It can intelligently control and monitor power devices through communication technologies. In this way, it can intelligently detect device/line faults, capacity restrictions, and power interruption/recovery, achieve fast power supply, and reduce the impact of power interruption caused by various reasons.

Currently, a smart grid adopts wired and wireless communication. The wired communication refers to optical fiber communication. Currently, new energy modes such as clean energy and charging piles are emerging rapidly. They are widely used and all use optical fiber communication networks, resulting in high construction costs and long construction periods. However, the existing wireless communications network (including Wi-Fi, 2G, 3G, 4G, and satellite communications) cannot meet the power production and control requirements due to its insufficiency in transmission bandwidth, security, latency, and provision of differentiated services.

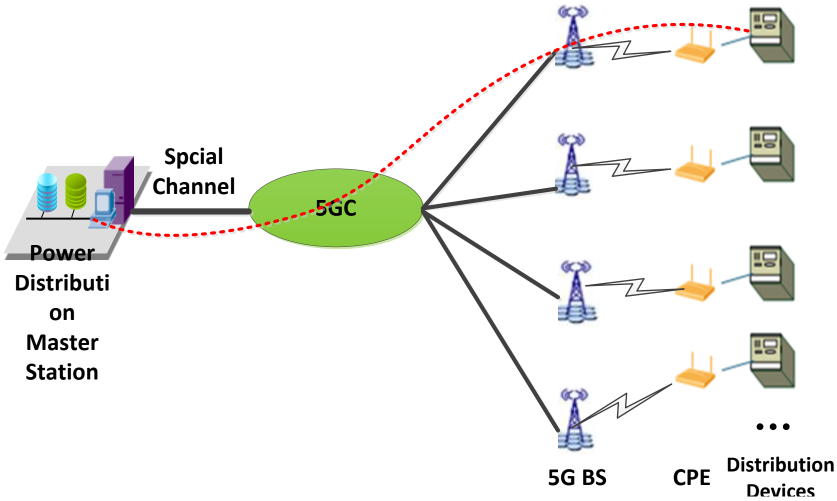
As the most advanced wireless communication technology, 5G can provide enhanced mobile broadband (eMBB), URLLC, and massive machine-type communications (mMTC) services. Operators can customize and deploy enterprise networks based on the requirements of electric power enterprises and network slicing mode to implement dedicated use of the public network. In this way, services are physically or logically isolated from other customers' services and automatic O&M is implemented, meeting the communication requirements of power generation, transmission, transformation, distribution, and consumption on the power grid.

2.2.2 Typical Scenarios

Based on the requirements of the electric power industry for wireless communication, the 5G network can be used in the following electric power service scenarios:

(1) Three remote services of the power distribution network

With the highly reliable transmission feature of 5G, data and command interaction in the power distribution phase can be quickly completed. The wide coverage of 5G solves the problem of massive terminals connecting to the master and slave sites.

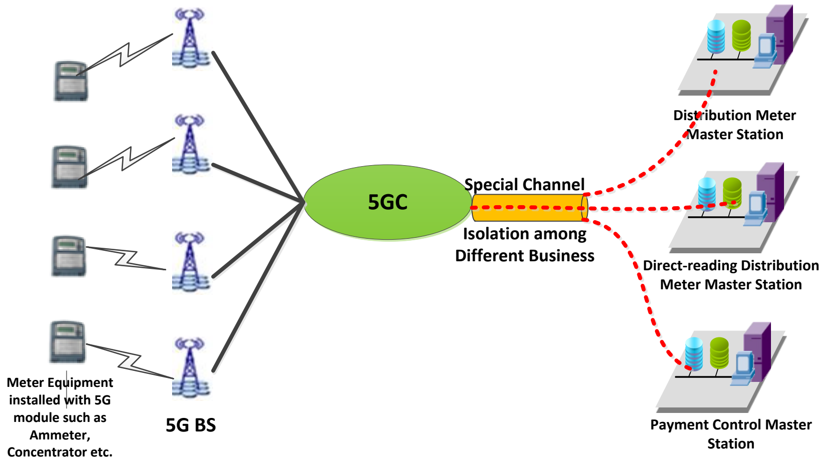


This scenario is mainly used for routine detection and power supply reliability of the power distribution network. The three remote services of the power distribution network include remote communication (device status monitoring), telemetry (measurement value of the measured variable), and remote control (command for changing the running device status). Various smart distribution XTUs (including DTUs, FTUs, and TTUs) in the power grid communicate with the master station through the 5G network. The 5G network transmits the remote communication status and remote measurement data in the uplink and transmits remote control instructions in the downlink.

(2) Advanced metering

Currently, the power grid uses the low-voltage centralized metering mode to collect power consumption information. The collection frequency is low and the data volume is small. To effectively implement peak-to-valley power consumption shaving, implement the bidirectional interactive marketing mode, and support flexible tiered pricing, the measurement interval will be shortened from hours to minutes in the future, and the data volume of each terminal will reach Mbps, achieving quasi-real-time data feedback. Driven by industry technologies, direct collection from smart meters and smart sockets will be gradually promoted in the future. The number of connected terminals will increase by 50 to 100 times compared with the current number.

Advanced metering refers to the communication and transmission of electricity consumption data through 5G networks by various smart electric power terminals.



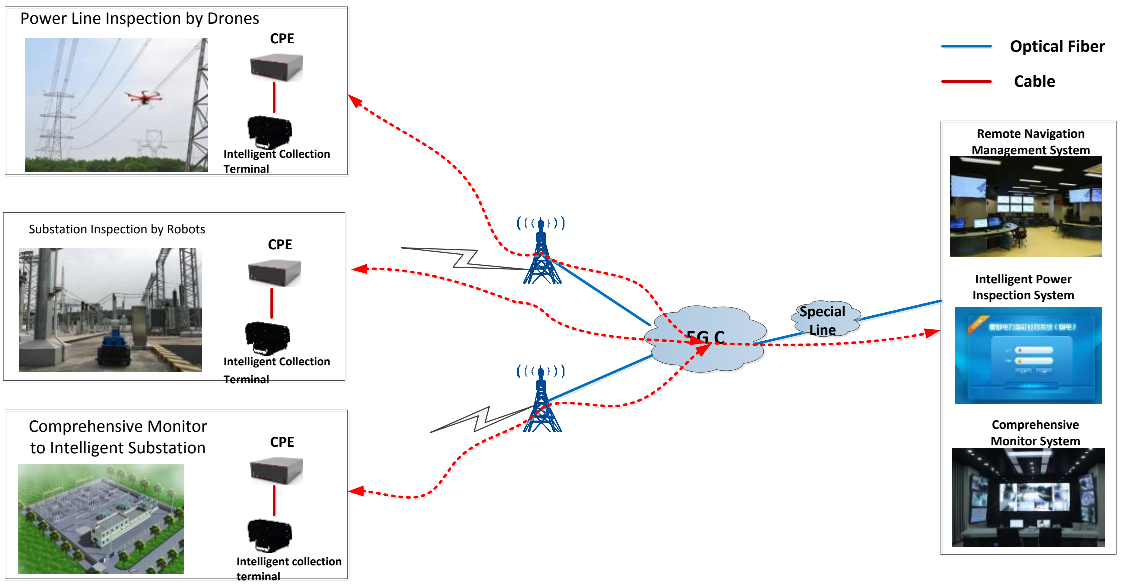
The 5G massive connectivity feature is used to feed back a large amount of electricity meter data to the power grid substation or master station, and its wide coverage feature is used to solve the connection problem of deployed application terminals in a complex environment.

(3) Precise load control

Traditional power distribution networks lack communications network support and can only cut off the entire power distribution line for load control. Through precise load control, non-important loads that can be interrupted, such as electric vehicle charging piles and discontinuous power supply in factories, are preferentially cut off. With low-latency and high-reliability transmission, 5G can quickly report the power grid load information in the power distribution phase to the control center and perform fast load switching based on the importance of electricity users, improving power supply reliability.

(4) Power grid inspection and comprehensive monitoring

High-voltage distribution substations, high-voltage power transmission lines, dangerous areas, and areas where personnel are difficult to reach are equipped with HD cameras or professional devices such as robots and drones. The 5G wireless network can be used to send onsite collected video to the analysis center in real time, replacing manual information collection for power grids in dangerous areas. Comprehensive analysis is performed to reduce risks, improve power grid reliability, and improve efficiency.



In this scenario, high bandwidth and high reliability features of the 5G network are used to transmit HD videos of power transmission and transformation lines and substations to the power grid. The data analysis center performs comprehensive analysis, predicts and processes risks, improving the robustness of the power grid.

2.2.3 Key Technical Requirements

Table 2-1 Requirement summary

Item	Three remote services of the power distribution network	Advanced metering	Precise load control	Power grid inspection and comprehensive monitoring
Current Connectivity Technology Used	Optical fiber, cellular (2G/3G/4G)	Cellular (2G/3G/4G), power communication (PLC)	Optical fiber	Optical fiber
Form of Device	Gateway	Gateway	Gateway	Gateway
Pain Point	A large number of power distribution terminals are deployed. Optical fibers are costly and the construction period is long.	Limited bandwidth of the PLC Limited public network coverage	Only optical fibers are used, which is costly. The latency of the existing wireless private network cannot meet the requirements. Public network latency and security cannot meet the	Wi-Fi is used, which is insecure. Real-time backhaul of machine inspection images is unavailable.

			requirements.	
Protocol	EtherCAT	EtherCAT	EtherCAT	EtherCAT and Wi-Fi
Capacity Requirement	About 50 terminals per square kilometer	About 1,000 terminals per square kilometer	About 2 to 4 terminals per square kilometer	About 1 terminal per square kilometer
Coverage Requirement	Indoor, outdoor, and underground	Indoor, outdoor, and underground	Indoor, outdoor, and underground	Indoor and outdoor
Mobility Requirement	*None*	*None*	*None*	< 10 km
Latency Requirement	Information collection < 3s, control < 1s	< 1s	< 15 ms	< 200 ms
Bandwidth Requirement	Uplink: 512 kbps to 2048 kbps Downlink: 512 kbps	Uplink: 10 kbps to 2048 kbps Downlink: 128 kbps to 512 kbps	Uplink: 512 kbps to 2048 kbps Downlink: 512 kbps	Uplink: 1,024 kbps to 2048 kbps Downlink: 512 kbps
Traffic Model	Event Trigger or Periodic	Periodic	Event Trigger	Event Trigger or Periodic
Positioning Requirement	*None*	None	None	None
Voice Requirement	*None*			
Reliability Requirement	99.9999%, packet loss rate < 10^{-6}			
Security Requirement	Security Level 1: It belongs to the premier production business of power grid, which needs the isolation from information management business. Data is required to be saved locally.			It belongs to the information management business of power grid, which needs the isolation from the premier production business.
Deployment Model Requirement	Dedicated RAN, UPF, core network deployed locally	Dedicated RAN, UPF, core network deployed locally	Dedicated RAN, UPF, core network deployed locally	Adopt public network of the operators, implement the isolation from the business of other users via MEC and network slicing.

Business Model Requirement	To be determined

2.2.4 Industrial Value Chain Analysis

The smart grid industry involves multiple application scenarios, and their communication latency requirements, data transmission sizes, and device quantities are different. As a result, information exchange varies greatly. Therefore, mobile network operators (MNOs) need to work closely with power grid enterprises to provide different network slice configuration combinations and end-to-end full-lifecycle services for different application scenarios of power grid enterprises, including but not limited to slice provisioning, KPI monitoring, slice optimization, and slice disabling. In addition, electric power enterprises lack professional technical personnel for wireless network construction and maintenance. Therefore, MNOs need to be responsible for the O&M of the 5G electric power network and provide the 5G network management system and open interfaces for electric power enterprise users. In this way, users can manage the leased 5G network and collect data.

Implementing 5G on smart grids needs to consider the development trend and investment pace of the smart grid industry. Take State Grid Corporation of China (SGCC) as an example. For class-1 and class-2 cities, most power distribution stations have completed optical fiber network deployment. Currently, there is no rigid requirement for 5G networks. However, with the promotion of the "three-in-one" (enhancing the existing substation to combination of the substation, storage station, and data center) concept of State Grid, a 5G network can be constructed to carry power services related to power distribution stations. In addition, renewable energy has become the energy development strategy of each country. For solar power plants that are centrally deployed, auxiliary facilities are complete, and there is no rigid requirement for the 5G network. However, if all the scattered and miniaturized solar and wind energy devices use optical fiber communication, the cost will be very high. In this case, the 5G network is a good communication solution. With the acceleration of smart grid reconstruction in many countries, advanced metering is affecting people's energy recognition and usage habits. Last-mile communication is still the major issue and 5G is the best solution.

Implementing 5G on smart grids require close cooperation with vertical industries such as MNOs, power grid enterprises, 5G equipment manufacturers, and equipment vendors in the grid industry. 5G network slicing provides differentiated and deterministic Quality of Service (QoS)/Service Level Agreement (SLA) assurance, service isolation, and independent operation for power grid enterprises, thereby bringing direct benefits and improving management efficiency for power grid enterprises. 5G electric power communication terminals also require collaboration of multiple parties to develop 5G smart grid terminals, such as independent converged gateways, industry-specific terminals, and embedded communication modules, to meet complex requirements of the power grid industry.

With the joint promotion of electric power enterprises, MNOs, communications equipment vendors, and equipment vendors in the electric power industry, 5G will surely support the sustainable development of smart grids.

2.3 Transportation

2.3.1 Industry Overview

Vehicle to everything (V2X) refers to vehicle to vehicle (V2V), vehicle to infrastructure (V2I), vehicle to network (V2N), and vehicle to pedestrian (V2P) data transmission using the C-V2X technology over peripheral or roadside radars, visual sensors such as cameras, and in-vehicle terminals. Collected data is analyzed and processed on the MEC or cloud service platform and then sent to the vehicle, thereby improving the driving safety, efficiency, and information service level.

According to the development of communications technologies, the development of V2X can be divided into three phases. The first phase involves the vehicle entertainment based on 2G and 3G cellular communication networks and remote information processing services such as eCall. In the second phase, vehicles are interconnected by using communications systems such as the LTE-V2X and dedicated short-range communications (DSRC) to provide intelligent V2V, V2P, V2I, and V2N transportation services. The third phase is based on the 5G and 5G-V2X networks, where vehicles are connected to the cloud and services such as autonomous driving and platooning are provided based on accurate location information. At present, the industry is transitioning from the second phase to the third phase.

The V2X technology can greatly increase the vehicle sensing distance and the range of sensed information within a certain cost range, and is not affected by bad weather. This improves the speed and security of intelligent driving, thereby improving proactive safe driving, effectively relieving urban road congestion, increasing the traffic resource scheduling efficiency and travel rate, and helping implement smart transportation. V2X technology development has been regarded as an important direction for future technological innovation, industry cultivation, and transportation service transformation in many countries around the world.

The preceding content is excerpted from *MEC-based 5G V2X Service Analysis and Application*.

2.3.2 Typical Scenarios

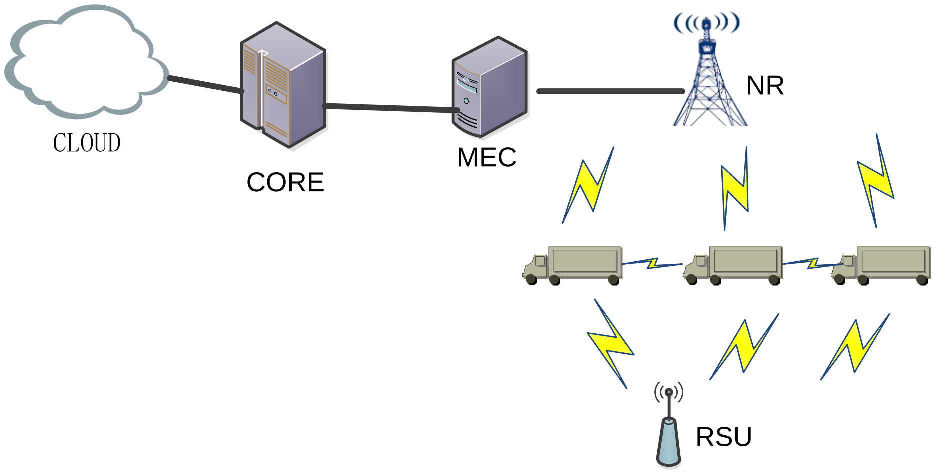
V2X can be classified into vehicle driving safety, traffic efficiency improvement, and information service by service type. Traffic safety scenarios include collision warning, vehicle out-of-control warning, and pedestrian anti-collision. Vehicle collaborative cruise and remote vehicle diagnosis provide information services for vehicles and improve traffic efficiency. In addition, 3GPP TR 22.886 defines several enhanced service application scenarios of eV2X, including platooning, green wave traffic, and remote driving.

- Vehicle platooning

Platooning is mainly used in the freight and logistics industries. Multiple vehicles form a fleet using the intelligent network technology. The leading vehicle uses the advanced autonomous driving mode. Subsequent vehicles need to implement synchronous acceleration, lane change, and braking based on high-precision positioning module and V2V, V2I, and V2N technologies. In addition, the vehicles should maintain proper distances throughout the process.

The leading vehicle periodically obtains its own vehicle information (including the location, speed, direction, and autonomous route planning), and periodically sends the information to the subsequent vehicles by using the V2V or V2N technology. The subsequent vehicles receive and parse the information sent by the leading vehicle by using the on board unit, to implement synchronous moving with the leading vehicle. In addition, the subsequent vehicles pack their own vehicle information (driving data such as a location, a speed, and acceleration) and periodically send the packed information to the leading vehicle. The leading vehicle receives and parses the information, adjusts its own actions, and collaborates with other vehicles to ensure consistent running speed and sufficient inter-vehicle distance, avoiding collisions. In this way, relevant requirements can be met. If the self-driving capability of the leading vehicle is lower than L3, the vehicle-end and road-end cameras need to transmit the surrounding environment information of the vehicle to the MEC and cloud in real time, and the MEC or cloud makes vehicle driving decisions.

Figure 2-1 5G + vehicle platooning

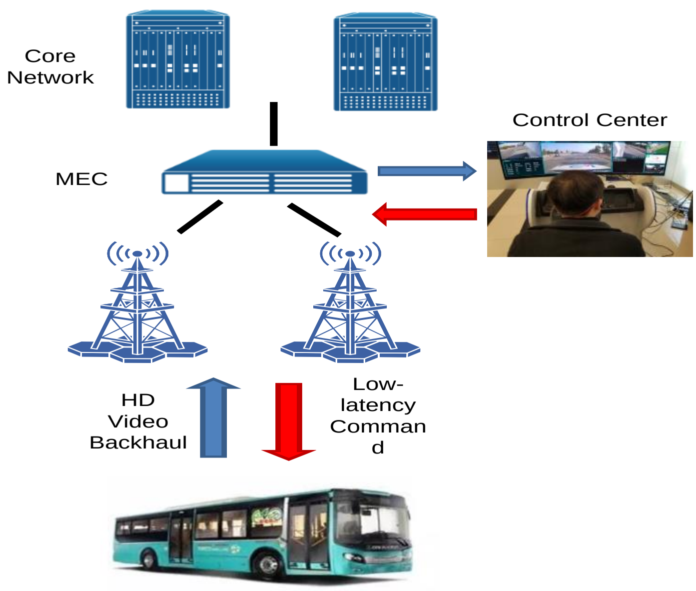


- Remote driving

In hazardous areas, such as toxic, high temperature, and high radiation environments, performing operations is difficult. In remote factory inspection, marine inspection, and safety survey, timeliness and safety need to be improved and cost needs to be reduced.

Remote driving can meet the preceding requirements. The vehicle-mounted cameras of a remote-controlled vehicle use the 5G module to fully utilize the large bandwidth, massive connectivity, and low latency of the 5G network, and send the full-round road conditions of the vehicle to the cockpit in real time in HD mode. The cockpit performs precise control and sends the commanding to the vehicle through the 5G network, achieving various operations such as steering, acceleration, deceleration, and braking.

Figure 2-2 5G + remote driving

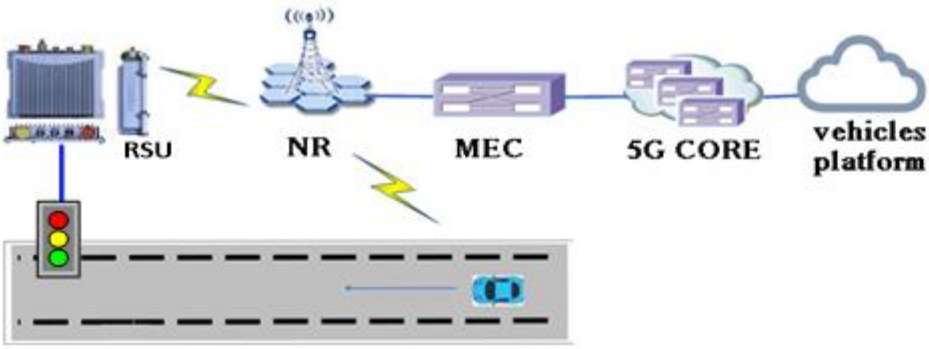


- Green wave traffic

At present, the traffic efficiency at intersections controlled by city signal lights is low. The main symptom is that vehicles must wait for the periodic change of traffic lights during off-peak hours (especially at night). Traffic congestion is severe in peak hours in the morning and evening. The traffic signal controller cannot adjust the traffic light status in real time based on the vehicle speed at intersections. If the line of sight is limited or the driver misjudges the traffic light information, traffic accident such as rear-tracking may occur, which also cause traffic congestion.

Signal controllers deployed at intersections report the status of traffic lights to the roadside unit (RSU) in real time. The RSU transmits the status to the MEC system through the 5G network. The MEC system calculates whether a vehicle needs to slow down in order to pass through the traffic lights at subsequent intersections without stopping based on the vehicle location, driving direction, and traffic light status. The calculated results are sent to the on-board unit (OBU) of the vehicle using the MEC and the 5G network. In this way, green wave traffic can be achieved. This can greatly improve traffic efficiency, alleviate urban congestion, and provide a green and efficient travel experience for people.

Figure 2-3 MEC-based green wave traffic



2.3.3 Key Technical Requirements

Table 2-1 Requirements in major V2X scenarios

Scenario	Specific Service	Communication Mode	Latency (ms)	Positioning Accuracy (m)	Communication Distance (m)
Information services	Vehicle-mounted entertainment	V2N	≤ 500	–	Base station wide coverage
	Remote vehicle diagnosis	V2I/V2N	≤ 500	–	Base station wide coverage
	High-Definition map download and update	V2I/V2N	≤ 500	–	Base station wide coverage
Traffic safety	Forward collision warning	V2V	≤ 20	1	≥ 300
	Emergency alarming	V2V/V2I/V2N	≤ 100	5	≥ 300

	Road exception alarming	V2I	≤ 100	None	≥ 300
Traffic efficiency	Autonomous driving	V2V/V2I/V2N	≤ 10	0.3	≥ 300
	Remote driving	V2I/V2N	≤ 10	1	≥ 300
	Green wave traffic	V2I/V2N	≤ 500	5	≥ 150
	Adaptive cruise	V2V/V2I	≤ 100	2	≥ 100
	Vehicle platooning	V2V/V2I/V2N	≤ 10	0.3	≥ 150

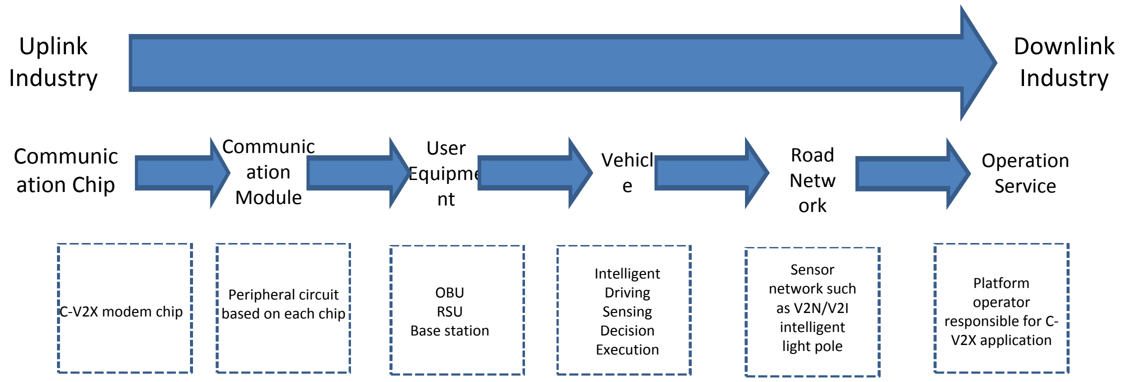
Table 2-2 Requirements of platoon driving, remote driving, and green wave traffic

Item	Vehicle platooning	Remote driving	Green wave traffic
Current Connectivity Technology Used	None	None	Wi-Fi
Form of Device	Integrated wireless module	Integrated wireless module	Integrated wireless module
Pain Point	Limited sensing distance, unable to adapt to all-scenario platooning such as high-speed moving	The uplink transmission bandwidth and transmission latency are limited.	Fixed traffic light time is configured and the system cannot flexibly adjust commanding based on traffic conditions. When a vehicle is waiting for traffic lights intersections, large vehicles in front of it may block the sight of the vehicle.
Capacity Requirement	A channel of 1080p HD video backhaul requires a bandwidth of about 5 Mbps to 8 Mbps. Video transmission data analysis is required for key intersections and road sections where accidents frequently occur.	A channel of 1080p HD video backhaul requires a bandwidth of about 5 Mbps to 8 Mbps. Generally, four cameras are required for remote driving.	Messages are transmitted in short packets, which are generally less than 300 bytes.
Coverage Requirement	Indoor or outdoor	Indoor or outdoor	Indoor or outdoor
Mobility Requirement	Moving speed ≤ 150 km/h	Moving speed ≤ 70 km/h	Moving speed ≤ 70 km/h

Latency Requirement	Latency < 10 ms	Latency < 10 ms	Latency < 100 ms
Bandwidth Requirement	Uplink: 65 Mbps Downlink: 3 Mbps	Uplink: ≥ 25 Mbps Downlink: 1 Mbps	Short message notification
Traffic Model **Positioning Requirement**	Periodic	Periodic	Periodic
Positioning Requirement	≤ 30 cm	≤ 1 m	Meter-level positioning
Voice Requirement	None		None
Reliability Requirement	99.999%		99.99%
Security Requirement	Data must be stored locally.		Data must be stored locally.
Deployment Model Requirement	D2D has dedicated frequency (China: 5905–5925 MHz), V2N can adopt the public network slicing (with the consideration of network security and cost). The network consists of 5G base stations, MEC and network slicing (reducing latency via MEC).		
Business Model Requirement	On demand		

2.3.4 Industrial Value Chain Analysis

The C-V2X industry chain includes vehicle-mounted sensors, vehicle-mounted chips, communications devices, vehicles, map navigation, smart roads, and operation and services. The participants include chip vendors, device vendors, host factories, solution providers, MNOs, transportation operation departments, and transportation management departments.



The upstream of the V2X industry chain mainly involves component and chip manufacturers. They do not produce final products, but provide intermediate products to car manufacturers, various types of equipment manufacturers and so on. There are a large number of such enterprises in China, but most of them are small in scale and need improvement on the performance of the product compared with the other outstanding foreign enterprises.

The midstream of the V2X industry chain mainly involves automobile manufacturers, sensor device manufacturers, and software algorithm platform developers. Automobile manufacturers are directly oriented to consumers and can pre-install smart vehicle-mounted terminals to implement autonomous driving. More advanced autonomous driving has higher requirements on V2X. Therefore, automobile manufacturers have a say in the industry chain.

The downstream of the V2X industry chain mainly involves system integrators, platform operators, and various service providers. System integrators and platform operators play an important role. System integrators are the direct owners of the V2X application industry. They need to plan and design the V2X application based on project requirements, purchase and develop various software and hardware products, and perform joint tests. After the acceptance and related indicators are met, the system integrators deliver the V2X application to platform operators. Platform operators are responsible to the V2X platform delivery and need to work with vehicle manufacturers and various service providers, find a proper business model, and promote sound operation in the industry.

The above content is excerpted from *Development of Internet of Vehicles Industry and its Market Potential*.

2.4 Mining

2.4.1 Industry Overview

The mining industry is a hotbed of global economic activity, with revenues in excess of USD 500 billion. To move millions of metric tons of rocks on giant machines requires minute precision, and any disturbance in the finely tuned flow of materials can have major consequences for the mine's operations.

Improving profitability in the mining industry requires working relentlessly on efficiency, transport and metal extraction to optimize the flow of ore. However, incremental improvements are facing diminishing returns, and the industry is gradually turning its attention toward automation as the next area of opportunity.

The mining industry expects an increased automation in their mines in the future. However, introduction of a new automation technology is not fast paced due to strict security and safety policies and regulations. New technologies must be proven to not jeopardize any policies or regulations.

The mining industry has identified that network performance (in terms of latency, latency variation, and packet loss) and security of future services may not be possible to meet with their current Wi-Fi network installation. This is true for opencast mines, and also for underground mines. This is the main driver for them to move towards LTE, or even more likely 5G. And network reliability is also an important factor for mine automation.

2.4.2 Typical Scenarios

2.4.2.1 Remote-Controlled Machines and Vehicles

One important aspect of mine automation is the introduction of remote-controlled machines and vehicles, with the aim of creating a safer working environment in the mine, and also a more efficient process for mining.

These services require high network throughput from the machine to the operator, preferably located above ground. Often there are 6 to 8 HD cameras streaming real-time videos from the machine. In addition, sensor data may augment the data stream. Further, there are strict requirements on low latency for control commands sent from the operator to the machine.

2.4.2.2 Positioning

The mine industry points out that positioning is critical for further automation. The accuracy of the current technology is considered good enough for safety, that is finding where people are in case of an emergency, but it is not accurate enough for critical applications such as remote-controlled driving. Positioning is of very high importance for further steps in automation.

Positioning is an enabling service for many applications. For example, for remote-controlled vehicles, it is important to understand the exact position of the vehicle, and also to understand the signal strength and received signal strength indicator (RSSI) threshold values for a path in the mine. The mine wants to ensure that no vehicles are entering an area with limited coverage, which might result in a stuck vehicle. Traffic control is another use case.

Another scenario is to provide the exact position of an electrician's tablet (with the mine map in the background) used when maintaining.

The positioning service provides an opportunity for more advanced mine automation showing vehicle position with prioritized vehicle, meeting places etc. All employees will be equipped with their own tablet which could be used for presentation.

2.4.2.3 Smart Rock Bolts and Sensors

Connected sensors and actuators in the mine are also pointed out as important for mine automation. One example is connected rock bolts that measure movements in the rock, which can be used for varying types of alarms and safety applications. Other types of sensors, for example measuring temperature or gas concentrations, are also considered. The application is also safety, in this case to monitor fires.

The requirement on the network is to ensure support of massive machine-type communication, with lots of sensors with relatively low requirements on latency and throughput.

2.4.2.4 Voice

Voice is already now a critical service in the mine, and any new infrastructure must continue to support, for example, push-to-talk and other services.

2.4.3 Key Technical Requirements

- Local data split and processing

The mining industry is expecting local split and processing for data services, specifically for latency-critical services such as remote-controlled vehicles. The machines are located in the mine, while the machine operator would be placed on the ground.

- Local survivability

Although local survivability for an LTE or 5G network is considered important, it is on the other hand not required that all services and functionality must be available during survival mode. For example, it is critical that the voice service survives as it is used for safety and security in the mine, and it is desirable to have basic network monitoring capabilities, while for example local user management is considered non-critical.

Local survivability includes two perspectives. The first relates to the connectivity and associated services within the mine and up to ground level. The survivability of this part of the network is critical specifically from a security and safety point of view. The second perspective relates to the fact that each mine is dependent on several central IT systems for production control. These IT systems reside centrally and support multiple mines. The connectivity, and hence survivability, between each mine and the central IT system must also be operational. Otherwise, production will be impacted or in the worst case stopped.

An optical fiber cannot be recovered when it's cut. During this time, local survivability is needed with monitoring status views and possibility for basic trouble shooting. An example would be to have the possibility to restart equipment locally in respective mines.

- On-site hardware management

The network in the underground mines poses challenges in terms of on-site installation and maintenance. Access points need to be moved due to mine shafts or tunnels being extended, covered, or production moving to new areas.

This type of hardware management must be possible with LTE and 5G nodes, at a low cost and with minimal manual intervention. Changes in the underground mine must be fast and safe in order not to cause any disturbances to 24x7 production in mines.

- Local monitoring and troubleshooting

Local monitoring capabilities is a requirement, and there is normally an IT engineer on-site responsible for operation of local IT and communication services. In general, the requirement is that monitoring must be simple, and they see visualization, including an overview of the network on a 3D map, as an important tool for their personnel. The mine would like to see dashboards with metrics such as latency, uplink and downlink throughput, and packet loss. Thresholds for violation of service agreements must also be visible, and alerts (email or phone) to IT staff in the case no personnel is actively monitoring the network.

The mine also wants to know the "health" of the radio equipment, what nodes are functional and what coverage is available at a given point in time. The status and coverage map should also be possible to export in real time to other systems like information to, for example, a remote-controlled vehicle.

It is important for the mine to be able to do basic troubleshooting on site, or at least via the network operation center (NOC).

- Local user management

The mine would like to have support for subscriber provisioning locally, that is, adding, deleting and changing profile of subscribers. This is not necessarily needed during failure situations, that is, local survivability of provisioning tasks upon failure is generally not required.

Explosion-proof is required for like coal mines. The detailed requirement is specified in relevant specifications and standards in mining industry.

Table 2-1 Key technology requirements

Item	Remote control of machines and vehicles	Positioning	Smart sensors
Current Connectivity Technology Used	Not in place or via fiber	UWB, ZigBee, RFID, etc.	Wi-Fi, LTE, etc.
Form of Device	Gateway	Gateway	Integrated module or gateway
Pain Point	Key to implement unmanned mining, for people safety	Complicated deployment, dedicated system	Lack of general network access environment.
Protocol	Industrial Ethernet protocols possibly be involved		
Capacity Requirement	Low density		
Coverage Requirement	Outdoor or underground	Outdoor or underground	Outdoor or underground
Mobility Requirement	20 km/h	5 m/s	N/A
Latency Requirement	10-20 ms	N/A	N/A
Bandwidth Requirement	Depends on video for controlling, 50 Mbps to 100 Mbps	Small, normally not exceeding 2 Mbps	Small, normally not exceeding 2 Mbps
Traffic Model	Trigger and periodic	Trigger and periodic	Trigger and periodic
Positioning Requirement	Outdoor or underground	Outdoor or underground	Outdoor or underground
Voice Requirement	Yes		
Reliability Requirement	99.999% or remote control; 99.9% for sensors		
Security Requirement	Yes		
Deployment Model Requirement	All on premise, self-survival capability		
Business Model	Need to own or fully control the assets. Need managed services.		

Requirement	

2.5 Port

2.5.1 Industry Overview

As a hub of transportation, port plays an important role in promoting international trade and regional development. Operational efficiency is crucial for ports, considering about 90% of global trade is carried by the maritime industry. In the context of Industry 4.0 and Internet Plus, ports have been undergoing transformation and upgrade toward digital, automatic, and smart operation. Increasingly, higher-level automation is being used for container terminals to improve productivity and efficiency and ensure competitive edges.

At present, dozens of container terminals worldwide have realized automation. With the increase of the shipping throughput year by year, ports around the world are actively undergoing automation upgrade and are bound to witness booming development.

Smart ports are demanding in terms of latency, bandwidth, and reliability. This means the communications system of automated ports must be able to efficiently and reliably carry control data and multi-channel video data across special, large-scale equipment. However, legacy communication modes (for example, optical fiber and Wi-Fi) have drawbacks not confined to high construction and O&M costs, poor stability, and low reliability. Against this backdrop, 5G is introduced to empower smart ports through such merits as low latency, large bandwidth and capacity, and high reliability as well as private port network solutions and end-to-end application components backed by 5G access.

2.5.2 Typical Scenarios

The four typical smart port application scenarios that 5G may enable in the future are as follows:

- Remote control of gantry crane

At present, the port is in urgent need of new remote control of gantry cranes. Traditional gantry crane driving is a special type of work. The driver operates the gantry crane in a 30-meter-high cab. The working conditions are harsh, and onsite operations are prone to fatigue and security risks. To ensure 24-hour operation at ports, each gantry crane is equipped with three drivers in turn. A port usually requires hundreds of gantry crane drivers, which is manpower-intensive. After the remote control reconstruction, cameras and programmable logic controllers (PLCs) are installed on the gantry crane. The driver watches multiple channels of real-time videos in the central control room to perform all operations on the gantry crane, such as precise movement of the crane and container grasping. Remote control of gantry cranes can greatly cut down labor costs, with one remote operator in a favorable environment controlling 3–6 gantry cranes. Requirements on drivers are also lowered, and operational security is improved.

- Remote control of bridge crane

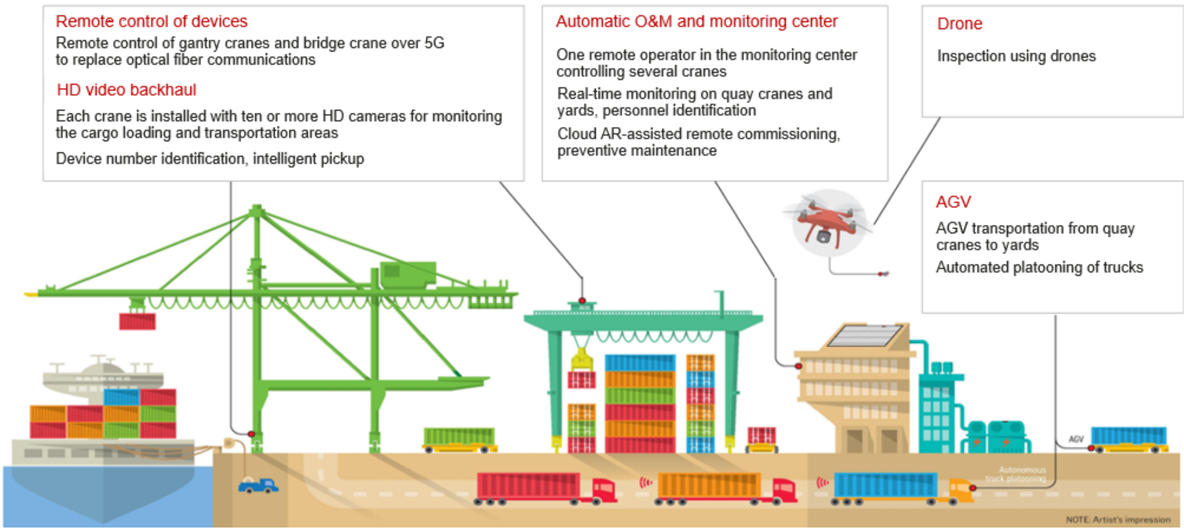
Bridge crane is a main service unit in the cargo handling area. The height of a bridge crane is 60–70 meters, and the electrical room is located somewhere 50 meters high. Therefore, wireless coverage is required in the operation area. The communications of a bridge crane include remote control and monitoring. In remote control, the number of cameras that simultaneously upload videos for a single bridge crane and the uplink bandwidth required are several times those of a gantry crane. In addition, bridge cranes are usually deployed densely, about 8–12 sets along a 1 km coastline of a port. Also, remote control requires a low latency because the vertical and horizontal moving speeds of a bridge crane are higher than those of a rubber tyred gantry crane.

- AGV truck control

Port automation has brought about another noticeable trend: AGVs are evolving to Intelligent Guided Vehicles (IGVs). In future, remote control will also be feasible on unmanned container trucks. When trucks encounter faults in the working area, operators can control cameras to survey the surrounding environment and determine faults and instruct trucks to exit from the target area. AGV or IGV remote control requires at least four cameras, each requiring a 10–20 Mbps uplink bandwidth. Hopefully, 5G can provide better network support for such applications.

- Video surveillance and AI-based identification
  - AI-based identification of container IDs using crane cameras and automatic cargo tally
  - Security protection: Intelligent analysis of drivers' facial expressions and status and alarms for fatigue and sleepiness
  - Operation management: License plate recognition, facial recognition, and cargo recognition
  - Intelligent inspection: Rapid and intelligent inspection using drones and robots

Currently, optical fibers cannot be deployed in many areas of a port. In temporary deployment and mobile scenarios, wireless backhaul, as a supplement to optical fibers, features flexible deployment, easy adjustment, and low costs. 5G provides high bandwidth and wide connectivity, and supports backhaul of multi-channel HD video and sensor information. Based on edge computing and AI capabilities, 5G will help port devices and production systems coordinate with each other to automatically and efficiently complete tasks, improving port operation efficiency and intelligent operation level.



2.5.3 Key Technical Requirements

Item	Remote crane operation (control signaling)	Remote crane operation (video transmission)	AGV	Video surveillance
Current Connectivity Technology Used	Optical fiber	Optical fiber	Wi-Fi	Optical fiber

Form of Device	Gateway	Gateway	Wireless module integrated	Gateway
Pain Point	Deploying optical fibers is not suitable, and the mobility of transition operations is poor.	Deploying optical fibers is not suitable, and the mobility of transition operations is poor.	Deploying APs for Wi-Fi is not suitable due to the wide coverage area. Service are prone to disconnection during handovers.	
Protocol				
Capacity Requirement	No data available.			
Coverage Requirement	Outdoor	Outdoor	Outdoor	Outdoor
Mobility Requirement	Yes	Yes	Yes	Yes
Latency Requirement	RTT latency < 30 ms		RTT latency < 50 ms	RTT latency < 200 ms
Bandwidth Requirement	50–100 kbps	30–200 Mbps per crane; 5–16 cameras per crane	10–20 Mbps	2–4 Mbps
Traffic Model	Event-triggered	Event-triggered	Event-triggered	Event-triggered or periodic
Positioning Requirement	No	No	Yes	No
Voice Requirement	No	No	Yes	Yes
Reliability Requirement	99.999%	99.9%	99.9%	90%
Security Requirement	Yes	Yes	Yes	No
Deployment Model Requirement	Dedicated RAN, dedicated UPF, dedicated core			
Business Model Requirement	To be determined			

2.6 Warehouse

Intelligent logistics is the most important challenge for the intelligent warehouse field. Mobile technology accelerates the integration of advanced logistics organization methods and advanced supply chain organization methods. High-tech logistics scenarios, such as unmanned vehicles, drones, and unmanned warehouses, begin to reshape the future logistics industry ecosystem to ensure efficient, stable, and secure logistics operations.

2.6.1 Typical Scenarios

2.6.1.1 Warehouse Robotics

The introduction of mobile robots can transform traditional human-sea tactics into intelligent and unmanned operations. The entire system integrates the automatic warehousing system, automatic transportation system, online picking system, automatic sorting system, logic control system, computing systems, and corresponding integrated management systems, optimizing the intermediate logistics operations and achieving unmanned operations in the warehouse.

AGVs use intelligent transportation methods, such as positioning, navigation, and real-time control to transfer materials along the production line inside the factory, solving the problem of dense transportation and improving the production efficiency. In addition, cranes are widely used in industries such as mechanical equipment, large machine tools, and professional equipment. When large components or finished products are moved, video surveillance and hoisting status information needs to be sent back and controlled.

Currently, the existing AGV robots are mainly used for goods transportation. However, due to the stability limitation of wireless communication technologies, each robot needs to have its own complex "brain" (chip) to meet the complex computing requirements of machines, which brings high costs. In addition, working modes must be preconfigured for all existing works, which cannot be remotely controlled or dynamic adjusted. In some scenarios, more manpower is required.

Therefore, if new wireless technologies featuring low latency and high bandwidth are mature, centralized management can be implemented. At that time, the central brain manages hundreds of AGV robots, which will bring the following changes:

- Collaboration efficiency improvement: Robots have self-organization and collaboration capabilities. Through global scheduling, optimal working paths and modes can be designed to improve efficiency.
- Security collaboration: Changes in factory work can be detected in real time and the current status can be reported in a timely manner, ensuring human-machine collaboration security.
- Remote control: In some special environments such as high temperature and high voltage, workers can remotely operate the AGV robots in real time through the 5G network in the monitoring center to achieve the preset work objectives in a synchronous and secure manner.

2.6.1.2 People and Asset Management

The core of warehousing is to achieve efficient material transfer. Currently, the following problems are common in warehousing: no guidance for vehicles, disordered personnel entry and exit, loss risks, and difficulty in tracking valuable materials and packages. The current security protection methods are labor-consuming and ineffective. Specifically, the video surveillance requires manual efforts; no preventive measures are taken; escape channels are blocked; intrusion, theft, and fire cannot be proactively identified. In warehousing operations, each "end" needs to obtain process data in a more intuitive, timely, and accurate manner. That is, logistics operation information must be quickly obtained from the equipment, operation, and management ends, achieving seamless end-to-end connection and improving efficiency.

- Dynamic location-based personnel management and control

For example, inspection on warehouses storing high-risk materials may be not performed as required. The inspection result is easy to be modified and the inspection is not managed electronically. As a result, missing or incorrect inspections occur during the inspection process. There is a blank area in the monitoring system, and it is difficult to trace and review historical records. In addition, it is difficult to ensure safety. During inspection, some special areas require working at heights. When a danger occurs, it takes a long time to find the location of the personnel and perform real-time rescue.

With wearable devices or high-definition AI cameras, personnel can be located easily. In this way, congestion in the production area in the warehouse can be detected in real time, and security control and resource scheduling can be performed in a timely manner to improve production efficiency.

- Dynamic location-based asset management and control

The typical application scenarios are as follows: device inbound and outbound management, inventory counting, inventory transfer, and split case picking. These services are sensitive to packet loss. If high-bandwidth services occupy wireless channel resources, the work efficiency is low, affecting work performance of MNOs (MNOs are paid by piece. The network out-of-service time directly affects their performance and easily causes complaints and disputes.)

  - Terminals are mainly hand-held scanning terminals, bar code scanners, and smart tablets.
  - Different types of terminals belong to different departments and have different access rights and policies. Therefore, differentiated management and monitoring are required.

Other material management scenarios are exemplified as follows:

A company produces more than 400 forklifts per day and more than 100,000 forklifts per year. There are more than 1,000 models of forklifts in total. The large quantity and model variety of forklifts make it difficult to quickly find forklifts in production and warehousing. During the customized production, it takes more than half a day to find the target forklift if the production schedule is advanced. In addition, after goods are put into the warehouse, forklifts are densely parked. The forklifts parked in the middle are surrounded by others. More than 3,000 forklifts in a warehouse cannot be found when they are taken out of the warehouse. Therefore, more than three persons are needed to search for target forklifts. Because the distance between forklifts is small, to view the vehicle identification number of a forklift in the middle, a person needs to climb over the surrounding forklifts.

The glass produced by a company needs to be packed with dedicated turnover iron boxes during turnover between factories. Each iron box is customized based on the product form, and there are more than 4,000 types of glass. Among the 11 warehouses in China, each warehouse uses about 10,000 to 20,000 packing cases, and the cost of each packing case is about CNY 2,000. The following problems occur during the use of the packing cases:

- High loss rate: Packing cases are lost due to ineffective management. The annual loss is about CNY 10 million.
- Low utilization rate: After glass is produced, the supply is delayed because the proper packing cases cannot be found or allocated in time, which affects the brand image.

In different scenarios, different power consumption, loading capacity, and material adaptability are required. 5G may address issues in data backhaul of the existing positioning mechanism and bring new positioning technologies that can reduce costs in personnel and large-scale devices.

Item	UWB positioning	Active RFID positioning (Similar to Bluetooth)	Passive RFID application
System Cost	High	Medium	Low
Positioning Accuracy	Decimeter-level	Meter-level	Existence determining
Deployment and Implementation	Complex	Convenient	Slightly complex
Cost of Base Stations	High	Low	High
Positioning Tag Cost	High	Medium	Ultra-low
Tag Endurance	Low	Medium	No power supply is required.
Applicable Scenario	Location management of personnel and objects that require high-precision positioning at the decimeter level, for example, in high-precision positioning scenarios such as corridors, factories, and power plants	Personnel and object location management with meter-level precision requirements, such as indoor environments in large factories	Tags are read through antennas. The precision is not required. Identity collection, material reading, and stocktaking at entries and corridors of factories.

2.6.2 Key Technical Requirements

- Requirements of mobile robot services:

As shown in the following figure, the issue of signal fluctuation caused by severe blocking need to be addressed. Real-time communication and a large number of terminals are required. There are a lot of mobile roaming services.

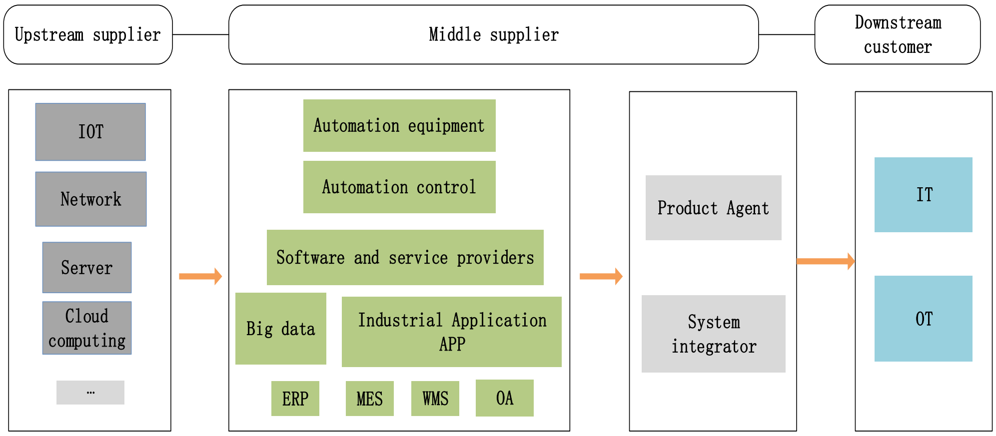
Item	Mobile robot
Current Connectivity Technology Used	Wi-Fi
Pain Point	Zero roaming and low latency
Capacity	50 automated robots in a 1,000 m^2 warehouse.
Coverage	In the warehouse scenario, signals are blocked. Some warehouses have explosion-proof requirements. Some warehouses have low temperature requirements, such as cold chains.
Mobility	0.8–2 m/s
	More than 1,000 m^2
Latency	Within 200 ms. If the computing unit that controls the robot motion is deployed on the cloud, the latency must be less than 10 ms.
Packet Loss Rate	Within 3%. If the control unit is deployed on the cloud, the packet loss rate must be within 0.01%.
Transmission Rate	4 Mbps on average, 10 Mbps during peak hours of natural navigation
	Within 4 Mbps
Traffic Model	Event-triggered
	1,500
Positioning Requirement	Indoor/Outdoor
	Mobility
	Within 10 cm

- Key technical requirements for personnel asset positioning:

In this scenario, 5G focuses on data backhaul, for example, data backhaul of barcode scanners, and replacement of existing positioning technologies in some scenarios.

Item	Asset positioning	Personnel positioning
Current Connectivity Technology Used	Active and passive RFID, UWB, and Bluetooth	UWB, Bluetooth, and camera
Pain Point	Positioning precision: Different scenarios have different requirements on positioning precision. For example, in some high-risk operation scenarios, the positioning precision of personnel must reach sub-meter level. Energy consumption: Requirements on energy consumption are high. Frequent battery replacement or charging will cause high maintenance costs. For example, a Japanese enterprise requires that the battery life of a positioning tag for expensive assets be longer than one year. Load capacity: For example, a cement factory needs to locate thousands of workers in a 1,000 m^2 area. A clothing manufacturer wants to locate hundreds of clothes in a box at the same time.	
Capacity	Within 1,000 m^2 As a positioning technology application, positioning of thousands of terminals needs to be met.	
Endurance	The battery life is required to be at least three months. In some scenarios, the battery life is required to be one to two years.	
Coverage	In the warehouse scenario, signals are blocked. Some warehouses have explosion-proof requirements. Some warehouses have low temperature requirements, such as cold chains.	
Mobility	Fixed	0.8–2 m/s
	Fixed	Moving
Traffic Model	Event-triggered and periodic	
Traffic Requirement	Data backhaul: Each terminal transmits tens to hundreds of bytes per second.	The maximum traffic requirement comes from video services, which is 10 Mbps or higher for each camera.
Positioning Requirement	Mainly indoor	Indoor/Outdoor
	Most of them are static and trace tracking is required.	Moving
	Mainly used for existence determination	Some high-risk areas, such as power plants, require submeter-level electronic fences. The higher the precision, the better.

2.6.3 Industrial Value Chain Analysis



The upstream of the intelligent warehousing and logistics industry chain involves the infrastructure device manufacturers, which provide sensing modules such as the RFID tags, various application sensors, cameras, and positioning technologies. The infrastructure device manufacturer provides network services, sensing technologies, and cloud service capabilities for the downstream.

The midstream of the intelligent warehousing and logistics industry chain involves the software, hardware, and content service provider, as well as an agent distributor and system integrator, such as the industrial equipment automation vendor. They are responsible for implementing automatic sorting system and warehouse management systems (WMSs). 5G technologies can reconstruct the work processes of such existing management systems or industrial equipment to make them more flexible and automated.

The downstream is the user end. Currently, there are two systems for business users. The IT system is responsible for building the existing network, providing the basic network for smart terminals, to connect people, devices, and service systems to the network. The OT system is the production automation department and is responsible for automation of mechanical operations based on human requirements through automatic detection, information processing, analysis and judgment, and operation and control. In the past, the OT department focused on monitoring and analysis of a single device. Therefore, better integration between IT and OT is required.

For MNOs, it is relatively easy to enter the infrastructure device end. The 5G network can provide communication capabilities of high bandwidth, low latency, and massive access for existing sensor modules. The second opportunity is to provide a positioning technology over the 5G network. However, most existing industrial devices have a service life of 20 to 30 years. Most devices do not support wireless networks. The best breakthrough point is the existing data backhaul field, such as mobile robots and videos. If 5G is required, hardware upgrade is required, which is costly. In addition, there are many electromagnetic interference sources and metal objects on the industrial site, which requires collaboration with industrial automation device suppliers, mobile robot device suppliers, and existing applications used in industrial intranet reconstruction to explore best practices.

Driven by 5G, core technologies such as artificial intelligence, big data and cloud computing, IoT, and blockchain can be quickly implemented in next-generation warehousing services. On the other hand, 5G is introduced as a key transport layer technology in the warehousing architecture. Because of a seamless access feature of 5G, services using other communications technologies can be effectively accessed and converged.

2.7 Health

2.7.1 Industry Overview

5G healthcare provides information-based, mobile, and remote medical services for disease diagnosis, monitoring, and treatment, fully utilizing limited medical manpower and equipment resources, and giving full play to medical technologies of large hospitals. 5G healthcare also provides innovative and smart medical service applications to reduce hospital operation costs, promote medical resource sharing, and boost medical efficiency and disease diagnosis. This helps to expand the reach of medical resources.

The global healthcare industry is continuously integrating 5G, AI, and big data technologies, making healthcare services truly intelligent and ushering in unprecedented opportunities. As the global population ages and medical resources become increasingly inadequate, governments and citizens pay more attention to the smart healthcare industry and promote the implementation and reform of related smart healthcare policies.

2.7.2 Typical Scenarios

Benefiting from the large bandwidth, low latency, and high reliability features of 5G, future smart healthcare and smart hospitals combine capabilities of the MEC and big data analysis platforms to provide everyone with timely and convenient healthcare services, meeting people's new requirements for future healthcare, such as telemedicine, remote first aid, remote outpatient, smart operating room, smart ward, and smart guidance.

Typical scenarios of 5G smart healthcare are as follows:

- Remote consultation

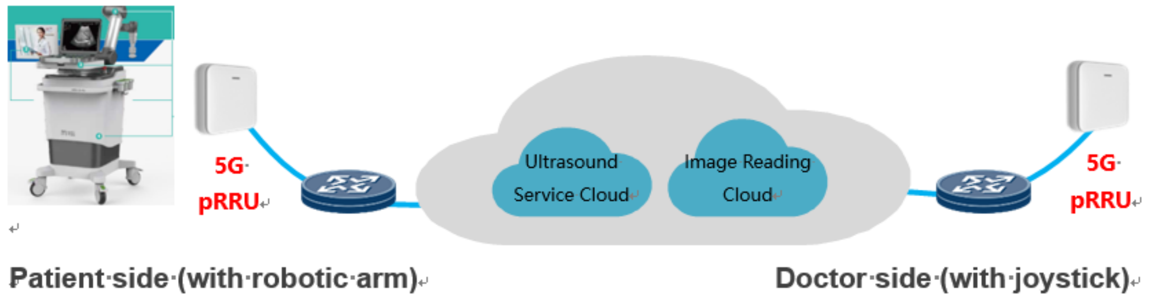
Owing to unevenly distributed medical resources, it is difficult for people in rural or remote areas to access timely and high-quality healthcare services. Traditional remote consultation uses wired connections for video communications, leading to high construction and maintenance costs and poor mobility. The high-speed 5G network supports 4K/8K remote HD consultation as well as high-speed transmission and sharing of medical image data. Experts can provide consultation anytime and anywhere, improving diagnosis accuracy and guidance efficiency and promoting close-to-patient deployment of high-quality medical resources.

- Remote ultrasound

Compared with the CT and MR, the examination using ultrasound largely relies on a doctor's scanning method. Different doctors have different habits in operating the probes. Their check results may also vary. Ultrasound examination expertise is often rare in grassroots hospitals. Therefore, a remote ultrasound system that supports HD and zero latency is needed to fully utilize expert resources from high-quality hospitals, enabling service guidance and quality control across regions and hospitals. Such a remote ultrasound system is helpful to ensure standardized and reasonable ultrasound examination in grassroots hospitals.

The millisecond-level latency of 5G will enable doctors at higher-level hospitals to remotely conduct ultrasound examination in real time through robotic arms.

Figure 2-1 Architecture of the remote ultrasound solution

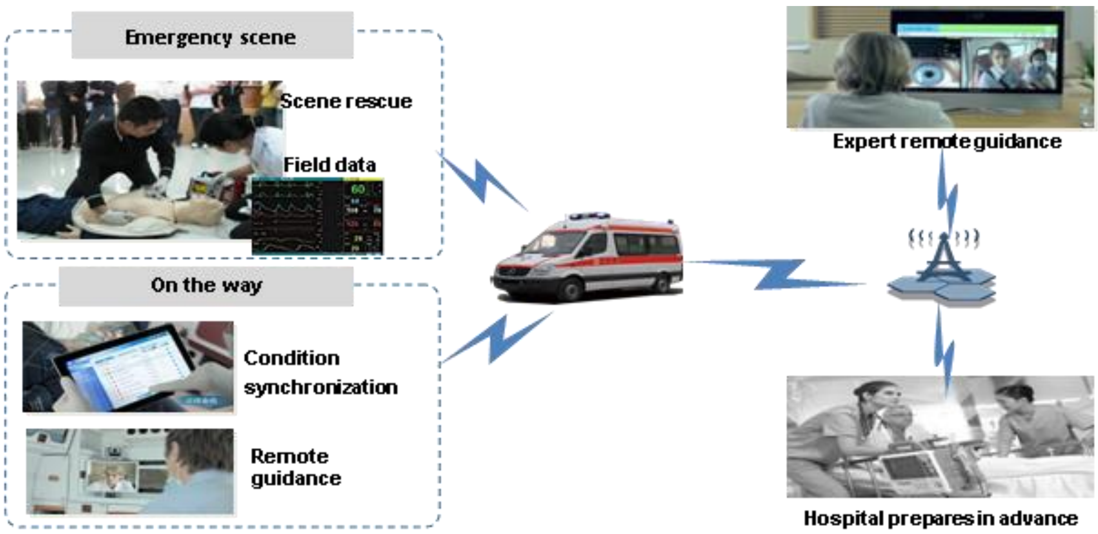


- Emergency rescue

First aid is a comprehensive science that deals with and researches various acute diseases and trauma. It requires emergency treatment measures for accidents and diseases that threaten human life and security in a short time. Other aspects such as onsite rescue, transportation, and communication also need to be considered in first aid. In addition, first aid equipment plays an important role during first aid.

The 5G network transmits medical equipment monitoring information, vehicle location, and video images inside and outside vehicles in real time, facilitating remote consultation and remote guidance. The collection, processing, storage, transmission, and sharing of pre-hospital first aid information can fully improve the management and treatment efficiency, enhance the service quality, and optimize the service process and service mode. Big data technologies can fully mine and use the value of medical data, and apply, evaluate, and assist in first aid management and decision-making.

Figure 2-2 Architecture of the emergency rescue solution



2.7.3 Key Technical Requirements

Item	Remote consultation	Remote ultrasound	Emergency rescue

Current Connectivity Technology Used	Optical fiber, Wi-Fi	Optical fiber	4G
Form of Device	Gateway	Gateway	Module
Pain Point	Difficult to deploy optical fibers in hospitals and guarantee Wi-Fi QoS	Difficult to deploy optical fibers in hospitals	Insufficient 4G bandwidth
Protocol	EtherCAT	EtherCAT	
Coverage Requirement	Indoor, full coverage in hospitals	Indoor, full coverage in hospitals	Outdoor, covering the first aid route
Mobility Requirement	N/A	N/A	120 km/h
Latency Requirement	< 100 ms	≤ 20 ms	< 100 ms
Bandwidth Requirement	≥ 40 Mbps	≥ 80 Mbps	≥ 100 Mbps
Positioning Requirement	-	-	≤ 1 m
Voice Requirement	Yes		
Reliability Requirement	*99.999%*		
Security Requirement	High. Data cannot be transferred out of hospitals.		High
Deployment Model Requirement	Operators' public networks are used in hospitals and "MEC+slicing" is used for user isolation.		
Business Model Requirement	Depends		
Whether Operators' Public Networks Meet the Requirements	Yes	Yes	Yes

2.8 Media

2.8.1 Industry Overview

The integration and development of traditional and emerging media is based on advanced technologies and content construction, and achieves in-depth integration of content, channels, platforms, operation, and management. A new platform-based, open, and interconnected media architecture is formed. Based on this architecture, new media will be extended to mobile terminals, cities, counties, and regions.

With the development of 5G technologies, video services have become the main form of media transmission. In addition, based on users' endless pursuit of video quality, video services will enter the ultra-HD era of 5G, 8K, and AI.

First of all, 5G will be widely used in media live broadcast scenarios: 5G+4K/8K ultra-HD live video broadcast, 5G+4K/8K VR live broadcast, 5G+smart stadium, 5G+drones live broadcast, 5G+mobile live broadcast, 5G+mobile phone live broadcast, can be used for news outbursts, remote multiple venues, sports events, concert venues, marathons, bicycle races, golfing, enterprises, public institutions, and family activities etc. to provide flexible and fast ultra-HD live broadcast and real-time HD video interaction connections anytime and anywhere.

2.8.2 Typical Scenarios

- Live news broadcast and video interaction

The environment of breaking news scenes is complex and full of uncertainties. For hot event tracking, media collection and editing personnel and systems must be able to respond in a timely manner, quickly get positioned, and upload video materials immediately. Besides, the onsite situation may change rapidly. The studio and onsite personnel need to communicate with each other in real time. Real-time interaction between the host or audience and onsite personnel is frequently required.

5G network enables journalists to use 5G terminals (backpacks, mobile phones, and CPEs) to perform live broadcast onsite and interact with the studio efficiently and in real time. For news materials such as onsite videos, the files can be quickly sent to the back-end media system through the 5G network for editing, producing, and distributing. In this way, news content can spread efficiently.

- Comprehensive HD live broadcast of large-scale events

Large-scale outdoor live broadcast activities, such as marathons, cycling, golfing, and water motorboats, feature long distance and wide range. Generally, 4K and 8K ultra-HD live broadcast signals are required.

The 5G network allows real-time backhaul of live broadcast signals, implementing diversified onsite shooting modes, such as multiple cameras with fixed or mobile positions, panoramic shooting using drones, and mobile phone shooting.

Backed by the 5G low-latency feature, live videos of multiple cameras are transmitted back to the studio in a timely manner, meeting the requirements for real-time HD live broadcast.

- Free-view live broadcast of smart stadiums

The 5G ultra-large bandwidth and edge computing platform contribute to free-view live broadcast for smart stadiums. Traditional live broadcasts are mostly conducted from a "tracking angle", and the content watched by an audience is determined by the tracking. However, the 5G free-view-angle service enables audiences to freely select a broadcast view from any angle, bringing brand-new stadium experience of sports events and art performances.

- Single-device live broadcast of small-scale outdoor activities

The 5G single-device live broadcast system can be used to carry out flexible live broadcast of personal outdoor activities, such as kindergarten activities, community activities, corporate culture activities, and weddings. Videos shot using a single camera or mobile phone, after being encoded and compressed, are uploaded to a cloud platform (live broadcast on WeChat or a website) for live broadcast through the 5G network.

The 5G single-device live broadcast system is easy to install and cost-effective. It provides flexible live broadcast modes for live broadcasts anytime and anywhere.

- VR, holographic, and other virtual reality communications

With the advent of the 5G era, the future seems to be no longer so distant. Virtual reality (VR), holographic, mixed reality (MR), and other VR communications are gradually feasible. VR communications including holographic integrates multiple technologies. A user can perform before a special camera matrix formed by lens and microphones. The camera matrix converts the performance into real-time 3D digital images for network transmission, and at the receiving end, images are presented as VR, holographic, or MR by using technical means. In this process, 5G high-speed communications technologies and computer graphics technologies closely cooperate with each other. 5G transmission technologies will play a crucial role in holographic communications. 5G excellent features such as high bandwidth, low latency, and high reliability render holographic possible.

2.8.3 Key Technical Requirements

Item	Live news broadcast and video interaction	Comprehensive HD live broadcast of large-scale events	Free-view live broadcast of smart stadiums	Single-device live broadcast of small-scale outdoor activities	VR and holographic communications
Current Connectivity Technology Used	Satellite and wired network	Satellite	Satellite, cable network, and Wi-Fi	4G network	Wi-Fi and wired network
Form of Device	5G CPE, 5G mobile phone, and 5G backpack	5G CPE and 5G backpack	5G CPE	5G backpack and 5G mobile phone	5G mobile phone and 5G VR glasses
Pain Point	Real-time news and live video broadcast	Substitutes for satellite live broadcast and real-time HD live broadcast of multiple cameras	Personalized game watching requirements of audiences in stadiums	Live broadcast of UGC type	VR, holographic, and MR communications and transmission
Capacity Requirement	Low	Low	Low	Low	Low
Coverage Requirement	Wide-area continuous coverage	Wide-area continuous coverage	Indoor coverage in specific areas	Wide-area continuous coverage	Indoor coverage in specific areas
Uplink Rate	50 Mbps (4K, H.265, 2 channels)	100 Mbps (8K, H.265)	100 Mbps (4K, H.265, 4 channels)	25 Mbps (4K, H.265)	100 Mbps (8K, H.265)
Latency	50 ms	50 ms	50 ms	50 ms	20 ms
Mobility Requirement	< 20 km/h	< 300 km/h	Fixed	< 20 km/h	Fixed
Traffic Model	Scenario-based	Scenario-based	Scenario-based	Scenario-based	Scenario-based
Reliability Requirement	99.99%	99.99%	99.99%	99.99%	99.99%
High-Precision	No	No	No	No	No

Positioning					
Security Requirement	Medium	Medium	Low	Low	Low
Voice Requirement	None	None	None	None	None
Deployment Model Requirement	Slicing	Slicing	Slicing and MEC	None	Slicing and MEC

2.9 Public Safety

2.9.1 Industry Overview

Public safety covers all aspects of daily activities of the public, including public security, natural disaster prediction, accident and disaster handling, public travel safety, and food and public health safety.

Public security management aims to detect, sense, and warn risks before or when they occur. When a risk occurs, onsite data is collected and analyzed for related departments to better understand and judge onsite situations and for them to interact with associated organizations and manage and control dangerous situations efficiently. To achieve this goal, data collection devices, such as sensors and cameras, need to be deployed in different security fields. The data transmission network must meet real-time and bandwidth requirements. In addition, intelligent analysis, decision-making, and response must be performed based on different security risks.

The development of multiple technologies, such as terminal technologies, transmission technologies, cloud computing, and visual recognition algorithms, will help build a more intelligent, efficient, and proactive public safety system. With ultra-large bandwidth, ultra-low latency, and massive connections, the 5G network provides adequate data channels for various services.

2.9.2 Typical Scenarios

Public safety involves many fields and segmentation scenarios. Key 5G capabilities are valuable to basic public security capabilities and can be widely applied in different industries and fields.

- HD security

5G provides large bandwidth and supports 4K and 8K video surveillance, facilitating HD security.

Cameras for public safety are widely deployed in various areas. Traditional wired transmission methods, such as trench digging and cable burying, feature high costs and long construction periods and may be infeasible in some areas due to property or geographical restrictions. Wireless technologies including Wi-Fi have obvious bottlenecks in transmission bandwidth or coverage, especially in massive connection scenarios. The bottleneck of data transmission hinders the video collection end from evolving to higher definition. However, 5G will address this issue with its large bandwidth.

HD video surveillance is important to security fields such as case investigation and mine environment monitoring.

- Intelligent recognition

5G high bandwidth and low latency, together with AI technologies, make AR intelligent recognition a powerful tool for security check.

AR intelligent recognition applications have the following key requirements:

- Higher-definition video images, providing a basis for recognition precision
- Lower transmission latency, higher computing power, and more efficient algorithms, guaranteeing quick recognition

5G can provide hundreds of Mbps bandwidth in the uplink, and the network loopback latency is as low as 10 ms. Coupled with AI and cloud computing, 5G will enable AR intelligent recognition.

AR intelligent recognition is important for public safety fields, such as policing, campus security, security check in densely populated areas including airports and railway stations.

- Drone surveillance

Drone surveillance makes security supervision more efficient and wider.

Featuring high-speed and unbound from ground obstacles, drones play a special role in fields such as rapid police dispatch and river pollution inspection. Traditional flight control technologies rely heavily on transmission conditions such as weather. As a cellular technology for wide coverage, 5G can ensure data transmission for drones around the clock and in all weathers. Drones usually come with data collection devices such as HD cameras. With 5G, drones can transmit data back quickly. In addition, stringent latency requirements are put on the flight control of drones in high speed. 5G, with its low latency, can come to help.

- Robot patrol

5G enables robot-based round-the-clock patrols in high risks.

Robotic operations in high risks are in great demand. Robots can work all-weather and are applicable to fields such as high-temperature operation environments in the steel and metallurgy industry, environments to which human bodies cannot be exposed in the chemical industry, and key areas calling for 24-hour uninterrupted patrolling.

When robots collaborate with HD cameras and sensors, move a lot during work, and carry services (such as intelligent inquiry) requiring interaction with humans, large bandwidth is desired for transmitting clearer images and low latency is in need for real-time action control and pleasant interaction. 5G, offering high bandwidth and low latency, will help popularize robotics applications.

2.9.3 Key Technical Requirements

Item	HD security	Intelligent recognition	Drone surveillance	Robot patrol
Current Connectivity Technology Used	Wi-Fi, Ethernet cable, optical fiber	Wi-Fi, eLTE	Wi-Fi	Wi-Fi
Form of Device	Cameras (built-in 5G modules)	AR glasses (built-in 5G modules)	Drones, mounted cameras, and sensors (built-in 5G module)	Robots, mounted cameras, and sensors (built-in 5G module)
Pain Point	The wired solution entails high deployment costs and a long deployment period.	The current transmission bandwidth restricts the definition of the uploaded video	The transmission bandwidth, latency, and coverage of Wi-Fi cannot satisfy the coverage	Robot operations feature mobility. Packet loss may occur during handovers on a

	Wireless technologies such as Wi-Fi: provide poor outdoor wide area coverage, and entail severe deterioration of access quality with the increase of access terminals.	images, and the transmission latency severely affects E2E identification and feedback efficiency.	requirements of large-scale drone operations. In addition, the transmission bandwidth, latency, and stability in mobile scenarios cannot be ensured.	WLAN. In addition, robots are latency-sensitive in interactive operations. For robots equipped with HD cameras, the uplink data transmission bandwidth in mobile scenarios also poses challenges.
Protocol	Wi-Fi for example: 802.11n, 802.11ac, etc.	Wi-Fi for example: 802.11n, 802.11ac, etc.	Wi-Fi for example: 802.11n, 802.11ac, etc.	Wi-Fi for example: 802.11n, 802.11ac, etc.
Capacity Requirement	High density	Low density	Low density	Low density
Coverage Requirement	Indoor and outdoor	Indoor and outdoor	Only outdoor coverage is involved. 5G-based drone services: require 300 m-high space coverage.	Ensure that the signal quality in the robot operation area meets the requirements. The signal quality varies greatly depending on the operation scenario. Both outdoor coverage and indoor coverage are required.
Mobility Requirement	Fixed	Low-speed	Medium- and high-speed (10 km/s to 60 km/s)	Low- and medium-speed (≤ 10 km/s)
Latency Requirement	20-100 ms	Take the facial recognition application of AR glasses as an example. The maximum latency that human nerves can perceive is about 100 ms. The latency of visual	The E2E data transmission latency must be less than 200 ms. The E2E latency of control instruction transmission varies greatly with services. For services with	< 20 ms

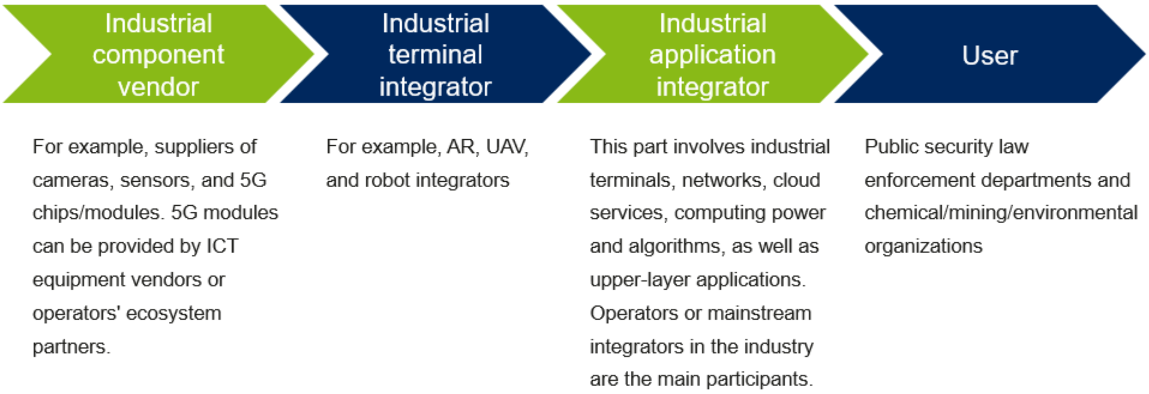
		processing can be minimized to 80 ms, and the transmission latency reserved for the wireless network is less than 20 ms.	frequent action control (such as surveying and mapping), the latency must be less than 20 ms. For operations involving little intervention (such as spraying pesticides along specific preset paths), the latency must be less than 100 ms.	
Bandwidth Requirement	Generally, the uplink rate of a 1080p camera is 6 Mbps, that of a 4K camera is 25 Mbps, and that of an 8K camera is 100 Mbps. However, 8K cameras are seldom used for HD security protection.	Generally, the uplink rate of a 1080p camera is 6 Mbps, that of a 4K camera is 25 Mbps, and that of an 8K camera is 100 Mbps. However, 8K cameras are seldom used for intelligent identification.	Uplink bandwidth required for single-channel 4K video transmission: 25 Mbps; Uplink bandwidth required for single-channel 1080p video transmission: 6 Mbps; Uplink bandwidth for laser mapping: 100 Mbps; Uplink bandwidth for transmission of other data than video and laser data (such as UAV location information): < 1 Mbps; Downlink bandwidth required for each type of service is generally less than 1 Mbps.	A robot usually needs to be equipped with multiple channels of HD videos to capture images without blind spots. For example, if three groups of cameras are configured for a dual-lens 4K camera, the uplink bandwidth required by the robot is up to 150 Mbps (25 Mbps x 2 x 3). For 1080p video, this bandwidth is 36 Mbps (6 Mbps x 2 x 3).
Traffic Model	Continuous shooting	Shooting in the operation time window	Shooting in the operation time window	Shooting in the operation time window
Positioning Requirement	Generally, location data is not provided by a cellular network, but is	Generally, location data is not provided by a cellular	GPS-based location data	Generally, location data is not provided by a cellular network,

	comprehensively determined based on video images and location information of the camera.	network, but is comprehensively determined based on video images and location information of the camera.		but is comprehensively determined based on video images and location information of the camera. The outdoor location information of a robot can be provided by a GPS.
Voice Requirement	Generally not involved	Voice can be used for recognition notification and recognition result feedback, but the requirements are not high.	Rarely involved	Interactive robot applications involve voice services, but the requirements are not high.
Reliability Requirement	Different sectors may have different requirements. Based on the industrial monitoring requirements defined in 3GPP TR22.804, the reliability must reach 99%.	Different sectors may have different requirements. Currently, there is no specific industry requirement data.	99.999%	Different sectors may have different requirements. For example, the industrial reliability requirement is high, even reaching 99.9999%.
Security Requirement	Stored by the public security system, inaccessible outside, and requiring access authentication	Connected to databases such as facial recognition databases, requiring high security and access authentication	Connected to the public security system or security system, requiring high confidentiality and access authentication	Connected to the public security system or security system, requiring high confidentiality and access authentication
Deployment Model Requirement	Slicing	Slicing, UPF	Slicing, MEC	Slicing, UPF
Business Model Requirement	Typical business model requirements: 5G Inside, industry's requirements for 5G chips, modules, and terminals	Typical business model requirements: 5G Inside, industry's requirements for 5G chips,	Typical business model requirements: 5G Inside, industry's requirements for 5G chips, modules, and	Typical business model requirements: 5G Inside, industry's requirements for 5G chips, modules, and

		modules, and terminals	terminals	terminals

2.9.4 Industrial Value Chain Analysis

Public safety covers a wide range of fields and involves the following key industry partners:



Operators are advised to play an important role in the industry chain from the following aspects:

1. Enrich modules and terminals that meet industry requirements as soon as possible, and drive the price to enter the industry expected range.

2. Cooperate with industry integrators to share Know How. Operators quickly obtain industry recognition and requirements from integrators. Integrators help promote 5G technologies to the industry.

3. Different industries may have different business models. Operators can provide flexible business model options based on the refined industry chain and existing business models.

2.10 Cloud Office

2.10.1 Industry Overview

Modern enterprises are pursuing more efficient and secure office processes and management modes. Traditional office working are shifting to mobile and cloud-based office. Cloud office services based on cloud computing and cloud storage technologies are gaining popularity and posing higher requirements on network communications technologies. Incorporating edge computing and AR/VR technologies into cloud office products has become a trend, and will bring enterprises differentiated competitive advantages and more market recognition.

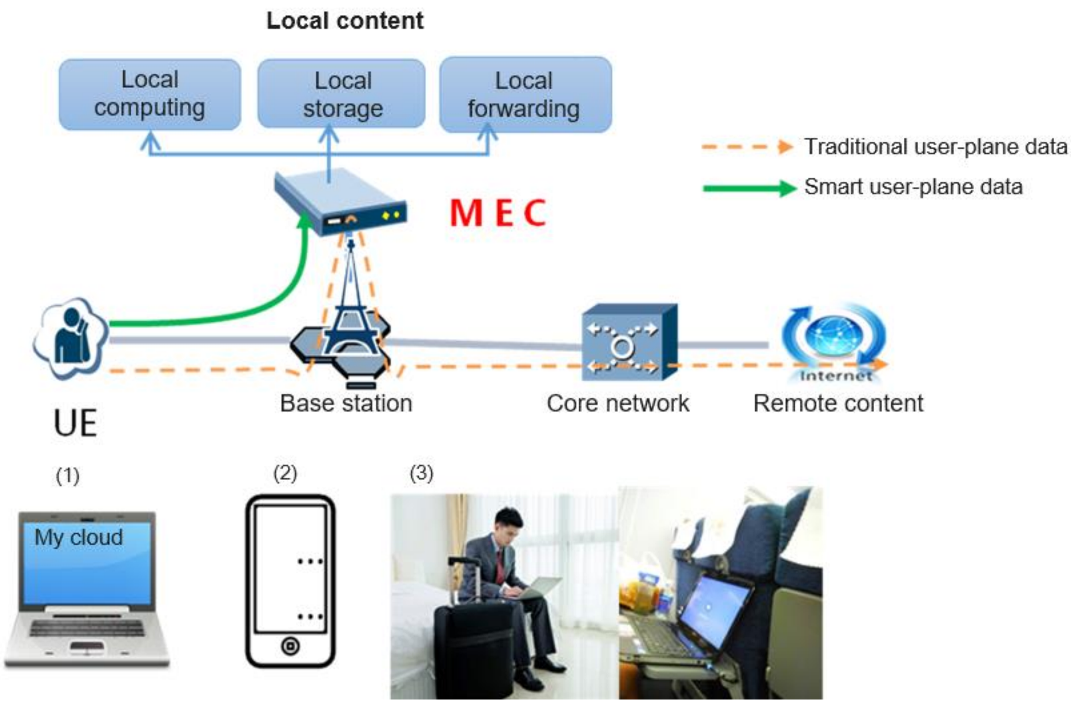
Currently, enterprises are facing an increasingly harsh competition environment, with growing labor costs. Driven by efficiency improvement and cost reduction, enterprise-oriented services will prosper.

2.10.2 Typical Scenarios

- Cloud storage

With 5G, the office cloud storage synchronizes office files with the cloud in real time, enabling users to obtain and operate files anytime and anywhere. Cloud-based storage reduces the requirements for local hard disks of office devices or hard disks are simply unnecessary. Terminals can be lighter and more cost-effective, and consume less power.

Figure 2-1 Office cloud storage network

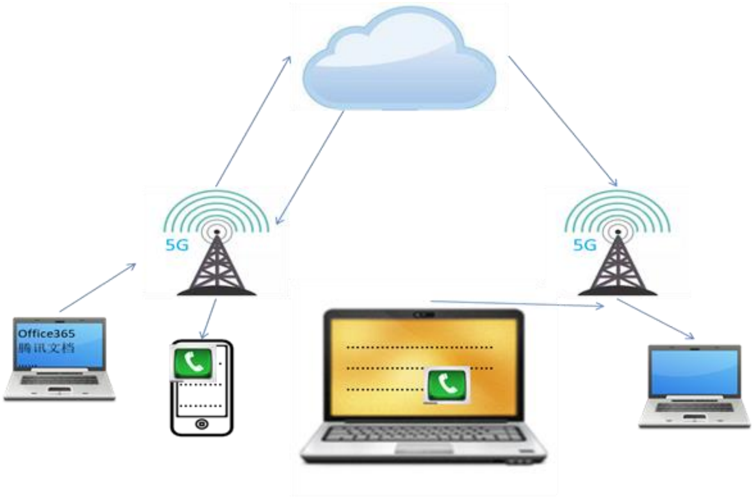


In scenario 1, content is stored in the cloud in daily office work. In scenario 2, employees in, outside or after work can use mobile terminals to quickly synchronize resources and upload processed resources, greatly improving work efficiency. In scenario 3, 5G cloud office devices are used for employees on business trips, especially cross-border business trips. After arriving at the destination, they can synchronize data in a timely manner.

- Cloud synergy

Office cloud synergy allows multiple users to concurrently edit the same document on different terminals and displays editors and updates in real time. Collaborative office at different locations is shaping a trend. Cloud synergy software coupled with 5G enables fast sharing of large files and collaborative editing of documents, reducing the latency of collaborative office and development and improving cooperation efficiency.

Figure 2-2 Cloud synergy



- Immersive video conferencing

The 5G immersive video conference system is based on devices such as laptops, mobile phones, conference terminals, and AR glasses. It supports multi-party access through apps, web pages, and mini programs, allowing for mobile and collaborative office. Compared with traditional video conference systems, this system ensures that users can experience immersive conference anytime, anywhere, and through any device or any access mode.

Real-time interactive video services have strict requirements on network features such as high rate and low latency. As shown in the following figure, 5G, with its large bandwidth, enable high-speed and stable 4K and 8K HD video transmissions. For subscribed video conference services, when a terminal initiates a video conference, the terminal is connected to the video conference server through a dedicated bearer. This ensures that video conference services can enjoy higher priorities and better scheduling policies on the network.

Figure 2-3 Wireless QoS guarantee solution for real-time interactive video services

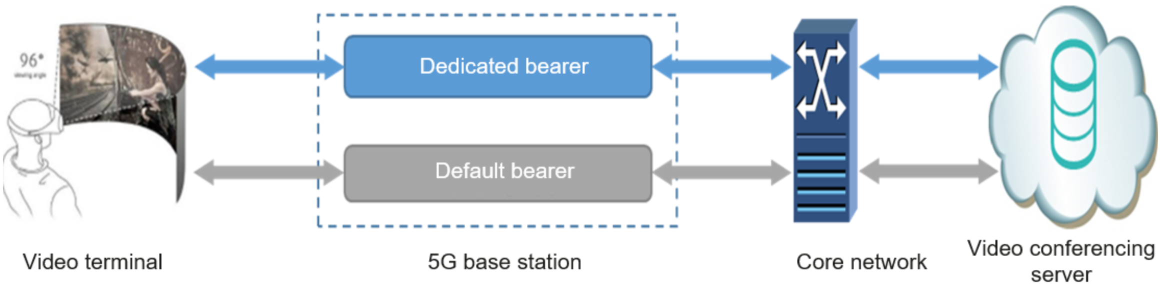


Figure 2-4 Multiple types of terminals accessing the video conference system

Figure 2-5 AR holographic video conference

2.10.3 Key Technical Requirements

Item	Cloud storage	Cloud synergy	Immersive video conferencing
Current Connectivity Technology Used	Wi-Fi, optical fiber	Wi-Fi, optical fiber	Wi-Fi, optical fiber
Form of Device	Desktop computer/Laptop	Desktop computer/Laptop	Desktop computer, laptop, or video conference terminal
Pain Point	1. High document storage costs 2. Inconvenient sharing	Multiple users unable to share and edit data at the same time, resulting in low efficiency	Un-guaranteed network quality and poor video quality
Protocol	3GPP protocols		
Capacity Requirement	High density	High density	High density
Coverage Requirement	Full coverage for indoor and outdoor areas	Full coverage for indoor and outdoor areas	Full coverage for indoor and outdoor areas
Mobility Requirement	Same as 5G public network requirements	Same as 5G public network requirements	Same as 5G public network requirements
Latency Requirement	200 ms	100 ms	150 ms
Bandwidth Requirement	Uplink/Downlink rate: 2 Mbps	Uplink/Downlink rate: 2 Mbps	Uplink rate: 15 Mbps Downlink rate: 15 Mbps

			(4K is used as an example)
Traffic Model	-	-	-
Positioning Requirement	-	-	-
Voice Requirement	No	No	
Reliability Requirement	Same as 5G public network requirements	Same as 5G public network requirements	
Security Requirement	1. Data is circulated within the campus. 2. MNOs and non-enterprise authorized users cannot monitor or trace enterprise network data flows. 3. An enterprise can set a whitelist to authenticate terminals. Only authenticated terminals can access the enterprise network. 4. An enterprise has the right to locate and trace IoT devices connected to the enterprise network. 5. MNOs and non-enterprise authorized users cannot query key information (such as the number of online devices) that may expose the enterprise production and operation status.		
Deployment Model Requirement	The public network and private network solution can work with MEC and network slicing to improve network performance.		
Business Model Requirement	-	-	
Whether the Public Network Meets the Requirements	No	Yes	Yes

2.11 Education

2.11.1 Industry Overview

With the popularization of Internet and smart terminals, learners in the future will grow in a new social environment: network-based, digital, and individualized. Intelligent learning environments and self-learning activities will become new forms of future learning. Against this backdrop, education informatization presents the following characteristics:

- Smarter education environment. The ubiquitous communication network and sensor devices intelligently sense the scenarios and characteristics of learners and proactively adapt to individual requirements.
- Standardized models of education data collection and analysis established for seamless education information circulation
- Intelligent education service collaboration for reorganizing business processes and innovating service forms
- Precise analysis of individuals provided by a smart learning system and high-quality education resources allocated on demand

- High-quality education resources and services shared on the network to provide equal learning opportunities

To facilitate education informatization, schools are deployed with multiple networks, including wired networks, Wi-Fi, campus networks, IoT networks, and TV networks, to carry campus services such as scientific research sharing, multimedia teaching, electronic reading, material storage, and other services such as administration, teacher office, school forum, and social networking. With the deepening of digital transformation, smart network terminals and more and more innovative applications are transforming and upgrading traditional education. Students and teachers are expecting better network services and richer multimedia experience, including online learning, immersive teaching, online course preparation, and smart management. In addition, they also want to enjoy efficient and convenient network experience anytime anywhere in areas such as public places, classrooms, libraries, auditoriums, conference rooms, and dormitories. Realization of those requirements depends on the maturity and application of technologies represented by AI, VR, and big data in the 5G era. 5G will help traditional networks to, as much as possible, break limitations in speed, latency, and transmission capacity. 5G can provide a stronger impetus for the transformation in the education field.

2.11.2 Typical Scenarios

The education industry can be divided into early education, K-12 education, higher education, and vocational education and skill training. In fields such as early education, K-12 education, and vocational education and skill training, 5G networks serve as WAN for outdoor use cases. Use case examples include access to cloud video surveillance through mobile phones in early education, live videos and outdoor courses on large playgrounds in K-12 education, and practical trainings in vocational education and skill training, where a large amount of video and sensor data needs to be transmitted over 5G networks during vehicle driving tests. In higher education, application scenarios are diverse because of large areas and a large number of employees. A campus LAN and a professional equipment room are constructed and connected to the education network and Internet. To ensure communication inside and outside the campus, operators need to deploy networks across the entire campus to provide full indoor and outdoor coverage. The following describes some typical application scenarios.

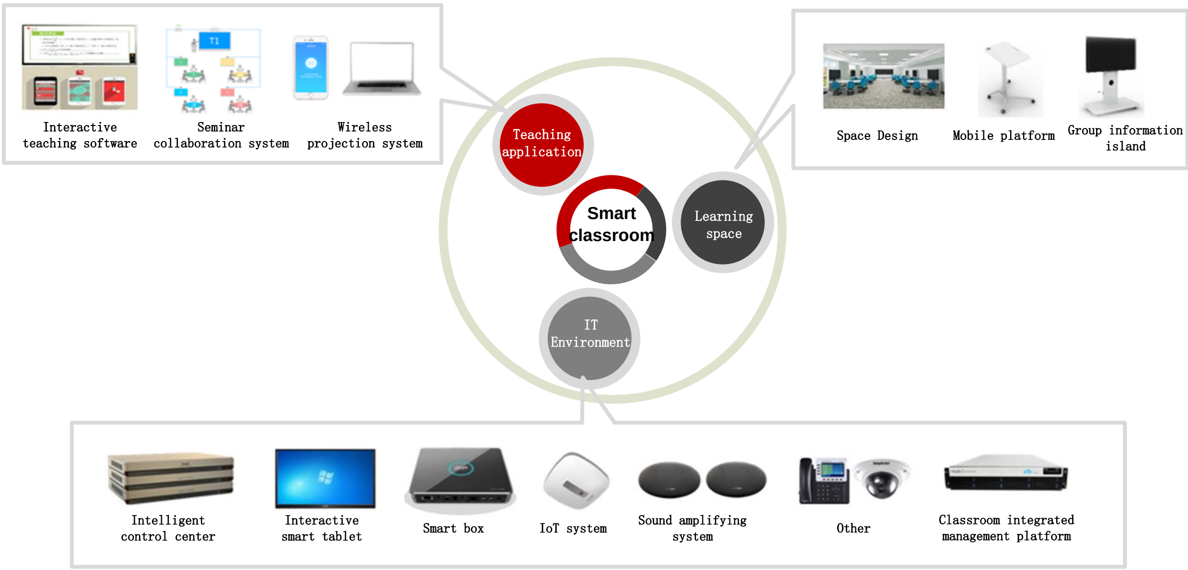
- Smart classroom

In the vision of education informatization 2.0, smart classrooms facilitate teaching mode innovation by deeply integrating technologies with teaching to incubate new teaching modes such as inquiry-based teaching, small-class teaching, hybrid teaching, and flipped classroom.

In higher education, based on the constructivism theory and the Pedagogy-Space-Technology (PST) framework, "5C" (construction, communication, connection, collaboration, and creation) is proposed regarding learning environment and "simple integration", realizing the deep integration of learning space, information technologies, and education and teaching.

In general education, based on the theory of group cooperative learning, information technologies and new teaching methods are deeply integrated to cater to the transformation of classroom teaching. Smart classroom allows for regular group cooperative learning and learning data collection, providing basis and support for teachers to continuously improve teaching.

Figure 2-1 Smart classroom solution



- 4K VR/AR

4K VR/AR will be widely used in classrooms, labs, teaching, and scientific research.

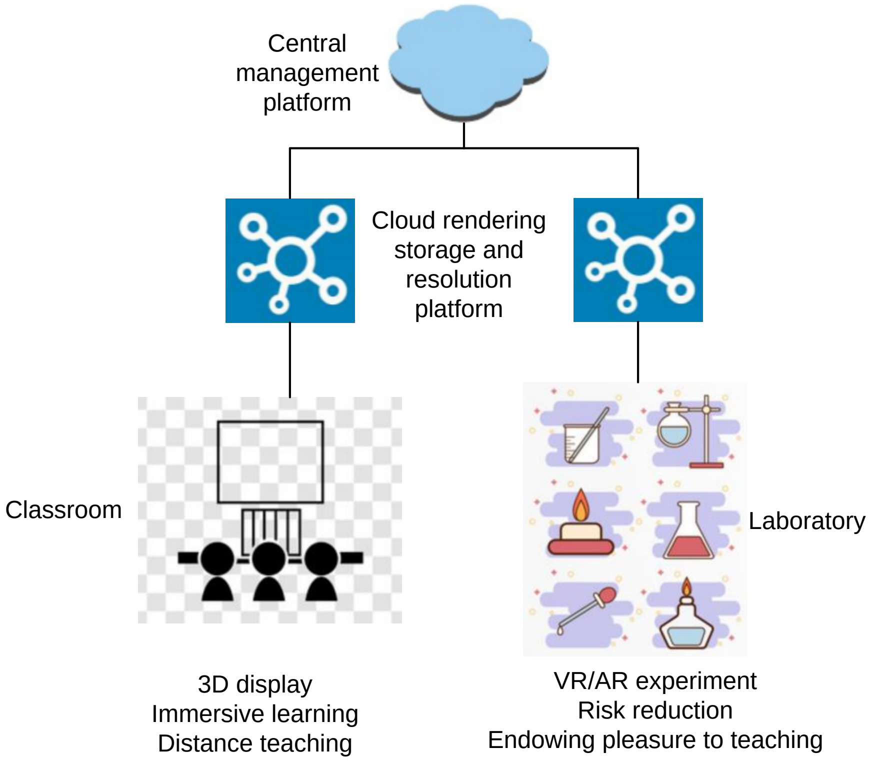
In classroom teaching, the VR/AR technology can visualize abstract learning content with natural interaction, such as 3D object display, 3D space display, exhibit introduction, virtual space creation and construction, and virtual scenario construction. The VR/AR technology can provide students with an unparalleled immersive learning experience than traditional teaching materials, helping to promote students' initiative to acquire knowledge and achieve better knowledge retention.

Many experiments are infeasible due to existing school conditions, such as nuclear reaction experiments, those involving radioactive or toxic substances, as well as experiments using materials of whopping prices. The VR/AR technology can effectively resolve such problems and allows repeated operations. In addition, a VR lab is of absolute security, meaning that it does not cause personal accidents due to misoperations.

In distance education, some teaching experiments and courses that should be provided cannot be carried out considering experiment equipment, experiment sites, and teaching funds. The VR/AR technology can make up for these shortcomings. Students can perform various experiments at home just as real experiments, enriching their perceptual knowledge and deepening their understanding of teaching content.

Regarding scientific research and experimental observation, users are allowed to observe more accurate and effective data for subsequent analysis or use. Therefore, 5G use case for a high simulation enables some phenomena that are difficult to observe into a virtual world so that users can observe in a more comfortable and convenient perspective. Correspondingly, the system also provides same data as a real experiment.

Figure 2-2 VR/AR scenario



2.11.3 Key Technical Requirements

Item	Smart classroom	4K VR/AR
Current Connectivity Technology Used	Wi-Fi	Wi-Fi
Pain Point	5G hardware and terminals	High bandwidth and low latency
Capacity Requirement	In a classroom with 64 users, nine users use the projection function and other users access the Internet normally.	A classroom or lab with 20 to 60 terminals
Coverage Requirement	Classrooms where laptops, handheld terminals, or TVs are used	Classrooms or labs where VR/AR terminals are used
Mobility Requirement	Less likely to move	Less likely to move
	Less likely to move in classrooms	Less likely to move in classrooms or labs
Latency	< 50 ms	< 20 ms
Bandwidth Requirement	Screen projection: 10 Mbps (Windows and Android)/40 Mbps (Mac pro and iPad); multicast detection required	5 Mbps

	Downlink: 32 Mbps	Downlink: 60 Mbps
Traffic Model	Incident-triggering	Incident-triggering
Positioning Requirement	Indoor	Indoor
	Stationary	Stationary
	Room-level positioning	Room-level positioning
Voice Requirement	Required	Not required
Reliability Requirement	99.99%	
Security Requirement	Stored locally	
Deployment Model Requirement	Exclusive spectrums	
	Exclusive base stations	
	Local UPF	
Business Model Requirement	Build a fully connected education private network, deploy an education-specific edge cloud that integrates computing, storage, AI, and security capabilities, and provide an application enablement platform with management and security capabilities to build a smart campus and diversified applications.	

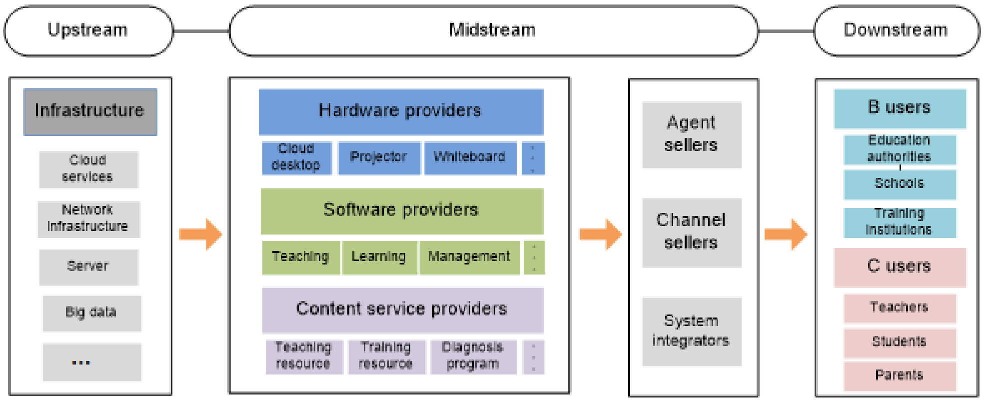
Compared with traditional teaching, 5G will bring a faster, better, and smoother experience to school users.

- Unified network bearer: All powered-on terminals, like mobile phones, access 5G networks. All teaching background applications can be carried on the 5G edge cloud platform of MNOs or schools, which is secure and maintenance-free.
- Ultra-high bandwidth: empowers interactive display terminals and signal transmission and processing terminals to produce 4K images, bringing clear and natural display to teachers and students.
- Higher speed and lower latency: ensures normal recording and streaming in classrooms. During distance education, 4K or even clearer images are seen at remote sites without delay.
- High reliability: 5G networks ensure stable and reliable data collection and transmission, bring more stable, richer, more efficient, and more valuable data services to students and teachers.
- Network slice: constructs multiple private, virtual, isolated, and on-demand logical networks to meet various service requirements (such as latency, bandwidth, and number of connections).

2.11.4 Industrial Value Chain Analysis

The education informatization industry has formed a clear closed-loop industry chain. See the following figure.

Figure 2-1 Industry chain of education informatization



The upstream refers to the infrastructure, including network infrastructure and cloud services. It provides storage, computing, and network services for midstream and downstream enterprises.

The midstream includes software and hardware providers, and content service providers, agent channel sellers, and system integrators. It provides various intelligent services such as teaching for downstream users. The 5G network can revolutionize education services from the traditional communications network. With high speed and low latency capabilities of 5G, various services such as teaching, learning, practice, management, and evaluation can collect more comprehensive data through real-time awareness. 5G base stations enable fast data processing and computing, providing precise support for various intelligent services. Midstream enterprises can feed back data to the upstream to improve infrastructure construction.

The downstream refers to users, including B2B and B2C users. Downstream users can enjoy various services provided by the upstream and midstream enterprises and in turn promote services of the upstream and midstream enterprises by providing data support and guidance for refined services.

5G drives education informatization to develop faster. Infrastructure is the easiest way for MNOs to provide users with network, computing, and storage services. The infrastructure includes 5G base stations, server clusters, and storage devices. At the same time, MNOs need to seek for partners to build an ecosystem for the entire industry. For example, working closely with hardware suppliers in the midstream to accelerate 5G terminal upgrade, cooperating with software suppliers in the midstream to obtain more refined data and improve the operation and service efficiency, collaborating with enterprises and authoritative organizations in fields such as big data and AI to explore more value of data resources.

Such features as large bandwidth, low latency, and edge computing and control capabilities of 5G will lay a solid foundation for future smart education. With presence of traditional 2G/3G/4G, broadband, and Wi-Fi networks, MNOs can build a ubiquitous network access layer that integrates multiple networks based on 5G, achieving seamless, efficient, and real-time transmission of sensor data and information. In addition, MNOs can build a comprehensive IoT network through computers, mobile phones, iPads, sensors, cameras, and wearable devices, implementing all-round sensing of "people, things, and scenes" on campuses.

3 Key Use Case Clusters

3.1 Camera/Video/AR/MR

Since the second half of the twentieth century, the computer vision technology has gradually prospered. Digital images have become important information sources in the contemporary society. The requirements and applications of image processing and analysis continuously incubate technological innovations. Cameras are widely used in vertical industries. Videos are transmitted to clouds and processed either by humans or AI.

With machine vision and cloud computing technologies are becoming more and more popular, cameras are used in vertical industries to collect images and transmit videos to clouds for intelligent analysis, improving production efficiency. Wireless transmission of vision data is applied in cloud surveillance, cloud live broadcast, cloud control, and cloud vision, which differentiate in bandwidths and latency. Cloud surveillance and cloud live broadcast require video transmission in the uplink. Cloud control and cloud vision require not only video uploading but also low-latency, high-reliability reverse control.

Cloud surveillance and cloud live broadcast services usually transmit videos only in the uplink, with larger bandwidths required by cloud live broadcast.

Cloud control and cloud vision not only require uplink video transmission, but also require low-latency and high-reliability reverse control of engineering and medical devices.

In 5G video transmission, video sources may come from real scene shooting and computer rendering, and videos may be processed either by humans or AI. From the perspective of video sources and video processors, 5G video use cases can be classified into the following three types:

1. Videos are generated by computer rendering and sent to humans (cloud X).

- Cloud game
- Cloud PC
- Cloud VR

2. Videos are shot in real scenes and sent to humans for processing (cloud vision).

- Cloud control: Use cases include remote medical ultrasound, remote control of engineering vehicles, and remote control of campus buses.
- Cloud live broadcast: Use cases include professional media production and live broadcast.

3. Videos are shot in real scenes and sent to AI for processing (cloud vision).

- Cloud surveillance: Use cases include security surveillance, and robot and drone patrol.
- Industrial machine vision: Use cases include industrial camera detection and recognition, cloud-based intelligent service robots, and industrial AR remote assistance.

Cloud X applications transmit a large amount of video data in the downlink and a small number of control instructions in the uplink.

Cloud vision applications transmit a large amount of video data in the uplink and a small number of control instructions in the downlink.

Cloud X is mainly used for entertainment and office work, whereas cloud vision applications are mainly used for production in vertical industries. Real-time video data and control are both required in cloud X and cloud vision applications.

Typical scenarios are as follows:

- Cloud surveillance – mobile security surveillance

Security is the cornerstone of a society and an enterprise. Security surveillance systems have been widely used in fields such as public security, traffic management, banking and finance, industrial production, retail, and civil security. Video surveillance is developing towards HD, sharing, and intelligent. In 2019, video surveillance embraced the 4K era. Videos are sent over networks using standard protocols and video sharing is inevitable. Cloud-based AI facial recognition, vehicle license plate recognition, road information recognition, pollutant recognition, and other intelligent video analysis become more mature.

In addition, fixed-point surveillance cannot avoid blind spots, and dense camera deployment costs a lot. Fixed cameras in communities and campuses cannot cover all corners without costing a fortune. Mobile and wireless surveillance is sought after in scenarios such as community patrol, temporary surveillance, visualized patrol in factories and mines, and mobile law enforcement. With mobile robots and drones emerging, cloud vision surveillance is being applied in more scenarios. A sky-to-ground integrated security protection system with mobile HD wireless backhaul becomes a must.

- Cloud live broadcast – professional media live broadcast

The introduction of 5G makes it possible for outdoor ultra-HD professional media live broadcast. Traditional live broadcast requires high costs in satellite lease, private line operation, and fixed location cabling as well as a long construction period of private lines.

5G cloud live broadcast applies to scenarios such as concerts, press conferences, sports events, breaking news, and onsite activities. It uses large bandwidth in the uplink to transmit 8K/VR videos, and supports various applications such as video analysis based on live broadcast services, person and scenario identification, real-time display of athletes and sports event metadata, and VR live broadcast interaction. With 5G, cloud live broadcast provides a brand-new and richer sports event watching experience than 4G. The event scene is broadcast in real time through HD video, delivering an excellent experience to the audiences. At the same time, audiences in the stadium can use mobile applications to enrich their onsite watching experience.

- Cloud control – remote control of engineering machinery

The number of casualties related to construction machinery worldwide reaches 100,000 every year, and the construction and engineering industry is the highest-risk industry. Cloud control enabled by 5G technologies will play a significant role in improving the security and efficiency in ports and mines.

Reliable and stable 5G mobile networks are required to carry applications such as remote driving of AGVs, intelligent cabin surveillance, transparent cargo transportation surveillance, remote control of cranes, and surveillance image identification in ports, remote driving of AGVs in mines, and remote operations of excavators and shovels.

- Cloud control – remote surveillance and intervention of autonomous driving vehicles

In the next 10 years, the number of 5G connected vehicles will hit the 10 million mark and all new cars are connected to the network. People, vehicles, and transportation infrastructure will be interconnected. The improvement of connectivity capabilities shifts vehicle connections from in-vehicle entertainment to unmanned driving, fleet orchestration and management, and intelligent transportation services. While the potential of the IoV market is unleashed, the transportation cost will be greatly reduced.

Autonomous driving in specified scenarios will be put into commercial use, such as logistics vehicles and shuttle buses in factories, schools, and on campuses. Some national laws and regulations require that these vehicles be monitored remotely through the network. If necessary, the vehicles can be controlled remotely by humans.

- Cloud control – telemedicine

Cloud control also applies to wireless medical activities, such as telemedicine and first aid interconnection. Remote real-time consultation and remote ultrasound examination break space limitations between doctors and patients, empowering patients in remote areas to access high-quality medical resources. This can benefit patients who are reduced to poverty due to illness, save medical costs.

The remote ultrasound integrates communications, various sensors, and robot technologies. Doctors remotely control the robot to conduct ultrasound examinations, according to the video and force feedback from patients. The video communication is dependent on the cameras at both the doctor and patient ends. The force feedback information is collected and transmitted by the sensors of the robot manipulator at the patient end. The remote control of the robotic device is performed using a joystick. The robot ultrasound has two video signals, one joystick control signal and one force feedback tactile signal. The two channels of video signals come from the 1080p camera video and ultrasonic image video at the patient end. The data rate of each channel is about 5 Mbps. The data amount of the joystick control signal and the force feedback tactile signal is very small, and the transmission rates of the two signals are both about 150 kbps.

- Cloud vision – industrial machine vision

Machine vision technologies can be used to detect parts invisible to humans, such as infrared rays, microwaves, and ultrasonic waves. Such information can be captured and processed by sensors, extending human's visual range. Compared with machine vision, human vision is easily affected by individual status, prone to weariness after long-time observation, and deteriorates in a harsh environment. However, machine vision does not have such issues, and is widely used in various processes of industrial production. In the smart manufacturing system, the application of machine vision presents four directions: dimension measurement, object positioning, part detection, image recognition.

The video image data volume generated by industrial cameras far outweighs that generated by common cameras. A 100 Mbps data rate is required for transmitting uplink data of a single industrial camera. The reasons are as follows:

- Industrial cameras output raw data with a wider spectral range. The raw data is suitable for a high-quality image processing algorithm, for example, machine vision. However, common cameras generate pictures with a spectrum range only suitable for human eyes. The picture quality is poor after compression, which is unfavorable for later analysis and processing.
- The shutter speed of industrial cameras is very short, which can take snapshots of objects moving at a high speed.
- The image sensors of industrial cameras perform progressive scanning, while the image sensors of common cameras perform interlaced scanning.
- The frame rate of industrial cameras is much higher than that of common cameras.

Wired connections of industrial cameras to PCs in the production line have the following shortcomings:

- Cables are prone to tangling and detachment, affecting production efficiency.
- Local computing resources are non-scalable.
- The same detection object and algorithm cannot be reused by different cables.
- For serial production work stations, local computing resources cannot be reused at different time.
- Video algorithms are difficult to update since products are produced in parallel.

3.1.1 Key Requirements

3.1.2 Functionality Requirements

- Network coverage

Cloud vision applications have high requirements on uplink bandwidth. For a single-channel 1080p camera with a bit rate of 2 Mbps to 6 Mbps, the network needs to provide a bandwidth 1.5 times the bit rate to ensure reliable video transmission. In large-scale application, a single cell may transmit dozens of channels of video streams at the same time, and the uplink network bandwidth needs to reach hundreds of Mbps.

Cloud control and cloud vision applications require E2E high reliability and low latency.

- Data security

Cloud vision is applicable to areas such as factory campuses, ports, airports, and stadiums where users usually expect service data to be isolated from the public network. Additionally, they hope that data is not uploaded to core networks and circulates only within the campus. Furthermore, applications need to be deployed on edge nodes to reduce latency.

- Service assurance

In addition to providing pipe capability, the cloud vision application needs to be optimized in the following aspects: video shooting, encoding, push-pull stream forwarding, decoding, display, storage, and computing at the application layer. Compared with traditional web page access and FTP download services, cloud vision applications are more complex. Industry users require video-based end-to-end quality evaluation tools and reliability evaluation tools to ensure smooth and efficient service operation and to help them identify bottlenecks on service links in a timely manner.

3.1.2.1 Performance and Reliability Requirements

Item	Application Scenario	Typical Uplink Rate of a Single Terminal	Density of Terminals Served by a Single Base Station	Terminal Usage	E2E Latency	Reliability	Mobility	Security
Cloud surveillance	Video surveillance	1080p: 4 Mbps 4K: 20 Mbps	Outdoor: 50	Fixed camera: 7 x 24 hours Temporary mobile cameras: 2 hours	2s	99.9%	Fixed Indoor Outdoor, high speed	VPN
Cloud live broadcast	Media live broadcast	4K: 40 Mbps 8K: 160 Mbps	Outdoor: 5	Temporary: 2 hours	2s	99.9%	Indoor, low speed Outdoor, low speed	Public network
Cloud control (Cloud AR)	AR remote maintenance	1080p: 4 Mbps 4K: 20 Mbps	Outdoor: 5	Temporary: 2 hours	500 ms	99.9%	Indoor, low speed Outdoor, low speed	Public network
	Autonomous	1080p x 4:	Outdoor: 5	Temporary: 2	100 ms	99.9999%	Outdoor,	VPN

	driving Telemedicine	16 Mbps		hours			high speed	
	Remote control on engineering machine	1080p x 8: 32 Mbps Dual-lens: 40 Mbps	Outdoor: 5	Temporary: 2 hours	100 ms	99.9999%	Outdoor, high speed	VPN
Cloud vision	Industrial machine vision	Image cropping: 80 Mbps Raw data: 600 Mbps	Indoor: 10	Industrial camera: 7 x 24 hours	50 ms	99.9999%	Indoor	VPN

3.2 Wireless Control and Automation

This part summarizes key requirements related to industrial controlling and automation.

The contents are extracted from:

- 3GPP Technical Specification TS 22.104: Service requirements for cyber-physical control applications in vertical domains.

3.2.1 Motion Control

A motion control system is responsible for controlling moving and/or rotating parts of machines in a well-defined manner as described in previous chapters.

Table 3-1 Service performance requirements for motion control

Use Case #	Characteristic Parameter				Influence Quantity						
	Communication Service Availability: Target Value in %	**Communication Service Reliability: Mean Time Between Failures**	**E2E Latency: Maximum**	**Service Bit-Rate: User Perceived Data Rate**	**Message Size [Byte]**	**Transfer Interval: Lower Limit**	**Transfer Interval: Upper Limit**	**Survival Time**	**UE Speed**	**UE Quantity**	**Service Area (Note)**
1	99,999 to 99,99999	~ 10 years	< transfer interval value	–	50	500 µs – 500 ns	500 µs + 500 ns	500 µs	≤ 72 km/h	≤ 20	50 m x 10 m x 10 m
2	99,9999 to 99,999999	~ 10 years	< transfer interval value	–	40	1 ms – 500 ns	1 ms + 500 ns	1 ms	≤ 72 km/h	≤ 50	50 m x 10 m x 10 m
3	99,9999 to 99,999999	~ 10 years	< transfer interval value	–	20	2 ms – 500 ns	2 ms + 500 ns	2 ms	≤ 72 km/h	≤ 100	50 m x 10 m x 10 m
NOTE: Length x width x height											

Use cases 1 to 3: Characteristic parameters and influence quantities for a communication service supporting the cyclic interaction described above.

3.2.2 Control-to-Control Communication

Control-to-control communication, i.e., the communication between different industrial controllers is already used today for different use cases, such as:

- Large machines (e.g., newspaper printing machines), where several controls are used to cluster machine functions, which need to communicate with each other; these controls typically need to be synchronized and exchange real-time data.
- Individual machines that are used for fulfilling a common task (e.g., machines in an assembly line) often need to communicate, for example for controlling and coordinating the handover of work pieces from one machine to another.

Typically, a control-to-control network has no fixed configuration of certain controls that need to be present. The control nodes present in the network often vary with the status of machines and the manufacturing plant. Therefore, hot-plugging support for different control nodes is important and often used.

Use Case #	Characteristic Parameter			Influence Quantity					
	Communication Service Availability: Target Value in %	**Communication Service Reliability: Mean Time Between Failures**	**E2E Latency: Maximum**	**Message Size [Byte]**	**Transfer Interval**	**Survival Time**	**UE Speed**	**UE Quantity**	**Service Area (Note 1)**
1 (note 2)	99,9999 to 99,999999	~ 10 years	< transfer interval value	1 k	≤ 10 ms	10 ms	stationary	5 to 10	100 m x 30 m x 10 m
2 (note 2)	99,9999 to 99,999999	~ 10 years	< transfer interval value	1 k	≤ 50 ms	50 ms	stationary	5 to 10	1000 m x 30 m x 10 m
NOTE 1: Length x width x height NOTE 2: Communication may include two wireless links (UE to UE).									

Use cases 1 and 2: Control-to-control communication between different motion (control) subsystems.

3.2.3 Industrial Ethernet Wireless Replacement

Use Case #	Characteristic Parameter			Influence Quantity					
	Communication Service Availability: Target Value in %	**Communication Service Reliability: Mean Time Between Failures**	**E2E Latency: Maximum**	**Data Rate [Mbps]**	**Transfer Interval**	**Survival Time**	**UE Speed**	**UE Quantity**	**Service Area (Note 1)**
1 (periodic traffic)	99,9999 to 99,999999	~ 10 years	< transfer interval value	50	≤ 1 ms	3 * transfer interval	stationary	2 to 5	100 m x 30 m x 10 m
1 (aperiodic traffic)	99.9999 to 99.999999	~ 10 years	< transfer interval value	25	≤ 1 ms (note 2)		stationary	2 to 5	100 m x 30 m x 10 m
2 (periodic traffic)	99.9999 to 99.999999	~ 10 years	< transfer interval value	250	≤ 1 ms	3 * transfer interval	stationary	2 to 5	100 m x 30 m x 10 m
2 (aperiodic traffic)	99.9999 to 99.999999	~ 10 years	< transfer interval value	500	≤ 1 ms (note 2)		stationary	2 to 5	100 m x 30 m x 10 m
NOTE 1: Length x width x height NOTE 2: Transfer interval also applies to scheduled aperiodic traffic.									

Use case 1: In the case of the 100 Mbps link replacement, 50% periodic traffic and 25% aperiodic traffic are assumed.

Use case 2: In the case of the 1 Gbps link replacement, 25% periodic traffic and 50% aperiodic traffic are assumed.

3.2.4 Closed-loop Control

In the closed-loop control use case for process automation, several sensors are installed in a plant and each sensor performs continuous measurements. The measurement data is transported to a controller, which takes decision to set actuators. The latency and determinism in this use case are crucial. This use case has very stringent requirements in terms of latency and service availability. The required service area is usually bigger than for motion control use cases. Interaction with the public network (e.g., service continuity, roaming) is not required.

Table 3-1 Service performance requirements for closed-loop control in process automation

Use Case #	Characteristic Parameter			Influence Quantity							
	Communication Service Availability: Target Value in %	**Communication Service Reliability: Mean Time Between Failures**	**E2E Latency: Maximum**	**Message Size [Byte]**	**Transfer Interval: Lower Bound**	**Transfer Interval: Target Value**	**Transfer Interval: Upper Bound**	**Survival Time**	**UE Speed**	**UE Quantity**	**Service Area (Note)**
1	99,9999 to 99,999999	≥ 1 year	< target transfer interval value	20	– 5% of target transfer interval value	≥ 10 ms	+ 5% of target transfer interval value	0	Typically stationary	Typically 10 to 20	Typically ≤ 100 m x 100 m x 50 m
NOTE: Length x Width x Height											

Use case 1: Several sensors are installed in a plant and each sensor performs continuous measurements. The measurement data is transported to a controller, which takes decision to set actuators.

3.2.5 Mobile Control Panels

Control panels are crucial devices for the interaction between people and production machinery as well as for the interaction with moving devices. These panels are mainly used for configuring, monitoring, debugging, controlling, and maintaining machines, robots, cranes or entire production lines. In addition to that, (safety) control panels are typically equipped with an emergency stop button and an enabling device, which an operator can use in case of a safety event in order to avoid damage to humans or machinery.

Due to the criticality of these safety functions, safety control panels currently have mostly a wire-bound connection to the equipment they control. In consequence, there tend to be many such panels for the many machines and production units that typically can be found in a factory. With an ultra-reliable low-latency wireless link, it would be possible to connect such mobile control panels with safety functions wirelessly.

Use Case #	**Characteristic Parameter**				**Influence Quantity**							
	Communication Service Availability: Target Value in %	**Communication Service Reliability: Mean Time Between Failures**	**E2E Latency: Maximum**	**Service Bitrate: User Experienced Data Rate**	**Message Size [Byte]**	**Transfer Interval: Lower Bound**	**Transfer Interval: Target Value**	**Transfer Interval: Upper Bound**	**Survival Time**	**UE Speed**	**UE Quantity**	**Service Area (Note)**
1 (note 3)	99,9999 to 99,999999	~ 1 month	< target transfer interval value	–	40 to 250	– < 25% of target transfer interval value	4 ms to 8 ms	+ 25% of target transfer interval value	Target transfer interval value	< 7.2 km/h	TBD	50 m x 10 m x 4 m
2 (note 3)	99,9999 to 99,999999	~ 1 month	< target transfer interval value	> 5 Mbps	–	– < 25% of target transfer interval value	< 30 ms	+ 25% of target transfer interval value	TBD	< 7.2 km/h	TBD	TBD

Use Case #	**Characteristic Parameter**				**Influence Quantity**							
	Communication Service Availability: Target Value in %	**Communication Service Reliability: Mean Time Between Failures**	**E2E Latency: Maximum**	**Service Bitrate: User Experienced Data Rate**	**Message Size [Byte]**	**Transfer Interval: Lower Bound**	**Transfer Interval: Target Value**	**Transfer Interval: Upper Bound**	**Survival Time**	**UE Speed**	**UE Quantity**	**Service Area (Note)**
3 (note 3)	99,9999 to 99,999999	~ 1 year	< target transfer interval	–	40 to 250	– < 25% of target transfer interval value	< 12 ms	+ 25% of target transfer interval value	12 ms	< 7.2 km/h	TBD	Typically 40 m x 60 m; maximum 200 m x 300 m

NOTE 1: Length x Width (x Height)

NOTE 2: The transfer interval is not so strictly periodic in these use cases. The transfer interval deviates around its target value within bounds. The mean of the transfer interval is close to the target value.

NOTE 3: Communication may include two wireless links (UE to UE).

Use case 1: Periodic, bi-directional communication for remote control. Examples for controlled units include assembly robots and milling machines.

Use case 2: Aperiodic data transmission in parallel to remote control (use case one)

Use case 3: Periodic, bi-directional communication for remote control. Examples for controlled units include mobile cranes, mobile pumps, and fixed portal cranes.

3.3 AGV and Drone in Industrial Mobility

3.3.1 AGV

The manufacturing industry today is pressed to cater for diversified and individualized demands, making flexible production a general trend. Especially in the 3C industry such as smart terminal manufacturing, constant product updates call for flexible adjustment of production lines at all times. This entails production line modularization and flexible combination of operations. Automated guided vehicles (AGVs) have been widely used in smart factories to supplement flexible manufacturing by merits of high efficiency, flexibility, and low power consumption. Flexible manufacturing allows production to be changed rapidly with the least human intervention, and is incubating an array of new technologies. 5G will help manufacturing enterprises improve non-systematic application of wireless network technologies, profoundly promoting the rollout of Industrial Internet and deepening the transformation of smart manufacturing. Therefore, 5G and AGV mixed operation will benefit enterprises and exert advantages in the future.

The following discusses AGV types and application scenarios regarding 5G+AGV use cases.

Transport and Handling AGV

In the vision of Industry 4.0, AGVs will be widely used in various sectors as cargo transfer robots to replace manual handling. However, transferring goods is not the sole purpose. Instead, future AGVs will be next-generation smart industry devices that come with big data, IoT, and cloud computing capabilities to deliver multiple functions, such as real-time sensing, security identification, multi-obstacle avoidance, intelligent decision-making, and automatic execution. Throughout the smart production, AGVs can run uninterrupted without manual intervention, greatly slashing labor costs. Different AGVs coordinate with each other based on predefined paths and vehicle management solutions, maximizing the work efficiency and quality in limited time and space. Generally, the AGV moving speed does not exceed 5 m/s, but AGV control is latency-sensitive. In most cases, a latency longer than 100 ms has a significant impact on AGVs. This presents high requirements on wireless communication quality. AGV+5G mixed application will help improve the operation efficiency and stability of AGVs in smart warehousing systems. With a significant latency improvement over 4G, 5G is able to keep the latency of control signal transmission within an acceptable range.

With the large bandwidth, low latency, high reliability, and wide connection capabilities of 5G, the compute resources required by AGVs are managed by cloud and centrally scheduled on the MEC nodes deployed in smart factories (or industrial parks/ports and logistics campuses). This simplifies AGV functions to execution only, which significantly reduces costs.

Coverage Scope	**Vertical Coverage**	**Uplink Bandwidth**	**Downlink Bandwidth**	**Latency**	**Number of Connections/ km^2**	**Reliability**
Indoor	30 m	25 Mbps (4K, H.265, 1 channel)	25 Mbps (4K, H.265, 1 channel)	20 ms (multi-AGV collaborative control)	1,000	99.999%

Cloud V-SLAM AGV

The development of visual positioning technologies drives the maturity of global positioning and mapping technologies (simultaneous localization and mapping or shortly SLAM and Visual Inertial Odometry or simply VIO) that leverage image data of unmarked scenarios and sensor data of inertial measurement units. This allows for AGV positioning and control using only relatively low-cost sensors. However, in most cases cost-efficient embedded computers cannot provide all the required compute resources and therefore high-performance computers are required for processing. Also, the visual positioning algorithm is sensitive to image quality, and the image transmission rate on a 4G network is low. Even if an advanced compression algorithm such as H.265 is used, the air interface bandwidth still cannot meet the video transmission requirements. If cloud AGVs can transmit data over a 5G network that features higher bandwidth, lower latency, and better stability, cloud-based visual navigation can be applied to AGVs.

A 5G cloud AGV uses visual inertial ranging for real-time positioning and mapping (visual simultaneous localization and mapping or shortly V-SLAM), and cost-efficient radar obstacle avoidance. Thanks to large bandwidth and low latency of 5G, images are transmitted to the MEC node for processing in real time, and the MEC node implements high-precision AGV positioning, scheduling, and navigation based on machine vision. V-SLAM improves the AGV positioning accuracy to ±5 mm. MEC processing reduces the cost of a single AGV, and greatly improves cost-effectiveness in large-scale AGV adoption.

Coverage Scope	**Vertical Coverage**	**Uplink Bandwidth**	**Downlink Bandwidth**	**Latency**	**Number of Connections/ km^2**	**Reliability**
Indoor	30 m	100 Mbps (4K, H.265, 4 channels (one binocular camera at the front and rear))	25 Mbps (4K, H.265, 1 channel)	20 ms (V-SLAM image transmission and control)	1,000	99.9999%

3.3.2 Drone

Drones, also known as unmanned aerial vehicles (UAVs), are high-tech products controlled by wireless remote control systems and programs, integrating sensor, communications, information processing, intelligent control, and aeronautical propulsion technologies. They replace labor work in air operations by serving as an air platform and expanding the application scope together with other components. Though consumer drones account for a large market share, industry drones are also favored in fields such as agriculture and forestry protection, electric power and oil pipeline inspection, emergency communications, meteorological surveying and mapping, and logistics due to technological advantages and economic benefits.

A drone flies across areas with 5G coverage so that real-time videos are uploaded to the flight control handle. The handle is connected to a CPE, which then transmits the videos to a 5G base station. Networked drones that access a low-altitude mobile communications network can monitor and manage devices, standardize flight lines, improve efficiency, and promote proper utilization of airspace. 5G enables real-time ultra-HD image transmission, remote low-latency control, and always-online capabilities for networked drones. Real-time control will be significantly improved for drones. The mixed application of 5G and machine vision enables drones to be used in more fields and bring huge economic value.

Drone Application in Agriculture and Plant Protection

Mechanization of plant protection means is crucial for farming mechanization and modernization. Compared to manned aircrafts or large aircrafts, 5G drones are advantageous in terms of efficiency, coverage, cost-effectiveness, footprint, and mobility. They have been widely used in countries such as Japan. 5G drone application in plant protection includes soil analysis, planting, pesticide spraying, monitoring, irrigation, and crop health evaluation.

5G networks assist in drone-based agriculture and plant protection in phases such as task delivery and execution, and drone status reporting. In other activities, such as soil analysis, patrol surveillance, and crop health inspection, drones upload real-time HD videos and multi-spectral images to 5G networks, and can switch to manual intervention mode when necessary.

Coverage Scope	Vertical Coverage	Uplink Rate	Downlink Rate	Latency	Number of Connections /km^2	Reliability
Limited WAN	300 m	25 Mbps (4K, H.265, 1 channel)	1 Mbps (control command data)	20 ms (instruction control)	100	99.999%

Drone Patrol

Traditionally, oil and gas pipelines and power cables are maintained and inspected manually. However, oil, gas, and power pipelines are widely distributed and a majority of them are located in remote areas. Manual inspection is time-consuming and labor-intensive, and faces certain security risks. In the case of natural disasters or accidents, the security status of oil, gas, and power pipelines cannot be obtained in a timely manner.

In particular, with energy industry expansion, energy Internet development, and the ever-increasing growth of oil and gas power pipelines, manual inspection and maintenance face huge challenges. To improve pipeline inspection efficiency and ensure pipeline security, it is an inevitable trend to introduce 5G and drones for pipeline inspection. Nowadays, the civil drone industry is developing rapidly. 5G drones are gradually applied in oil and gas pipeline inspection and are highly favored by energy enterprises.

Coverage Scope	Vertical Coverage	Uplink Rate	Downlink Rate	Latency	Number of Connections /km^2	Reliability
Limited WAN	100 m to 300 m	25 Mbps (4K, H.265, 1 channel)	1 Mbps (control command data)	20 ms (instruction control)	100	99.999%

Drone Application in Surveying and Mapping

Drone-based surveying and mapping unleash potentials in fields such as emergency response, scientific research, education, smart agriculture, smart city, surveying, and scenario-specific inspection. Drones use low-altitude multi-lens cameras to generate HD 3D image data, and automatically generate a 3D geographic information model to quickly obtain geographic information. Drones feature high efficiency, cost efficiency, data accuracy, and flexible operation, meeting specific requirements of different surveying and mapping partners.

Drones require support from 5G networks for remote control in typical surveying and mapping activities such as flight status monitoring, remote control, and network-based positioning. In real-time surveying and mapping model construction activities, drones also require 5G large bandwidths for real-time image transmission and processing. Traditionally, it takes days, weeks, or even months to update a map. With 5G networks, 5G networked drones can generate a real-life vector map within milliseconds. Drones complete the entire process of updating maps, including capturing, transmitting, stitching, and correcting map data, and uploading data to the cloud, improving the efficiency by hundreds of times.

Coverage Scope	Vertical Coverage	Uplink Rate	Downlink Rate	Latency	Number of Connections /km^2	Reliability
WAN	300 m	100 Mbps (4K, H.265, multiple channels)	1 Mbps (control command data)	20 ms (instruction control)	100	99.999%

Drone Application in Live Broadcast

In the future, 5G drones will be widely applied in live broadcast of large-scale activities such as sports events and performances to provide an ultimate experience, and in commercial activities such as advertisements, news, and movies. HD panoramic live broadcast will be available anytime and anywhere so that users are provided with an experience even better than what's seen onsite.

Drones can shoot images and videos from the sky. Panoramic VR live broadcast through drones will bring an immersive experience. A 360-degree panoramic camera is mounted to a drone for video shooting. The panoramic camera capture videos, and stitches and processes video streams. In the uplink, the drone, which is connected to a 5G network, transmits 4K/8K panoramic videos to the video server on the core network. In the downlink, the videos are transmitted to multiple users. As long as users wear VR glasses, they can experience scenes anytime and anywhere without any latency.

Currently, the video resolution is mainly 1080p (highest resolution 2K) on dominant live streaming platforms. With the emergence of live streaming and terminal upgrades, live streaming players demand better experience, calling for a large number of 4K/8K live video streaming services. 5G large bandwidths suffice in assisting drones in live broadcast with a resolution lower than 4K and can even support live broadcast of 8K UHD videos in the future.

Coverage Scope	Vertical Coverage	Uplink Rate	Downlink Rate	Latency	Number of Connections/ km^2	Reliability
WAN	100 m	100 Mbps (8K, H.265, 1 channel)	1 Mbps (control command data)	100 ms (image transmission)	1,000	99.999%

Drone Application in Logistics

In the logistics sector, 5G low-altitude drones automatically transport packages to destinations with the help of 5G network remote control devices and self-provided program control devices. Delivering small packages and key items will be useful in special scenarios owing to improved delivery efficiency and reduced costs.

Drone-based logistics outperforms traditional logistics as follows:

- Congestion-free for efficient transportation
- Emergency management and delivery of small batches of key items
- No terrain restrictions and adaptation to extreme conditions

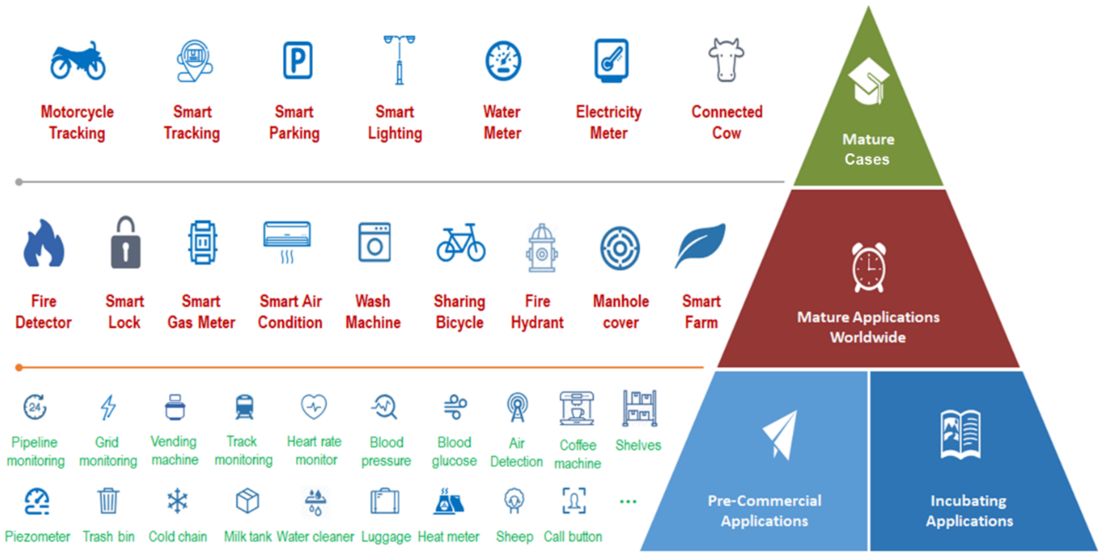
Transportation activities will benefit from 5G networks, such as transportation task delivery and execution, and drone status reporting. To ensure flight safety and for emergency handling, logistics drones also need to have real-time video transmission and control capabilities in cases switchover to manual intervention mode is necessary.

Coverage Scope	Vertical Coverage	Uplink Bandwidth	Downlink Bandwidth	Latency	Number of Connections/km^2	Reliability
Continuous WAN	100 m	25 Mbps (4K, H.265, 1 channel)	1 Mbps (control command data)	20 ms (instruction control)	100	99.99%

3.4 Massive IoT

Massive IoT is one of three principal 5G use cases, alongside URLLC and eMBB, that will enable developments such as smart cities and industrial automation. NB-IoT and LTE-M will be fundamental to the development of massive IoT and in supporting and complementing 5G's myriad use cases and applications. NB-IoT and LTE-M networks are already delivering trusted connectivity to millions of devices around the world, and these networks will continue to be a fundamental component of our 5G future ushering in an era of massive IoT.

The leading industry players have acknowledged the opportunity of NB-IoT and LTE-M in the market. There are many NB-IoT and LTE-M use cases deployed in different industries. Some cases have arisen to commercial adoption or have already been well deployed in world market.



3.4.1 Use Cases in Smart City

Smart Metering

Smart metering reduces the workforce by remotely collecting electricity, water, and gas meter data over the NB-IoT network. With due regard to the advantages of NB-IoT, such as low power consumption, low cost, and wide coverage, NB-IoT based smart meters are used worldwide. They will reduce human labor costs spent on meter reading and meter battery replacement. Smart metering involves water meters, gas meters, and electricity meters.

In addition, the pipeline monitor can detect the leakage of water or gas, it is very critical for utility companies.

Table 3-1 Basic requirements

Coverage	Duration of Battery	Model	Latency	Capacity
Indoor & Outdoor	5-8 years	Uplink < 200 bytes Downlink < 200 bytes	< 5s Reporting meter readings	1000 times/cell

Smoke Detector

Security is a crucial condition for people's living. Safety at residence, old buildings, ancient temples, or factories is constantly emphasized. Now with alarms and incident detection, end users can be notified of anomalies or intrusions in time. Fires can also be detected based on the increasing temperature or smokes at residence or manufacturing sites.

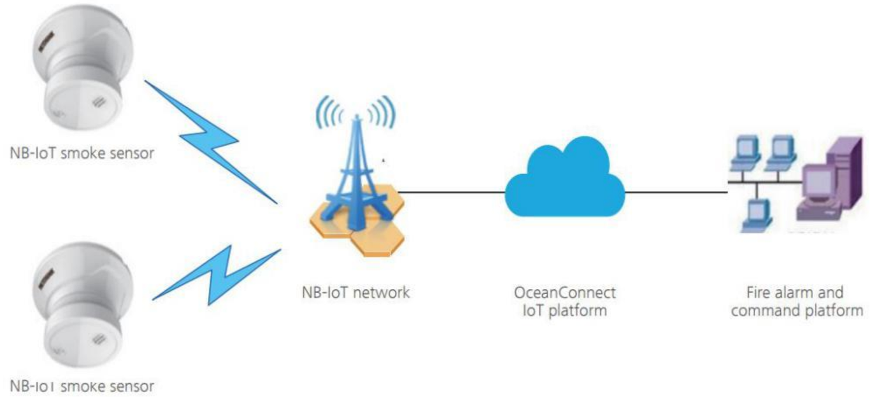


Table 3-2 Basic requirements

Coverage	Duration of Battery	Model	Latency	Capacity	Positioning
Indoor & Outdoor	2–3 years	Uplink < 200 bytes Downlink < 200 bytes	< 3s Alarm reporting	1000 times/cell	N/A

Smart Parking

Parking space is essential for vehicle owners in urban areas. However, drivers often find it difficult to find a vacant parking space, which is really time-consuming and will increase CO2 emission. Smart parking provides real-time information to the vehicle owners to provide greater-quality parking management.

Table 3-3 Basic requirements

Coverage	Duration of Battery	Model	Latency	Capacity	Positioning
Indoor & Outdoor	2–3 years	Uplink < 200 bytes Downlink < 200 bytes	< 2s Reporting status of parking space	1000 times/cell	100 m

Smart Lighting

Smart lighting or street lamp has become an important technology for city safety and energy saving. In an NB-IoT smart lighting solution, the mobile operator provides the network for customers, and the smart lighting solution provider uses the licensed spectrum to provide services with good coverage and high reliability. This solution delivers accurate single-lamp control and maintenance. Smart street lamps are turned on/off or dimmed automatically depending on the season, weather, and other factors. Smart lighting reduces power consumption by 10% to 20%. After applying the NB-IoT smart lighting solution, street lamp providers do not need to manually inspect the lamp status and breakdowns can be accurately and remotely detected.

Table 3-4 Basic requirements

Coverage	Duration of Battery	Model	Latency	Capacity	Positioning
Outdoor	5–8 years	Uplink < 200 bytes Downlink < 200 bytes	< 1s Reporting switch on/off information of street lamps	500 times/cell	100 m

3.4.2 Use Cases in Smart Industry

Asset Tracking

Asset tracking is mostly applied to physical assets by attaching a module device on the asset to transmit its location. Assets are generally tracked by using GPS. This service is significant to logistics and transportation management industries, where sensor modules are used to transmit information over NB-IoT networks. With asset tracking, it is possible to collect and manage data regarding the geographical location of assets, enabling asset owners to detect and respond to accidents in time.

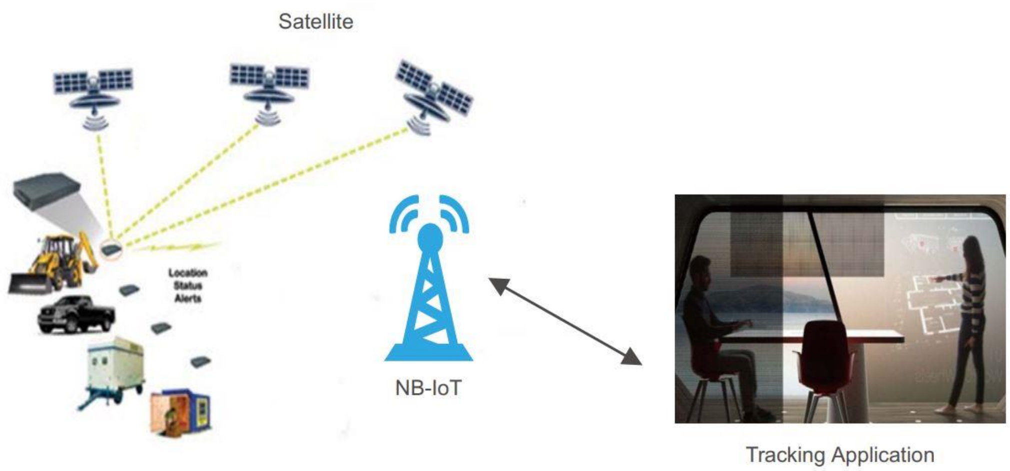


Table 3-1 Basic requirements

Coverage	Duration of Battery	Model	Latency	Mobility	Positioning
Indoor & Outdoor	2–3 years	Uplink < 200 bytes Downlink < 200 bytes	< 2s Reporting the location of goods	< 30 km/hour	100 m

Cattle Monitoring

This application is used to monitor the physiological conditions of cows or cattle, which is essential to effective ranch operation and production. Low-power and high-capacity NB-IoT modules can be attached to cows, enabling farmers to understand cows' natural cycles and when they are most likely to get pregnant, and also predict sickness through monitoring temperature. NB-IoT based devices can be stably connected and able to report the pH level and temperature of the rumen by every ten minutes. At any time the reported values rise to a critical level, ranch owners will receive notifications via APP to take actions as needed.

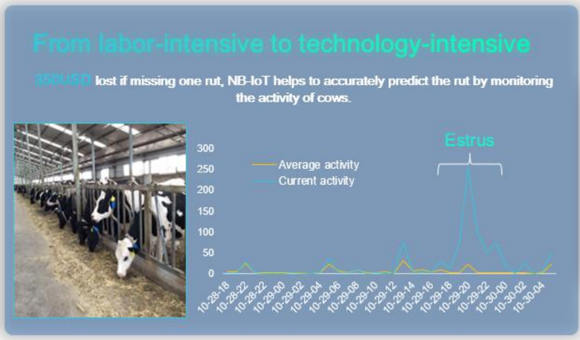


Table 3-2 Basic requirements

Coverage	Duration of Battery	Model	Latency	Capacity	Positioning
Indoor & Outdoor	5–8 years	Uplink < 200 bytes Downlink < 200 bytes	< 5s Reporting the physical condition of cattle	1000 times/cell	100 m

Logistics Tracking

There are big volumes of sensor data generated from tracking devices. Data on shipping containers is collected and kept in view for real-time analysis of shipment locations. Notifications are sent to the user's mobile device for real-time monitoring. NB-IoT based tracker also can detect and report the anomalies of containers.

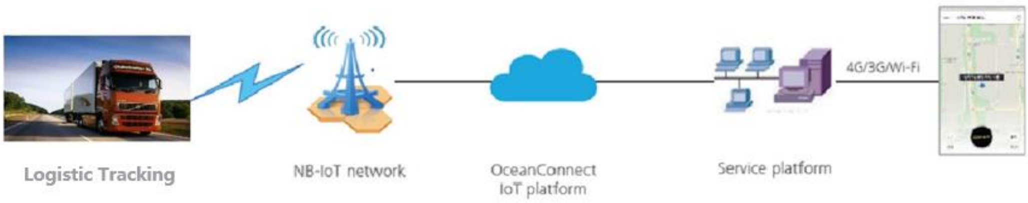


Table 3-3 Basic requirements

Coverage	Duration of Battery	Model	Latency	Mobility	Positioning
Outdoor	1–2 years	Uplink < 200 bytes Downlink < 200 bytes	< 1s Reporting the tracking information or shipment location	80 km/hour	100 m

POS Machine

The Point of Sale (POS) system provides shoppers a better customized experience with IoT. The wireless sensors on the shelves that alert when an item is out of stock may reduce customers' dissatisfaction. IoT will also address another problem for customers. For example, many shoppers report that a long checkout time leads to negative shopping experience. There are many POS machine types. Some simple ones can be supported by NB-IoT, but a high-end POS machine with high requirements on bandwidth is ideal for LTE-M.

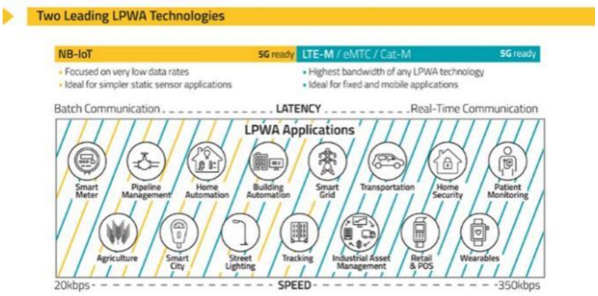


Table 3-4 Basic requirements

Coverage	Duration of Battery	Model	Latency	Capacity	Positioning
Indoor & Outdoor	2–3 years	Uplink: 350 bytes Downlink: 350 bytes	< 5s Shorter payment transaction latency is preferred.	500 times/cell	N/A

3.4.3 Use Cases in Smart Life

Motor Tracking

Motor vehicles (such as motorcycles and electric scooters) are essential for city traffic because of its convenience and mobility. There are more than 100 million motor vehicles nationwide in China. Therefore, the recognition-based motor vehicle management is crucial for a smart city that is trying to improve the public security and traffic management, and also can reduce theft.

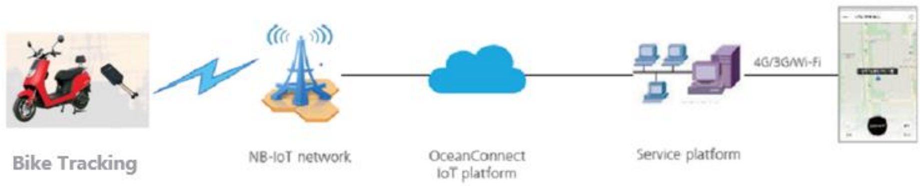


Table 3-1 Basic requirements

Coverage	Duration of Battery	Model	Latency	Mobility	Positioning
Outdoor	5–8 years	Uplink: 200 bytes Downlink: 200 bytes	< 2s Reporting location information	30 km/hour	< 100 m

Pet Tracking

A headache for many pet owners is that their pets may get lost or stolen. This application enables pet owners to constantly track their pet activities (especially the location). A small, lightweight device embedded with an NB-IoT chipset is attached to the neck of a pet, which can report the tracking information to the owner's mobile phone. Pet owners can specify whether the data is reported periodically or in real time.

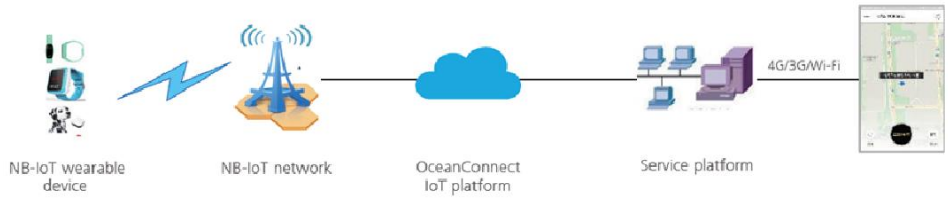


Table 3-2 Basic requirements

Coverage	Duration of Battery	Model	Latency	Mobility	Positioning
Indoor & Outdoor	5–8 years	Uplink: 200 bytes Downlink: 200 bytes	< 5s Reporting location information	< 15 km/hour	< 100 m

Wearables

The past few years witnessed a growth of connected wearables and a successful industry is progressively developing in the way that its applications generally focus on health, fitness, and wellness.

Table 3-3 Basic requirements

Coverage	Duration of Battery	Data Rate	Latency	Mobility	Positioning
Indoor&Outdoor	3–5 years	Uplink: 300 bytes Downlink: 300 bytes	< 2s Reporting detected information	10 km/hour	< 100 m

4 Fundamental Requirements of Industries

5G networks used for industrial productions must meet both differentiated and common requirements of various industries. Extracting common requirements is crucial for operators to accurately understand industry customer requirements, develop technical strategies and frameworks, and innovate business models. The common requirements of various industries on 5G are generally classified as follows:

- High bandwidth

  Concurrent access of multiple HD video devices has been widely used in industrial vision, media, medical care, and education, posing challenges to network bandwidth. In particular, scenarios such as industrial machine vision and multi-position media live broadcast impose higher requirements on uplink bandwidth. For example, data transmission of a single industrial camera, free-view four-channel 4K live broadcast, and uplink transmission of dozens of 1080p surveillance video streams in a single cell, require hundreds of Mbps.

- High reliability

  Industry customers have specific requirements on network reliability indicators. For example, in smart grid control scenarios, the reliability must reach 99.9999%. Only high-reliability networks can support continuous production activities and improve production efficiency.

- Low latency and limited jitter

  Low latency is critical to smart factories, remote vehicle control, autonomous driving, and drone-related signal transmission and control. Reducing the average E2E latency, as traditionally practiced, cannot support the actual production environment. Especially in the time sequence-based industrial control field, if the latency exceeds the threshold due to large jitter, industrial connections will fail. Operator-provided Enterprise Network require not only a low latency on average but also the capability to control the latency and jitter within a limited range.

- Strong isolation and local survivability

  Operators' 5G networks serve both the public and industry customers, allowing full utilization of operators' industry influence and network scale effect. In addition, Operator-provided Enterprise Network must be isolated from the public network. The isolation ensures that the enterprise networks used for production have the local survivability to function normally even in the event of public network faults.

- Security, privacy, and local processing capabilities
- Operator-provided Enterprise Network, through architecture design and security and privacy protection capabilities, can meet enterprises' confidentiality and geographical requirements of data transmission and sensitive information. For example, massive data generated during enterprise production often requires local storage and processing.
- Integration of the existing industry environment and industry technology trend

  During the in-depth integration of 5G with industries, how to use 5G with existing OT and IT infrastructure such as industrial networks and devices is a challenge. The Operator-provided Enterprise Network solution should not only be applicable to new factory construction environments, but also adapt to and connect to existing industrial environments to create value. In addition, 5G networks must be able to integrate with industry technology trends. Taking smart factories as an example, 5G networks must be able to integrate with industrial Ethernet and TSN-based automation environments and support technology trends such as OPC UA, thereby implementing wireless and mobile industrial automation.

- O&M capabilities

  The Operator-provided Enterprise Network need to self-management of enterprises and monitoring of networks. In addition, operators together with third-party integrators should be able to provide E2E O&M services.

- Network customization capabilities

  The capability is required to provide network customization for different sectors and objects in different industries based on the requirements of industry customers and the integration with key production links.

5 Key Network Technology Suggestions

The following describes the methods for deploying enterprise networks to meet the common requirements of various industries.

5.1 Network Slicing

Network slicing is a new capability defined by 5G SA. It aims to design E2E isolated virtual enterprise network connections and use a unified ID to identify terminals, wireless networks, transport networks, and core networks, implementing networkwide, centralized orchestration, management, and services Network slicing-based enterprise networks can use QoS, DNN, and edge computing technologies, as well as dedicated frequencies, dedicated base stations, and dedicated resource pools, to meet differentiated scenario-specific service requirements of industries such as industrial control, autonomous driving, and telemedicine. Network slicing can be constructed based on traditional dedicated hardware or universal NFV/SDN infrastructure to achieve low-cost and efficient operation. Network slicing has advantages such as agile network construction, function customization, and quality assurance.

5.2 Mobile Edge Computing

MEC deploys some functions, content, and applications of multiple access modes at the network edge close to the access side. It processes services closer to users and coordinates content, applications, and networks to provide low-latency, secure, and reliable services, assuring optimal user experience. MEC in 5G is valuable in basic service implementation, service security assurance, and business model support for vertical industry applications. From the perspective of service implementation, the user-plane functions of the core network are deployed at the edge, reducing the network delay. From the perspective of service security, the user plane of the core network is deployed on enterprise campus networks, so that enterprise service data can be processed locally, providing higher security assurance for enterprises. From the business perspective, MEC can save transmission resources. Especially for video applications that have a large quantity of video data transmission requirements, data can be locally stored and calculated within the campus networks, reducing the transmission resource overhead and business costs for applications at the edge to access the core network and Internet.

5.3 Wireless Enterprise Network

Customers of industries such as factories, ports, campuses, and mines, require local deployment and customized network performance. Significantly different from public networks, networks for these industries have high customization requirements in many aspects, such as the deployment area environment, network capability, and data isolation. Wireless enterprise networks are applicable to industries that have strong requirements for network localization and control. Based on the application modes of wireless network devices and spectrum resources, there are three types of wireless enterprise network solutions: mixed enterprise network solution (M-ENS), virtual enterprise network solution (V-ENS), and physical enterprise network solution (P-ENS). In addition, wireless enterprise networks need to consider the E2E network architecture, for example, the deployment mode of NEs on the core network side, how to perform O&M on enterprise networks, and how to introduce value-added capabilities such as wireless network positioning.

6 Key Values of Telecom Operators in the Service Industry

As a next-generation intelligent infrastructure, 5G will work with information technologies such as artificial intelligence, edge computing, cloud computing, and big data to accelerate the penetration of the information and communications industry into every part of the production and life of the society, enable digital transformation of the industry, and promote the upgrade of the industry model. The diffusion and penetration of 5G is a process of cross-industry integration and innovation, and also a process of creating value for enterprises. 5G brings about benefits in two aspects: 1. Improves the operation efficiency of enterprises. Through large-scale and deep data collection of production devices, working environments, and service processes, the 5G-based industrial Internet, such as IoT, campus network, and industrial wireless network, implements predictive maintenance of production devices, improves working conditions through remote control, and empowers automation and intelligence of service processes, boosting the overall operating efficiency of enterprises. 2. Supports intelligent decision-making thanks to the convergence of information technology and data value. In the 5G era, data will reshape the real world. Data sensing, transmission, storage, analysis, control, and sharing will enable production innovation, campus innovation, and operation innovation, support enterprise decision-making innovation, and integrate resources based on user requirements.

As a value-oriented blue ocean, the industrial Internet attracts the attention and participation of industry resources in various OICT fields. There are complex competition and cooperation relationships and technology evolution paths. Based on its advantageous resources, telecom operators launch enterprise network products for enterprise customers to enjoy dedicated network services, which is the first step towards industry interconnection. Based on the concept of discovering requirements and creating values together, learning interaction with the industry is enhanced to further demonstrate 5G capabilities and the value and advantages of operators in the industry chain, help overcome industry barriers and satisfy ecosystem collaboration requirements, and truly implement cross-industry convergence and innovation.

Designed to fully consider the requirements of vertical industries, 5G can flexibly provide combinations of different features such as large bandwidth, massive connection, and low latency. Different from 2G/3G/4G networks that provide the same services for common users, 5G networks are user-centric and provide differentiated and customized capabilities based on users' requirements on network quality, stability, bandwidth, latency, and security isolation, significantly improving operators' industry service capabilities. It is foreseeable that network replacements and upgrades dominate the initial phase of 5G and vertical industry convergence, for example, replacing wired networks with wireless networks, replacing Wi-Fi with mobile networks, and upgrading 2G/3G/4G networks to 5G networks. 5G enterprise networks, based on operators' frequency resources, have cutting edges in technologies, industries, and auxiliary services.

- Technology advantages
  - 5G spectrum advantage: 5G networks are constructed based on "spectrum land." Operators possess mainstream 5G spectrum in the world, providing strongest industry support and long-term technological evolution capability. In addition, operator-based unified coordination and operation of 5G frequencies can fully avoid existing problems in wireless enterprise networks that use unlicensed spectrums, such as vulnerability to interference, poor stability, and limited coverage.
  - Better networking performance: For example, in smart manufacturing scenarios, production equipment networking and smart logistics are the core support for digital factories and advanced manufacturing. In factory and workshop scenarios that are characterized by severe signal fluctuation due to severe blocking, a large number of real-time terminals, and frequent mobile roaming, the stability of network performance directly determines the production efficiency. Mobility management, as a key technology of cellular networks can keep multiple terminals reliably and stably online in roaming and handover scenarios, avoiding huge economic losses to industry customers due to production line suspension.
  - Differentiated capabilities: The 5G technology system enables carriers to provide network services for industry customers based on different scenarios, transform from basic connection services to customer-centric differentiated modes, and provide differentiated capabilities of integrating connections and computing natively, such as different enterprise network architectures, network slicing, and edge computing.
- Industry advantages

  The value of 5G in the industry requires E2E integration of the entire industry chain, covering items such as the chip, module, industry terminal, network, platform, and application system. It is difficult to build an E2E 5G industry ecosystem by relying on industry customers or individuals in some industries. Operators' cross-industry chain and cross-industry advantages can be leveraged to fully integrate the industry chain to form a scale effect, slashing the cost of enterprise networks and continuously optimizing network performance.
- Advantages in auxiliary services

  The planning, construction, and O&M of the 5G networks require powerful communication technologies and rich communication experience. Operators have unique advantages in 5G communications network planning, construction, and O&M management.

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