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SERIES Y: GLOBAL INFORMATION INFRASTRUCTURE, INTERNET PROTOCOL ASPECTS, NEXT-GENERATION NETWORKS, INTERNET OF THINGS AND SMART CITIES

Next Generation Networks – Packet-based Networks

Requirements and framework of industrial Internet networking based on future packet based network evolution

Recommendation ITU-T Y.2623

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Recommendation ITU-T Y.2623

Requirements and framework of industrial Internet networking based on future packet based network evolution

Summary

Recommendation ITU-T Y.2623 provides definitions and requirements of industrial Internet networking in support of customized, collaborative, service-oriented and intelligent production/services. It also describes a framework of industrial Internet networking for understanding significant relationships among the entities of factory internal network and factory external network.

History

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1 Scope

This Recommendation provides definitions and requirements of industrial Internet networking in support of customized, collaborative, service-oriented and intelligent production/services. It also describes a framework of industrial Internet networking for understanding significant relationships among the entities of factory internal network and factory external network.

2 References

The following ITU-T Recommendations and other references contain provisions which, through reference in this text, constitute provisions of this Recommendation. At the time of publication, the editions indicated were valid. All Recommendations and other references are subject to revision; users of this Recommendation are therefore encouraged to investigate the possibility of applying the most recent edition of the Recommendations and other references listed below. A list of the currently valid ITU-T Recommendations is regularly published. The reference to a document within this Recommendation does not give it, as a stand-alone document, the status of a Recommendation.

[ITU-T G.805] Recommendation ITU-T G.805 (2000), *Generic functional architecture of transport networks.*

[ITU-T G.809] Recommendation ITU-T G.809 (2003), *Functional architecture of connectionless layer networks.*

[ITU-T X.200] Recommendation ITU-T X.200 (1994) | ISO/IEC 7498-1:1994, *Information technology – Open Systems Interconnection – Basic Reference Model: The basic model.*

[ITU-T Y.2611] Recommendation ITU-T Y.2611 (2006), *High-level architecture of future packet-based networks.*

[ITU-T Y.2612] Recommendation ITU-T Y.2612 (2009), *Generic requirements and framework of addressing, routing and forwarding in future packet-based networks.*

3 Definitions

3.1 Terms defined elsewhere

This Recommendation uses the following terms defined elsewhere:

3.1.1 availability [ITU-T Y.2611]: A measure of the capability of a given entity (for example, a layer network, connection, flow, etc.) to maintain connectivity with the associated performance criteria that have been guaranteed by the entity.

3.1.2 delay [b-ITU-T G.1050]: The time required for a packet to traverse the network or a segment of the network (see latency).

3.1.3 Internet [b-ITU-T Y.101]: A collection of interconnected networks using the Internet Protocol which allows them to function as a single, large virtual network.

3.1.4 jitter [b-ITU-T G.1050]: Variation in packet delay.

3.1.5 latency [b-ITU-T G.1050]: An expression of how much time it takes for a packet of data to get from one designated point to another (see delay).

3.2 Terms defined in this Recommendation

This Recommendation defines the following terms:

3.2.1 industrial Internet: A kind of industrial application ecology, characterized by convergence of the Internet and the new generation information and communication technologies (ICTs) with industrial systems, which serves as the key comprehensive information infrastructure for industrial intelligent development.

3.2.2 intelligent manufacture: A general term for advanced manufacturing processes, systems and models that have functions of self-sensing, self-decision-making and self-implementation based on the next generation information technologies such as Internet of things (IoT), big data and cloud computing, which goes throughout all links of manufacturing activities including design, production, management, and services.

3.2.3 factory internal network: A network used for connection between the production factors, and between the corporate information technology (IT) management systems within a factory.

3.2.4 factory external network: A network aiming to support various activities during the whole industrial life cycle and used to connect the upstream and downstream of an enterprise, enterprise and intelligent products, as well as enterprise and users.

4 Abbreviations and acronyms

This Recommendation uses the following abbreviations and acronyms:

cl-ps	connectionless packet switched
co-ps	connection-oriented packet switched
DCS	Distributed Control System
DDS	Data Distribution Service
ERP	Enterprise Resource Planning
FCS	Field bus Control System
FPBN	Future Packet Based Network
HTTP	HyperText Transfer Protocol
ICT	Information and Communication Technology
IoT	Internet of Things
IP	Internet Protocol
IPv4	Internet Protocol version 4
IPv6	Internet Protocol Version 6
IT	Information Technology
LTE	Long Term Evolution
MES	Manufacturing Execution System
MQTT	Message Queuing Telemetry Transport
NB-IoT	Narrow Band Internet of Things
OPC UA	OPC Unified Architecture
OT	Operation Technology
PLC	Programming Logical Controller

QoS	Quality of Service
TSN	Time-Sensitive Networking
VPN	Virtual Private Network

5 Conventions

In this Recommendation:

The keywords "is required to" indicate a requirement which must be strictly followed and from which no deviation is permitted, if conformance to this Recommendation is to be claimed.

The keywords "is prohibited from" indicate a requirement which must be strictly followed and from which no deviation is permitted if conformance to this Recommendation is to be claimed.

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6 Introduction

Internet brings great successes in customer-oriented businesses like media, retail, travel and finance by interconnecting people and information. Now Internet, together with emerging information and communication technologies (ICTs), are penetrating industries, such as manufacturing, logistic, energy, etc., to create smart products, smart production and smart services to support the industrial digital transformation. Under such circumstances, the industrial Internet has emerged and has been widely accepted.

The foundations of industrial Internet include "networking", "data" and "security".

– Networking is the important infrastructure of industrial Internet to connect equipment, production lines, industrial systems and other applications to facilitate seamless integration of industrial data;

– Data is the core, which means to generate data-based systematic intelligence through the whole-cycle perception, collection and integrated application of the industrial data to enable flexible manufacturing, operation management optimization, collaborative production organization and business model innovation, which drives industry’s intelligent development;

– Security is the guarantee to protect networks and data in industrial Internet, including equipment security, network security, controlling security, data security, application security and comprehensive security management.

Networking in industrial Internet is expected to provide heterogeneous and universal availability of communication in industrial applications. It is an integration of existing and/or emerging industrial control network, computer network, data communication and other communication technologies. A large number of emerging industrial applications have put forward more requirements on the network. The generic requirements and framework of industrial Internet networking are outlined in the following clauses which should be considered when selecting an appropriate solution.

Future packet based network (FPBN) is composed of packet-based path layer networks (as defined in [ITU-T G.805] and [ITU-T G.809]) in the transport stratum, whereas high level architecture is defined in [ITU-T Y.2611] and general framework and mechanisms are defined in [ITU-T Y.2612].

An FPBN is located between the service stratum and the lower part of the transport stratum (the functionality is similar to layers 2 and 3 in [ITU-T X.200]) (see Figure 6-1). An FPBN may provide co-ps and/or cl-ps transport stratum services. An FPBN may be implemented with multiple layer networks. Each layer network 'system' in an FPBN consists of a user plane, a control plane and a management plane and each of the planes within a layer network will have its own traffic forwarding component which may belong to the same layer network (if the planes are not isolated from each other) or different layer networks (if the planes are isolated from each other).

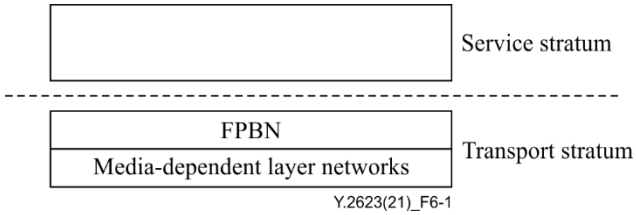


Figure 6-1 – Relationship between an FPBN and the transport and service strata

7 Requirements on industrial Internet networking

7.1 General requirements

7.1.1 Heterogeneous connectivity

It is required to have the ability to connect the heterogeneous entities inside or outside the factories involving different technologies finally to promote interoperability of data from different systems or networks. Those heterogeneous connected entities include:

– all kinds of sensing, measuring, controlling and actuating devices,

– people, such as workers, directors, warehouse managers, sales, designers, and customers,

– networks, such as wired networks and wireless networks,

– systems, such as MES and ERP,

– and cloud platforms.

7.1.2 Extreme differentiated QoS guarantee

It is required to provide whole-process service quality guarantee to satisfy end-to-end network quality requirements of different industrial internet applications.

It is required to provide different guaranteed quality of service (QoS) communication services between connected entities in different scenarios for the same enterprise and/or between different enterprises.

The QoS is recommended to be supported from the most stringent requirements, for example, latency of less than 1ms for some applications in time-critical closed-loop communication scenarios, to best effort qualities.

7.1.3 Service transparent

It is required that industrial Internet is transparent to different industrial applications and services to avoid frequent adaptation or switching across various industrial scenarios and vertical applications.

It is required to support the intelligent perception of industrial service requirements and network status, to efficient adaptation between industrial service requirements and network resources.

It is required to provide network service orchestration capability to support industrial users and users in other fields to make customization on network functions and protocols by open interfaces.

7.1.4 Trustworthy communication

To provide a trustworthy communication, it is recommended to have some abilities including

– reliable data transmission,

– strict resources management for guaranteed QoS communication so that the isolated resources would not be occupied by others,

– in-network security mechanisms to secure data transmission.

7.1.5 Enhanced network virtualization

It is required to provide large-scale of isolated virtual networks to different industry enterprises and industrial applications.

It is required to expose management function to customers to manage their virtual networks.

7.1.6 Data exchange

It is recommended to define industry data semantics and syntax to support industry data exchange.

NOTE – In different industry applications, there may be different industrial data which obeys different syntax and means different semantics, so it is necessary to define the common industry data semantics and syntax, which help for data transfer among different applications and different enterprises, to increase the value of industry data.

7.1.7 Compatibility

It is required to be compatible with the legacy industrial systems and networks (e.g., PROFINET, EtherNet/IP, EtherCAT) in order to protect past investment and still take the future developments into consideration.

7.1.8 Scalability

It is required to have the ability to provide information exchange on a wider and more fine-grained scale and to be expanded vertically and horizontally to keep the growth of the industry applications.

It is required to implement live update for network protocols to support the smooth integration of new network technologies into existing industrial Internet deployments.

NOTE – Network technology evolution has consistently followed a cycle similar to Moore's Law with frequent turnover of products and increases in performance. In contrast, operation technology (OT) systems comprise systems with longer life cycles, on average 19 years. This difference in development speed leads to slow adoption of new network technologies into existing OT deployments. Manufacturing subsystems should therefore be decoupled from the network devices while keeping a consistent interface between them.

7.1.9 Flexibility

It is required to support self (re)configure dynamically to provide flexibility and dynamics in network planning and re-configuration.

NOTE – To support flexible manufacturing, the network should be able to self (re)configure dynamically. Therefore, one of the design considerations is to provide flexibility and dynamics in network planning and re-configuration.

7.1.10 Reliability

It is required to provide means and measures to support reliable communication in harsh industrial environments.

It is required to provide embedded security capability to realize endogenous security and network tractability so as to protect the security of critical applications.

NOTE – Reliability and security are key requirements of industrial networks as any unexpected communication interruption and malfunction might result in work suspension, damage of equipment, or even casualty. The future industrial network must provide means and measures to support reliable communication in harsh industrial environments.

7.2 Requirements of factory internal networking

7.2.1 Network convergence

It is required to be able to facilitate connectivity between different industrial network protocols, such as time-sensitive networking (TSN) and industrial Ethernet protocols defined in IEEE 802 serial specifications.

It is recommended to support vertical integration and network flat by the way of the convergence of IT network, OT network and the Internet.

NOTE – The traditional automation pyramid comprises a sensor level, a device level, a control level and an enterprise level. Each level adopts different network infrastructures and technologies. Field bus or industrial Ethernet are used at the sensor and the device level. Standard Ethernet is commonly used at the control level and above. Gateways are required to bridge these two networks. In industrial Internet networking, the automation pyramid will become more and more flattened. Therefore, a common network infrastructure from top to down should be applied in order to support the convergence of IT, OT and the Internet without any need of technology conversion (e.g., interface type, switching, routing).

7.2.2 Openness and green

It is required to provide open architecture, protocols and technologies in Industrial Internet networking to support maximum interoperability and to promote wide cooperation among industrial partners.

It is required to provide highly efficient power consumption mechanisms to support green communication.

7.2.3 Determined real-time reliable communication

It is required to provide determined real-time reliable communication for automation production, including deterministic ultralow latency transmission in the order of sub-milliseconds, very low jitter to ensure the applications' integrity and predictable system performance.

7.2.4 Clock synchronization

It is required to provide the function of clock synchronization in Industrial Internet networking to support time-sequence sensitive factory activities, such as cooperative assembling with multiple robots.

7.2.5 Mobility

It is recommended to support different levels of mobility including workshop level and factory level. Characteristics of mobility include how frequently mobility occurs, how fast the mobile object is moving and requirements on needed bandwidth and latency while mobile.

7.2.6 Trustworthy communication

It is required to provide certain security mechanisms to secure data transmission.

It is required to provide means and measures to support the functional and process safety standards for automation systems.

NOTE – A high degree of safety assurance is required for life- and mission-critical manufacturing systems to avoid unintended consequences during system operation. Industrial Internet must be capable of providing means and measures to support the functional and process safety standards for automation systems.

7.3 Requirements of factory external networking

7.3.1 Heterogeneous connectivity

It is required to have the ability to connect the heterogeneous networks between factories, branches in one enterprise, or between enterprises.

NOTE – It is required to support tens of billions of terminal accesses, as the number of connected industrial equipment and products will reach tens of billions.

7.3.2 Isolated connectivity

It is required to provide isolated connectivity for different enterprises to connect their factories or branches or collaborative companies.

It is required to provide different types of QoS services in one isolated connectivity for different communication requirements in one enterprise.

NOTE 1 – It is required to support hundred-level application network plane. Considering the industrial site OT and IT applications as well as future business development, the network plane required by different qualities should be at the hundred-level.

NOTE 2 – It is required to support the segregation of millions of users. If it is calculated based on 3~5 virtual private networks (VPNs) for each enterprise, the network's bearing capacity needs to reach the mega-level VPNs.

7.3.3 Flexibility

It is required to support highly efficient virtual network configuration on Internet or specific Industrial Internet public network infrastructure.

It is required to support self (re)configure dynamically to provide flexibility and dynamics in network planning and re-configuration in factory external networking.

7.3.4 Trustworthy communication

It is required to have security mechanisms to secure data transmission in factory external network infrastructure.

8 Framework for Industrial Internet networking

Networking in Industrial Internet is expected to provide heterogeneous and universal availability of communication in industrial applications. It closely links equipment, production lines, employees, factories, warehouses, suppliers, products and customers, ultimately to share the various data of the entire process of industrial production.

Industrial Internet networking can be categorized into two layers which are network interconnection layer and data communication layer as shown in Figure 8-1. Network interconnection layer is further categorized into two parts, that is, factory internal network and factory external network. Edge computing cooperates with the factory internal network to provide convenient connectivity among industrial devices and fast intelligent response. It also cooperates with the factory external network to realize the data distribution of industrial enterprises and ensure that the data is not shipped. Data communication layer serves to provide interoperability of data and information from heterogeneous systems in order to support various industrial applications.

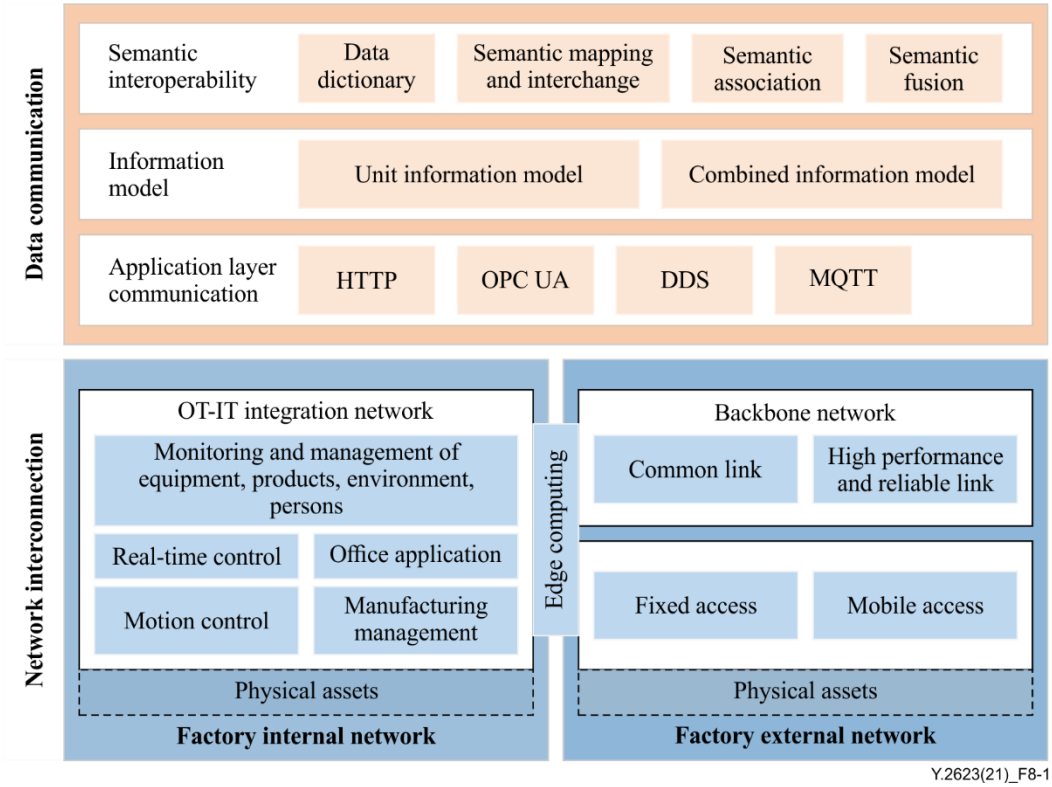


Figure 8-1 – Framework of Industrial Internet networking

8.1 Network interconnection

8.1.1 Factory internal network

The factory internal network is designed to connect physical assets and systems within a factory. It can be further divided into a factory OT (industrial manufacturing and control) network and factory IT network. For security reasons, the factory internal network should be separated from the factory external network by firewall.

As shown in Figure 8-2, an implementing framework of factory internal networking under the industrial internet scenario consists of six major aspects.

– **Factory IT network:** It mainly aims to connect office systems, mail servers, production management systems, data centers, and more via high-speed Ethernet and TCP/IP for network interconnection.

– **Factory OT network:** It mainly aims to connect physical assets such as controllers (PLC, DCS, FCS), sensors, servos and monitoring equipment at the manufacture site, and its enabling technologies includes the industry field bus and industrial Ethernet.

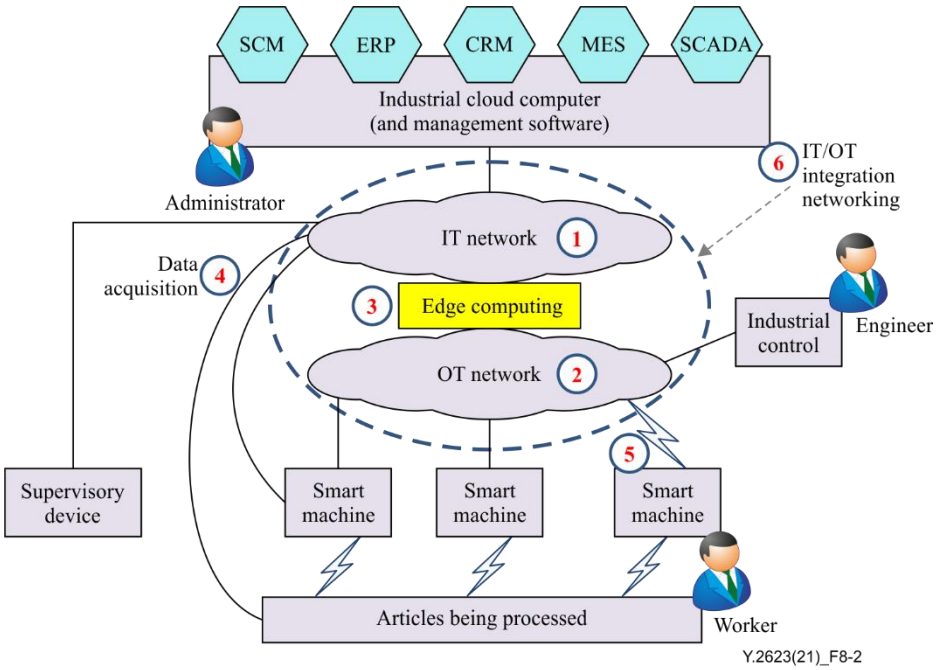
– **Edge computing:** To provide convenient connectivity among industrial devices and fast intelligent response, the industrial enterprises need to deploy edge computing close to production sites or factories. Edge computing is also a bridge between IT and OT networks.

– **Direct network connection to smart machines and articles in process:** Smart machines, sensors, articles in process and other manufacturing site equipment and items will be able to directly connect to the IT network to realize real-time data acquisition of the manufacturing site.

– **Ubiquitous wireless connection:** The smart machines, articles in process, sensors and transmission equipment on the manufacturing sites will be connected with various wireless technologies, such as Zigbee short-distance communication technology or Wi-Fi, LTE

enhanced, NB-IoT, IMT-2020 and other wireless technologies according to equipment power consumption and transmission distances.

– **IT/OT integration networking:** With the development of Industrial Internet, the factory IT and OT networks will be gradually integrated into a fully-connected network. The factory internal networking is developing towards flattening, IP-based, wireless, and flexible networking.



1. IT network
2. OT network
3. Edge computing
4. Network connection directly reaching smart machines and WIP
5. Ubiquitous wireless connection
6. IT/OT integration networking

Figure 8-2 – Implementing framework of factory internal networking

8.1.2 Factory external network

The factory external networking refers to the network that connects the upstream and downstream of industry chain, enterprise and intelligent products, enterprises, and users with the aim to support the activities in the whole industrial life cycle.

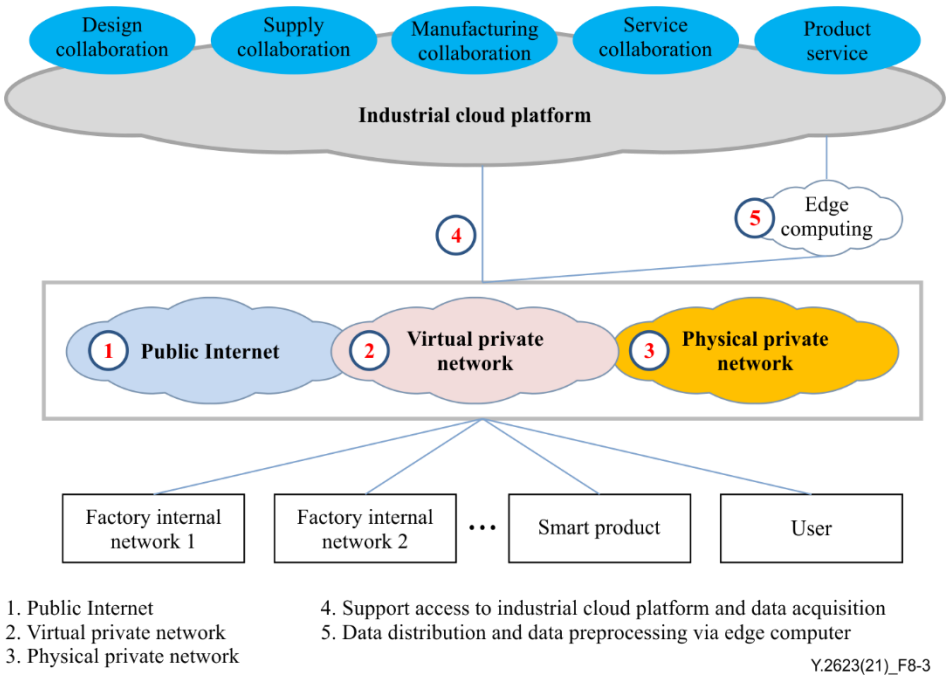


Figure 8-3 – Implementing framework of factory external networking

As shown in Figure 8-3, an implementing framework of factory external networking consists of five major aspects.

– **Public Internet:** As the industrial internet terminals will reach tens of billions, itis imperative to deploy IPv6 in the public Internet and take into consideration the transition from IPv4 to IPv6.

– **Virtual private network:** The interconnection between enterprises branches can be realized fast and flexibly through logical isolation technology.

– **Physical private network:** For some businesses that have higher network quality requirements or are critical, physical private network can meet the needs of resource isolation, high reliability, high security, etc.

– **To support access to the industrial cloud platform and data acquisition**: The factory external networking supports the enterprise's information system, manufacturing control system, data transmission from various intelligent products to the industrial cloud platform and relevant service quality guarantee.

– **Edge computing:** Edge computing cooperates with the factory external network to realize the data distribution of industrial enterprises and ensure that the data is not shipped. Edge cloud can also implement data pre-processing and edge caching to reduce the pressure on the backhaul link and improve the data processing efficiency.

Further integration of industry and external network will drive the development of customization, remote monitoring, intelligent product services and other brand-new manufacturing and service models. Therefore, the factory external networking needs to be faster in speed, better in quality, lower in latency, safer, more reliable and flexible in networking.

8.2 Data communication

The function of data communication layer is to deliver data and information between elements and systems seamlessly, in order to realize data interoperability and information integration. It provides access interfaces of multi-source heterogeneous system data to the upper applications and supports the rapid development and deployment of industrial applications.

The data communication layer includes application layer communication, information model, and semantic interoperability.

Using protocols such as OPC UA, MQTT, HTTP and DDS, the application layer communication realizes the establishment, maintenance, and shutdown of data transmission security channel, as well as the management of equipment, sensors, remote terminal units, servers, and other equipment nodes supporting the industrial data resource model.

The information model provides complete and unified data object expression, description and operation model via unit information model and combined information model. The unit information model aims at a single object, such as a PLC and a metering unit. The object of a combined information model will be more complex. The combined information model is an information cluster formed by the combination and superposition of interrelated unit information models.

The semantic interoperability realizes the discovery, collection, query, storage, interaction, as well as request, response, publication and subscription of industrial data. It includes data dictionary, semantic mapping and interchange, semantic association, and semantic fusion. The data dictionary is a collection of information used to describe data. The semantic mapping and interchange is to map and interchange industrial data with different description modes. The semantic association is to establish an association between industrial data and factory production information. The semantic fusion is a high-level application of semantic association which is to construct a knowledge graph of industrial scenarios.

9 Security considerations

Security is the guarantee to protect networks and data in Industrial Internet. The security requirements of factory internal and external networking are described in the relevant clauses in this Recommendation and will therefore not be repeated in this clause.

Bibliography

[b-ITU-T G.1050] Recommendation ITU-T G.1050 (2016), *Network model for evaluating multimedia transmission performance over Internet Protocol*.

[b-ITU-T Y.101] Recommendation ITU-T Y.101 (2000), *Global Information Infrastructure terminology: Terms and definitions*.

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