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Networking Architecture and Development Trend of Industrial Internet

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Abstract: As one of the three primary functional aspects of the Industrial Internet, networks provide the infrastructure for all-round interconnection between industrial elements. It can be challenging for existing "two-layer and three-level" industrial networks to satisfy the development needs of new Industrial Internet models and services. Emerging network technologies promote the evolution of network architecture. Factory internal networks are being developed for integration, openness, and flexibility. Factory external network services are universal, diversified, and flexible. This paper describes the networking framework of the Industrial Internet and suggests that industrial enterprises must build factory internal networks based on business requirements, real-time performance, transmission methods, and so on, while factory external networks must be built by selecting three dedicated lines and one networking mode according to the development requirements of different services.
Keywords: factory internal network; factory external network; openness; integration

1 Introduction

As one of the three major functional systems of the Industrial Internet, Industrial Internet networks provide the infrastructure for comprehensive interconnection of all-factory elements within the industry and promote free flow and seamless integration of industrial data. This forms the foundation of the Industrial Internet. In November 2017, the State Council, in the *Guiding Opinions on Deepening the Development of the Industrial Internet by the Internet + Advanced Manufacturing Industry*, decided on "compacting the foundation of the network" as one of its main tasks and proposed to vigorously promote the construction of internal and external networks of industrial enterprises.

Industrial Internet networking involves different technical fields within and outside factories and includes a wide range of influences and several optional technologies. Currently, there are several networking and connection technologies in the industrial field. These technologies are designed for specific scenarios and have played a prominent role in demonstrating increased performance in those scenarios. However, in terms of data interoperability and seamless integration, these technologies are often unable to meet the growing needs of new industrial networks and new models. Therefore, Industrial Internet networking will further promote the development of interconnection between systems, thereby freeing data from isolated systems/networks and making data more valuable for applications within and across industries.

2 The status of industrial network

Industrial networks currently reside within an industrial enterprise. In general, the networks within the factory present a "two-layer, three-level" structure, as illustrated in Fig. 1. The two-layer refers to the heterogeneous network technology of

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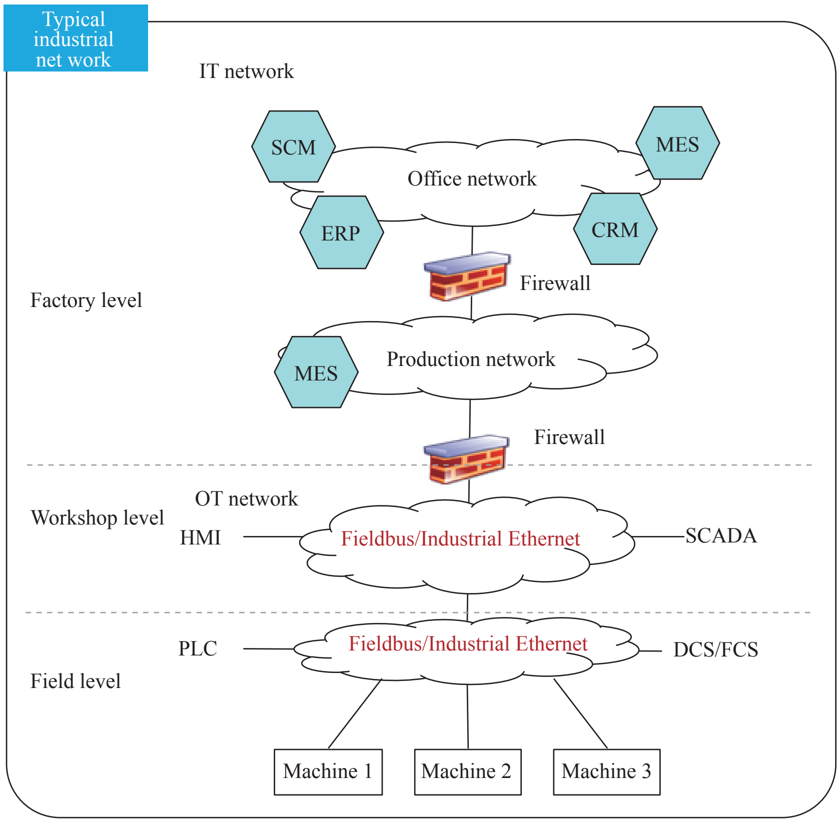

Fig. 1. Schematic of a current typical industrial network.
SCM: Supply Chain Management; MES: Manufacturing Execution System; ERP: Enterprise Resource Planning; CRM: Customer Relationship Management; HMI: Human−Machine Interface; SCADA: Supervisory Control and Data Acquisition; PLC: Programmable Logic Controller; DCS/FCS: Distributed Control System/Field Control System

the factory information technology (IT) network and the factory control technology (OT) network. The three-level is divided based on the current management level of the factory—field level, workshop level, and factory level/enterprise level. The network configuration and management policies for each layer are independent.

At the field level, industrial Fieldbus has been extensively used to connect field-sensing sensors, actuators, and industrial controllers, with communication rates ranging from a few kbps to tens of Mbps. In recent years, several field devices that support industrial Ethernet communication interfaces have been deployed, but some field devices are still connected to the controller through electrical hard wiring. At the field level, wireless communication is only used on some special occasions and is rarely used. This situation has made industrial systems inefficient in all stages of design, integration, and operation and maintenance, hindering the realization of refined control and high-level process management.

The workshop level network ensures communication between the controllers, between the controller and the local or remote monitoring system, and between the controller and the operating level. The Manufacturing Execution System (MES) also implements production execution control through workshop level deployment. Workshop-level networks are typically implemented using industrial Ethernet technology, and many manufacturers use ordinary Ethernet, industrial buses, or their own communication protocols to communicate between controllers and systems. Existing industrial Ethernet is often modified and extended based on a general Ethernet. The interoperability and compatibility between different industrial Ethernet protocols are poor, which limits large-scale network interconnection.

At the factory level, enterprise IT networks typically use high-speed Ethernet and Transmission Control Protocol/Internet Protocol (TCP/IP) for network interconnection. With the construction of smart factories, enterprise IT management and operation systems are strongly required to obtain on-site real-time process data and equipment status data. By efficiently deploying the communication interconnection of field devices and by using advanced network technologies to achieve high real-time and high-reliability data communication between field and management level systems, integration and intercommunication between OT networks and IT networks can be achieved, emphasizing the current focus of the factory network system technologies.

Outside the enterprise, because of different degrees of information development for different industries and fields, the degrees of development and utilization of industrialized data are different. Therefore, the construction and development of factory external networks are not balanced. Some industrial companies only use ordinary Internet access. This has led to the formation of information islands between different regions of industrial enterprises, which limits the development of new business models such as network collaboration and remote services across regions, industries, and enterprises.

3 Networking and connection trends

3.1 Factory internal network

With improvements in process technology in the industrial field, there has been a reduced possibility of current technological breakthroughs for improving industrial production efficiency. There has been a growing use of Industrial Internet technology to improve the refined management of industrial users for the entire lifecycle of design, production, operation, and maintenance, which reduces overall labor costs, resource consumption, and comprehensively improves production and operational efficiency.

The development of Industrial Internet business places higher requirements on network infrastructure. The factory internal network presents three development trends of integration, openness, and flexibility.

The integration trend of the network architecture in the factory. The first is the flattening of the network structure. The traditional "two-layer and three-level" network architecture severely affects the efficiency of information interoperability. With the demand for real-time data collection at the field level of big data analysis and edge computing services, the workshop-level and field-level in the OT network will gradually merge, especially in the process industry. The demand for information systems such as MES for extension to workshops and the field has promoted the convergence of IT networks and OT networks. The second level includes the control network and process data transmission on the common network. Traditional industrial networks are attached to the control system to realize the control of closed-loop information transmission. However, new businesses require the entire process data of industrial production, and the factory internal network controls the transmission of control information and process data. The third level involves the convergence between wired and wireless networks. The Industrial Internet business has created a demand for network coverage of production processes with no dead ends, making the deployment of wireless networks inevitable. The application of wireless networks will gradually move from information collection to production control and from the process industry to discrete industries. Simultaneously, the application of a variety of wireless technologies has also led to the development of positioning technology in factories.

The trend of openness in the factory internal networks. The first trend is the openness of technology. Network technology systems in internal factory networks will break technical barriers between the traditional systems of many industrial networks and realize decoupling between the various network layers. The control system and application system will no longer be strongly bound to a specific network technology. International standards organizations such as the Institute of Electrical and Electronics Engineers (IEEE) and the Internet Engineering Task Force (IETF) have joined the development of technical standards. In addition, the deployment of IP/IPv6 in the factory will further promote the opening of network technology in factories. The second trend is the openness of data. The strong demand for data in the Industrial Internet business has led to the opening of data that sinks or disappears in the closed loop of traditional industrial control, while data for the production process is open to higher-level applications through a more standardized grammar and data model. The third trend is the openness of the industry. The opening of network technology is breaking the "chimney-style" development model of traditional industrial networks and the control of a few giants on the entire industry chain. New chip manufacturers, equipment manufacturers, and network providers have joined to promote industry openness [1].

The flexibility trends in factory internal networks. First, the flexibility of network forms. In the future, the form of the factory internal network can be flexibly adjusted according to intelligent production, personalized customization, and other businesses, to quickly build a new production environment. The second trend is the friendliness of network management. With an upgrade to industrial networking, network management within the plant will be complicated. New data interoperability and software-defined technology applications will provide visibility of network systems, and the network management interface will be friendlier.

3.2 Factory external network

With the development of industrial networking and intelligence, systems and applications within factories are gradually expanding. Services provided by the Industrial Internet's external network are universal, diversified, and flexible.

Factory external network services are universal. Traditional factory external networks provide business information communication. Moreover, enterprise information systems are deployed on the factory network. There are few network connection objects outside the factory, and services are simple. With developments in cloud platform technology, some enterprise information systems such as enterprise resource planning (ERP) and customer relationship management (CRM) are being externalized, and IT software are increasingly being moved to the cloud. With developments in remote service businesses involving industrial products and equipment, the remote monitoring, maintenance, management, and optimization of mass equipment in the future will be based on the factory external network.

Services of the factory external network are diversified.

The factory external network of the Industrial Internet will realize the ubiquitous interconnection of the entire industry chain and value chain. Complex and diverse connection scenarios promote the diversified development of services. On the one hand, the connection demand for mass equipment has promoted the construction of mobile networks outside the factory and the rapid development of wide coverage services. On the other hand, changing enterprise online demand to on-cloud demand has led to the refinement of dedicated line services. A new enterprise dedicated line technology will provide segmentation services for different scenarios such as enterprise Internet access, business system on-cloud, and public cloud and private cloud interoperability.

Services of the factory external network are flexible. Network virtualization and programmability increase the flexibility of network services, thereby enabling the factory external network to quickly provision services and quickly adjust services based on enterprise requirements. The use of a large number of mobile communication network technologies improves the convenience and deployment speed of network access and provides a more flexible path for enterprises to achieve a wide range of interconnections.

3.3 Data intercommunication

According to incomplete statistics, there are currently more than 40 types of existing bus/industrial Ethernet protocols across the world. There are also some automation control companies that directly use proprietary protocols to implement information exchange across a wide range of industrial devices. In such an industrial environment, a silo-type business system is formed, and data in the same system can be interconnected to a certain extent, but data intercommunication across systems can be extremely difficult.

To address the problem of data intercommunication, many industrial enterprises provide a package solution for users in their own business scope, which can realize data intercommunication. However, this method only turns a silo system from small to slightly larger and does not fundamentally address the problem of data intercommunication. Moreover, it is difficult for the user’s business systems to rely on the products of one or two suppliers.

With developments in the Industrial Internet, the demand for data interoperability has become increasingly stronger, demonstrating the following trends.

The first is to standardize information. In traditional industrial control systems, data is solidified in a clear causal relationship to satisfy the most basic process management requirements. For example, a programmable logic controller (PLC) control process has a clear fixed processing object, and data information flows only between fixed devices. The Industrial Internet has a wider range of data processing subjects. For example, using big data analysis to diagnose equipment faults requires understanding and integrating data across systems, which requires further generalization and standardization of data storage and transmission.

The second is to strengthen connections to the cloud. With the help of the cloud platform, sharing expert experience and intelligent decision-making libraries can improve equipment management level of operation and maintenance and reduce operating costs. Dataset segmentation and regular search methods can then be used to help realize energy-savings and improve the efficiency of personnel input and control processes. In addition, big data analysis results can be used to enable manufacturing companies to provide targeted marketing, targeted R&D, and intelligent maintenance services. It can also be used to predict when a device may be down, provide a risk-free solution, and eliminate the loss associated with equipment failure.

The last is to strengthen interoperability with field level equipment. In traditional industrial production processes, devices are mostly independently operated. The core of the Industrial Internet intelligent factory is to open the field equipment layer and connect the intelligent equipment through communication technology to realize the vertical integration of resources within the enterprise. The communication and interconnection between devices have become a major trend. In the future, the number of interconnections between devices and objects will far exceed the interconnection between people.

Therefore, to meet the needs of data interoperability, the industrial community has executed a several actions to establish a unified data interoperability approach. It is hoped that a standard set of interfaces, attributes, and methods can be used to achieve seamless integration of data for each system and unit in an Industrial Internet factory system. Technologies such as OPC Unified Architecture (OPC UA), Data Distribution Services (DDS), and oneM2M for data collection of industrial field devices are becoming the focus of attention in the industry and are gradually being accepted and adopted by industrial enterprises.

4 The architecture of Industrial Internet networking and connection

4.1 The architecture of networking and connection

As shown in Fig. 2, the architecture of Industrial Internet networking and connection includes both network and data interconnection.

Network interconnections include factory internal and external networks. The factory internal network is used to connect various elements within the factory, for example, personnel (such as production personnel, designers, and external personnel), machines (such as equipment and office equipment),

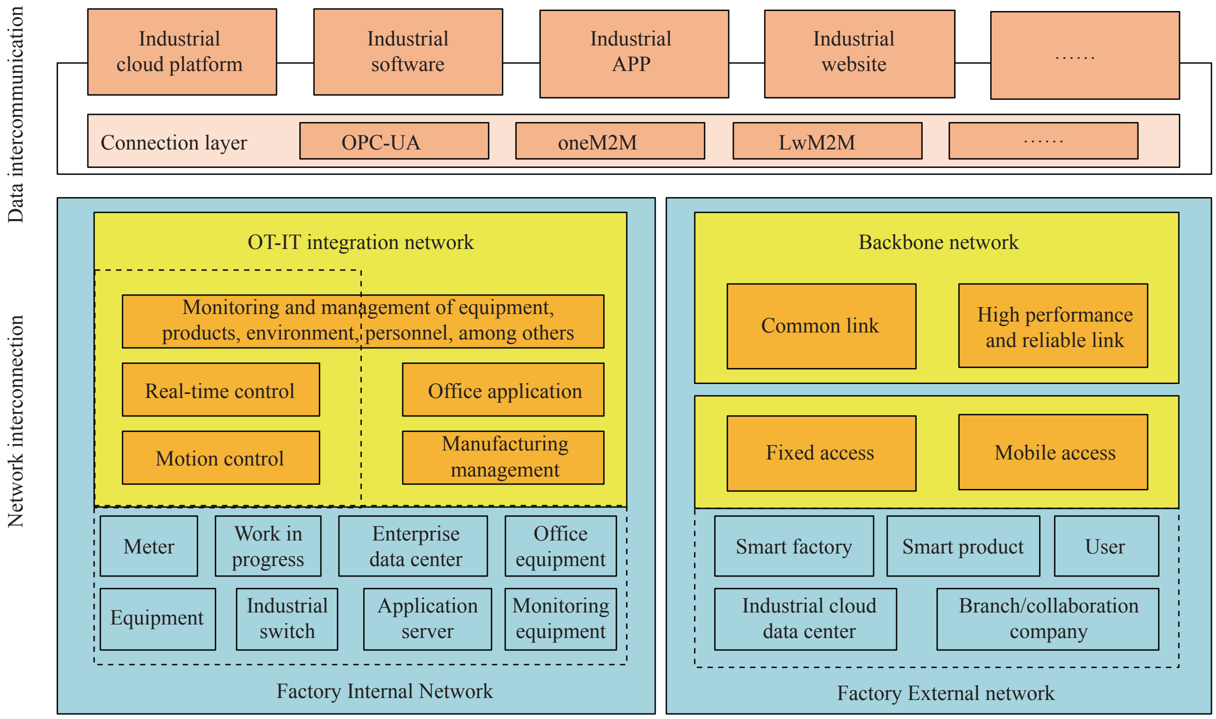

Fig. 2. Architecture of Industrial Internet networking and connection.
LwM2M: Lightweight Machine-to-Machine technology.

materials (such as raw materials, work in progress, and finished goods), environment (such as meters and monitoring equipment), among others. These elements are interconnected with enterprise data centers and application systems through the factory internal network to support business applications within a factory. The factory external network is used to connect smart factories, branch offices, upstream and downstream cooperative enterprises, industrial cloud data centers, intelligent products, and users. The data centers and application systems in the smart factory are interconnected with the industrial cloud data centers outside the factory through the factory external network. Branch/collaboration enterprises, users, and smart products are also connected to the industrial cloud data center or enterprise data center through the factory external network according to the configuration.

The interoperability of data in the Industrial Internet enables seamless transfer of data and information between various elements and systems, thereby enabling heterogeneous systems to understand each other at the data level, achieving data interoperability and information integration. Industrial Internet involves breaking information islands, realizing cross-system interoperability of data, and integration analysis. Therefore, the connection layer of data intercommunication supports the aggregation of the underlying data generated by various factory elements and manufactured products in the data center. On the contrary, it provides an access interface to the multi-source heterogeneous system data for upper layer applications and supports the rapid development and deployment of industrial applications.

4.2 The implementation of Industrial Internet architecture

4.2.1 The factory internal network

In the Industrial Internet factory, on the one hand, the digital network evolution of the factory requires that the digitization of many existing business processes be performed by the corresponding network. On the other hand, a large number of new networked devices have been introduced such as automated guided vehicles (AGVs), robots, mobile handheld devices, among others, and a large number of new business processes have been introduced, such as asset performance management, predictive maintenance, personnel/material positioning, among others. The introduction of new equipment and business processes creates new demands on the network. Consequently, the traditional production network and office network in the factory must be changed.

Because of the diversification of elements connected to the factory internal network, the types of edge access networks are diversified. According to business needs, the edge access network can be the industrial control network, office network, monitoring network, positioning network, and so on. When classified according to real-time requirements, the edge access network can be a real-time network or a non-real-time network. When classified according to the transmission medium, the edge access network can be a wired network or a wireless network. According to the classification of communication technologies, the edge access network can be the fieldbus, industrial Ethernet, general Ethernet, wireless local area network, cellular network, and so on. The coverage area of the network may be a workshop, an office building, a warehouse, etc. Industrial enterprises can consider business needs and costs to choose the right technology for deploying the corresponding edge access network.

The workshop, office building, warehouse, and cloud platform/data center in the factory are interconnected through a high-bandwidth, high-speed three-layer network. Depending on the size of the enterprise, the network can be a router cluster or only one or two backbone routers.

4.2.2 The factory external network

From the perspective of different business needs, the industrial extranet can be divided into three types of dedicated access lines and one type of Internet connection. Dedicated lines realize networked services with quality of service guarantees. The Internet connection achieves universal Internet access.

The Internet access line: It provides a connection between the smart factory and the Internet. It is acceptable for users or factory products to access smart factories via the Internet, which is the basic requirement of industrial enterprises.

The Interconnect line: It is a secure and reliable interconnection between smart factories and branch offices/upstream and downstream enterprises. For large and medium-sized companies, this is a common requirement.

The On-cloud line: It provides the interconnection between smart factories and industrial cloud platforms on public clouds. Usually, the dedicated line of the cloud service provider acts as a dedicated line for the enterprise to connect to the public cloud. The demand for such special lines has rapidly developed in recent years, especially as the country promotes the "millions of enterprises on the cloud" project. Furthermore, the demand for such special lines by industrial enterprises will be particularly strong.

The Internet connection: It provides the connection of factory products to the Internet and then interconnects with smart factories or industrial cloud platforms, which forms the basis for industrial enterprises in realizing manufacturing services.

5 Conclusions

As a key network infrastructure formed by the deep integration of new-generation information communication technology and industrial systems, the Industrial Internet has become a key support feature for the transformation of industrial innovation. Furthermore, the Industrial Internet is of great significance for promoting industrial digitalization, networking, and intelligent development. Building an Industrial Internet network infrastructure with low latency, high reliability, and wide coverage is an important foundation for the development of a new format and new model formed by the deep integration of new-generation information and communication technologies and advanced manufacturing. Therefore, it is necessary for industrial enterprises to improve their understanding of network architectures suited to their own business development, increase investment in the basic construction of network transformation, and ensure that the network is a critical support feature for intelligent production, networked collaboration, personalized customization, and service transformation.

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