Research and Application of Railway Engineering IoT Cloud Platform Key Technologies

Xie Yalong, Institute of Computing Technologies, China Academy of Railway Sciences Corporation Limited

Wang Wanqi, Institute of Computing Technologies, China Academy of Railway Sciences Corporation Limited

Yin Xunxiao, Institute of Computing Technologies, China Academy of Railway Sciences Corporation Limited

Jiang Ruofei, Institute of Computing Technologies, China Academy of Railway Sciences Corporation Limited

Abstract: Based on the analysis of the IoT research, this paper propose the definition of the Internet of Things (IoT) for railway engineering, analyze the development demands of railway engineering construction informatization and the construction goal of the engineering IoT cloud platform. The paper first proposes the technical architecture, data processing architecture, and functional framework for the railway engineering IoT platform. Establishing a unified railway engineering IoT cloud platform provides a complete development platform and technical components to support the rapid access of diverse terminal equipment, thereby solving the problems about the perceived source at the construction site. In addition, the HASH encryption algorithm implements secure data transmission based on the MQTT protocol and achieves the unified collection, storage, forwarding and comprehensive analysis of railway infrastructure whole life cycle monitoring information by using flexible rule definition engines, dynamic and efficient streaming computing engines, and data pre-processing and filtering technologies. The construction processes make dynamic remote data collection, automatic judgment, closed-loop tracing, and intelligent decision-making to create management tools which provide a new information foundation platform for intelligent railway construction.

Keywords: railway engineering IoT; IoT platform; streaming computing; secure transmission; rule engine; MQTT protocol; intelligent construction; monitoring system; railway engineering management platform

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1 Introduction

With the development of the informatization of railway engineering construction and the wide application of digital construction technology, a large amount of data of safety and quality monitoring is generated on the construction site, which has been characterized by its large volume, and being foreign and heterogeneous. The real-time analysis and big data application of such data is of great significance to improve the construction efficiency and quality of engineering construction, as well as better management and decision-making. At the same time, the continuous increase of intelligent equipment on the railway engineering process facilitates the better use of smart equipment for sensing on-site project dynamics. Therefore, it is necessary to establish a unified IoT cloud platform for the entire road for rapid access of various monitoring and inspecting equipment and comprehensive data analysis, improving the management ability of railway engineering construction.

In the *General Plan of Railway Informatization* (TZMI [2017] No. 152) issued by the former CHINA RAILWAY, the IoT has been identified as the key application direction of the new generation of information technology in China railway industry [1]. Many experts and scholars in China have carried out exploration and research on the application of the IoT in the railway industry: Shi Tianyun et al. [2] proposed the definition and conceptual analysis of the railway IoT, analyzed the application scenarios and cases of the railway industry, and put forward a concept of the overall framework of the IoT; Wang Du et al. [3] proposed the overall framework of the IoT in the railway logistics field, and analyzed the application scenarios and technologies in the railway logistics field; Chen Yan et al.[4] proposed the development of an intelligent chemical machinery management system based on the IoT technology to better regulate the management of tools; Li Yaqun et al. [5] analyzed the application status and prospects of the IoT in the field of railway disaster monitoring. However, in the field of railway engineering construction, the concept and plan of the IoT cloud platform have not been proposed.

Drawing on the international definition of the concept of the IoT, combined with the actual characteristics of railway engineering, we got the following definition of IoT of China's railway engineering: Railway engineering IoT refers to the use of information perception equipment such as identification (QR code, RFID, etc.), laser scanners, wearable devices, biometrics, smart sensors, digital chemical equipment, smart production equipment and satellite positioning. In accordance with the definition, it connects the personnel, equipment, environment, materials and engineering bodies and various railway projects through the network for information exchange and communication to realize the intelligent identification, positioning, tracking, monitoring and management of railway engineering objects, serving as an important support for the intelligent railway construction.

2 Demand Analysis and Construction Goals

With the advancement of science and technology and the improvement of business management capabilities, especially based on the demand for data governance, railway stakeholders have higher expectations and requirements for the level of railway infrastructure informatization. In this way, there is an urgent need for digital management and control solutions, on the basis of infrastructure management for the full life cycle, to solve problems such as the lack, reorganization, and transmission of data. In recent years, the rapid development of railway engineering construction informatization has accumulated a large amount of data on the construction site, but there are some problems with the use of the data: first, these data is only used to achieve real-time comparison and analysis with design and construction specifications to ensure that the specifications are effectively implemented on site with no further in-depth analysis of the data, especially the lack of cross-process, cross-professional, cross-cycle, cross-regional big data correlation analysis, as well as the lack of deep mining and proper utilization of existing massive data; secondly, the data is mainly concentrated in some links and some elements of the construction site without the entire process of data collection and analysis and the comprehensive perception and control of the on-site status. The major demand analysis of the IoT cloud platform for railway engineering is shown in Figure 1.

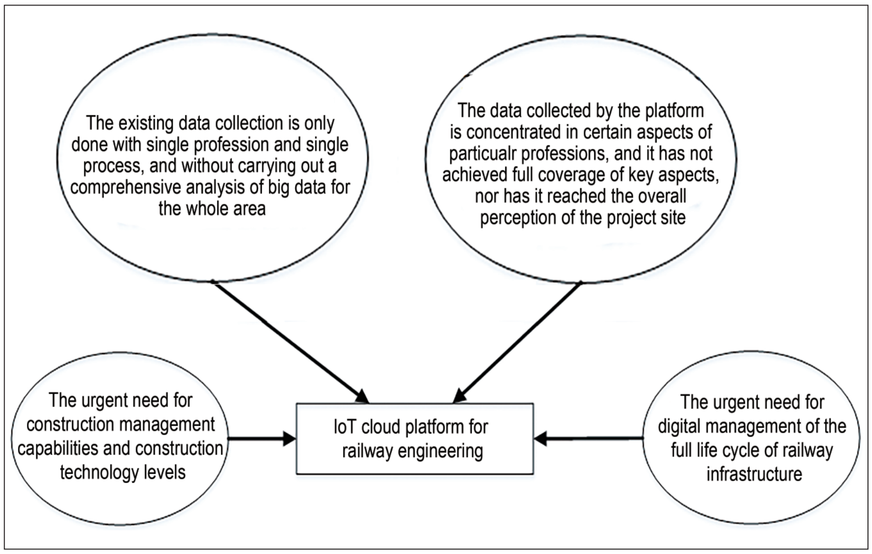

Fig. 1 The major demand analysis of the IoT cloud platform for railway engineering

In order to be well prepared for the rapid development of railway construction capacity, it is necessary to establish a unified railway engineering IoT cloud platform. The specific construction goals are as follows:

(1) Provide a unified access toolkit for various terminal equipment and digital tooling on the railway project site to achieve centralized access, storage and distribution of monitoring data;

(2) Build a railway engineering IoT platform covering all levels of management agencies and participating construction parties to help managers gain insight into on-site dynamics and to provide new means for construction management;

(3) Realize the unified management of various information collection equipment on the project site, and adopt a flexible classification structure to realize the management of intelligent terminal equipment and applications;

(4) Build a railway engineering IoT data-perception resource lake, and establish a big data analysis platform to realize the unified analysis of monitoring and perception data. Provide unified data services for business applications, and provide technology support for big data analysis and decision-making in the construction, operation and maintenance phases.

3 System Structure

The key to building the railway engineering IoT includes three parts: cloud, tube and terminal. The cloud is the brain of the IoT and the core of the data processing of it. The cloud computing platform is used to provide data analysis, storage, calculation, and even remote control and decision-making for the IoT; the tube is an important channel between the terminal and the cloud. Currently, it includes Wi-Fi, Bluetooth, NB-IoT, eLTE-IoT, Internet and other access methods; the terminal is the sensing tentacles of IoT, and is the main source of its data. According to different on-site application scenarios, the terminal takes different forms to lower the threshold for terminals to enter the cloud, and shield the diversity of the underlying IoT terminals by providing SDKs and other methods [6].

The IoT cloud platform for railway engineering mainly serves users such as China State Railway Group Co., Ltd. (hereinafter referred to as CHINA RAILWAY), Railway Group Administration Corporation/railway company, construction headquarters/project departments and construction units bid section, and provides data services to China Railway Group Corporation Limited, China Railway Construction Corporation Limited, POWER CHINA, China State Construction Engineering Corporation, China Communications Construction Company Ltd. and other group companies and their subordinate enterprises.

The technical framework of the railway engineering IoT cloud platform is divided into an equipment layer, platform layer and application layer:

(1) Equipment layer. That is, various terminal devices collect various data information through sensors, measuring instruments and smart terminal devices, and process messages through the built-in SDK, and then send them to the IoT cloud platform through the network;

(2) Platform layer. Perform data analysis for data cloud storage, streaming computing, message distribution and rule processing, and form a data collection resource lake;

(3) Application layer. Web and mobile terminal-based clients developed on the basis of unified processing and data services on the platform that can extract and display platform data by calling various RESTful APIs.

The technical framework of the railway engineering IoT cloud platform is shown in Figure 2. As shown in Figure 2, under this structure scheme, the combination of IoT devices and cloud platforms and remote supervision and control are achieved to ensure data security and ease of use, and enable managers at all levels to be informed of the real-time on-site dynamics through the flexible organization of the application layer, effectively improving the capabilities of management, engineering construction and information sharing of railway construction project.

The data framework of the railway engineering IoT cloud platform includes data collection, encrypted transmission, authentication, streaming processing, queue buffering, data storage, data services, etc. Data collection refers to source perception through sensors, smart devices, smart gateways, etc. on the project site. Then through on-site calculation and processing of smart terminals, and secure encrypted transmission through the built-in SDK to ensure data security. The data, transmitted to the platform for the authentication check of the interface and the security check of the data, will go through streaming calculations and data identification processing according to the built-in rules of the platform, and then be placed in the message queue for subsequent data storage after calculation. The data storage center has established storage solutions for various types of data, including meta-databases, memory banks, NoSQL databases, DFS file storage, relational databases, and other multi-data storage centers. Regardless of data types, all are standardized through metadata to ensure data sharing and joint analysis. Data service is to facilitate effective utilization and analysis of subsequent data, and provide data services for various applications through RESTful data interfaces. The data framework of the railway engineering IoT cloud platform is shown in Figure 3.

4 Function Design

Under the guidance of the technical and data frameworks, the railway engineering IoT cloud platform undertakes the functions of data collection, data storage and data services, and provides convenient SDK development kits for various smart terminals. The business application framework of the railway engineering IoT cloud platform is shown in Figure 4 and its specific functions are as follows:

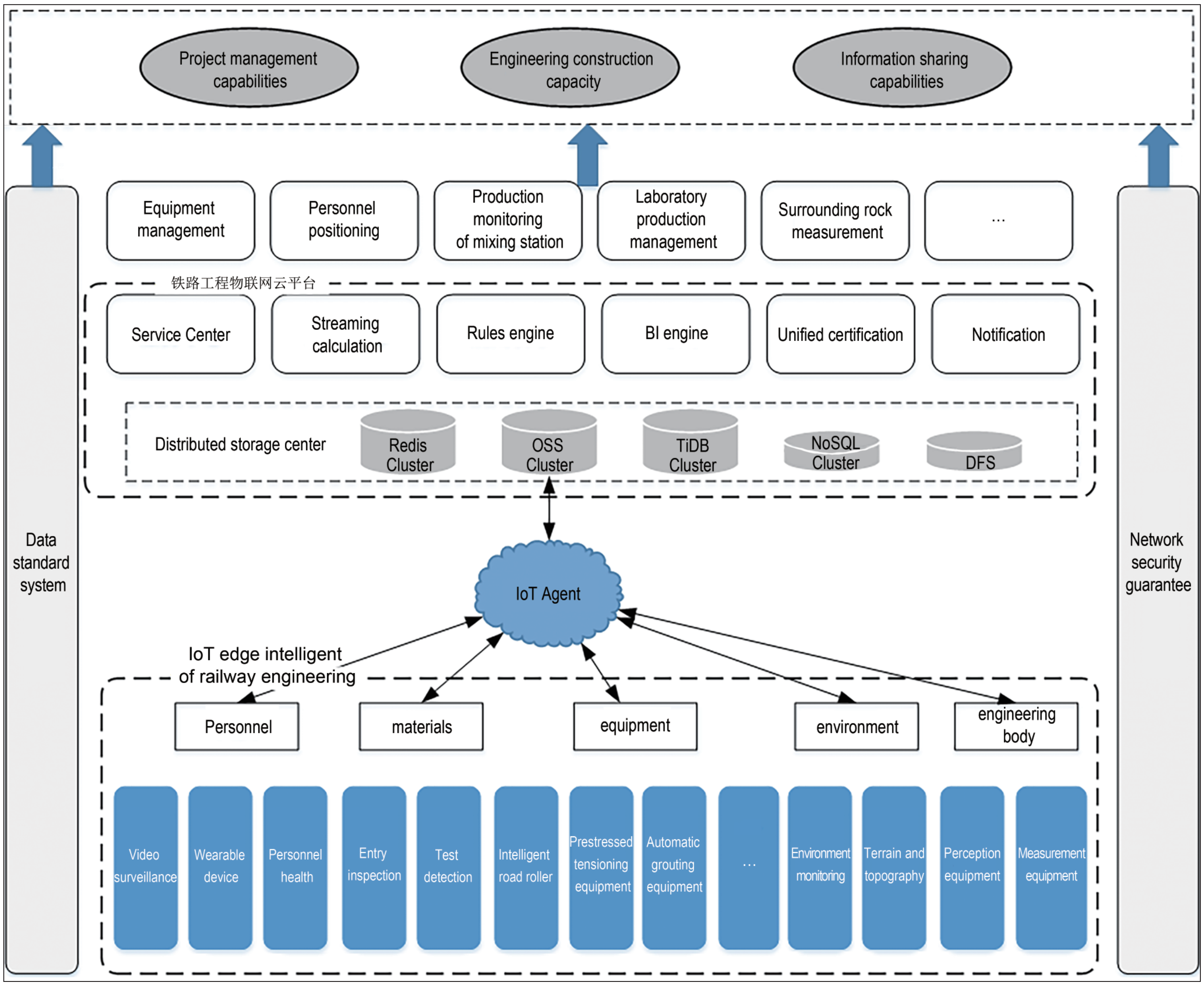

Fig. 2 Schematic diagram of the technical framework of the IoT cloud platform for railway engineering

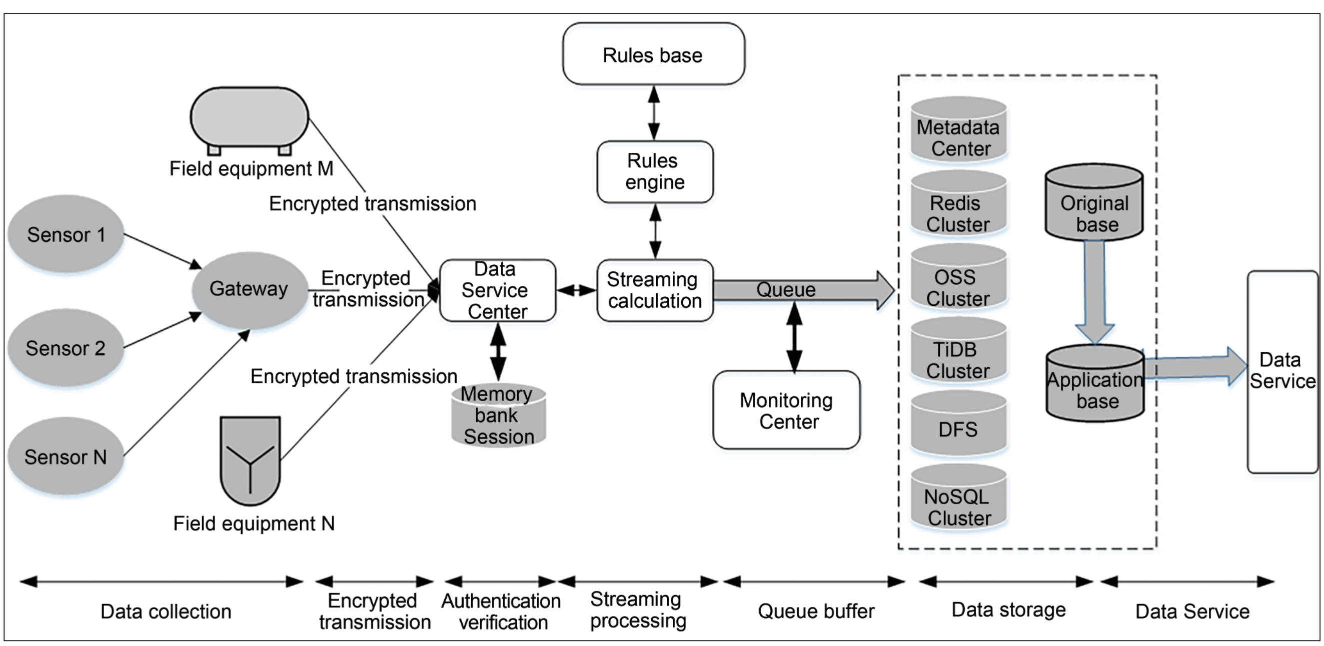

Fig. 3 Schematic diagram of the data framework of the railway engineering IoT cloud platform

(1) Provides SDK development kits for all types of terminals, as well as APIs such as device registration, management of authorization code registration, security transmission of data, etc., Through the SDK unified data transmission standards, access and upload of various terminal device data is achieved, compatible with various types data format to simplify development;

(2) The registration and management of smart devices is achieved, including basic terminal device information and on-site installation information, which further includes installation location, monitoring content, professional classification, project name, project code, terminal application, use period, number of authorization codes, etc., The unique UUID authorization code is then generated, and the terminal device can access the platform to upload data after binding the authorization code;

(3) The registration and management of access applications is achieved, and basic application information, development unit information, application deployment information, and hardware resource information are collected and registered;

(4) Provides a unified data collection interface management function, which makes it possible to realize interface registration and management, interface basic information registration, interface call monitoring and statistical analysis. The access data includes all kinds of monitoring data of personnel, materials, equipment, environment and engineering information, such as personnel attendance, personnel health, equipment trajectory, surrounding rock measurement, advanced geological prediction, safety step distance, mixing station, laboratory, settlement observation, deformation monitoring, health monitoring, ecological monitoring, etc;

(5) Provides a unified authentication function, and a unified login entrance for various users, a unified authorization management for various terminals, and a unified display portal for various applications;

(6) Unified storage of data is achieved through the use of heterogeneous distributed databases, which has multi-source heterogeneous data storage capabilities such as meta-database, memory library, NoSQL database, DFS file storage, relational database, etc.; There are two data resources lakes: original database and application database. The original database, after data cleaning and filtering, is transferred to the application database to provide high-quality data for data analysis, display, and mining, and to provide data services for business systems;

(7) The platform has built-in big data analysis tools, basic models and algorithms, providing basic big data analysis capabilities and data resource services. The business system can obtain IoT monitoring data across disciplines and cycles to provide data foundation and platform tools for application development and big data analysis.

5 Analysis of Key Technology

5.1 Access Capability of Being Compatible with Multiple Types of Equipment

Since the implementation of standardized management in railway engineering construction, a series of standards related to management, technology and operation have been issued. One of the very important concepts is to support the continuous upgradation of standards through innovation, technological progress, and the use of new materials and equipment in the operating process so as to form a virtuous circle of linkage innovation and spiral improvement. With the increasing degree of mechanization of railway

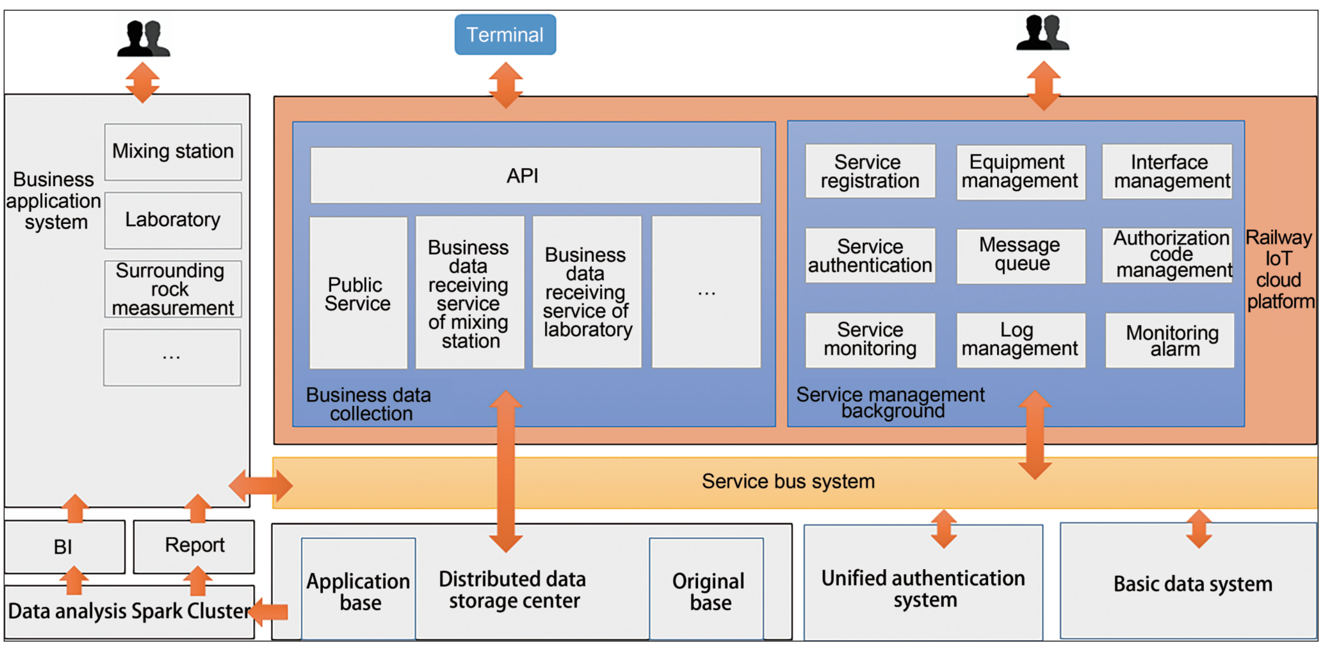

Fig. 4 Schematic diagram of business application framework of railway engineering IoT cloud platform

engineering construction, new tooling has been adopted for various professions and procedures to improve construction efficiency and quality, and enhance standardized management capabilities. Through the establishment of a railway engineering intelligent equipment cloud platform, an SDK development kit for on-site tooling equipment access management is provided. Regardless of whether the intelligent equipment system is based on PLC, ARM, FPGA, DSP and other embedded systems, or the smarter WinCE, Windows, Linux, Android and other airborne systems, the platform can provide access to a variety of smart devices, so as to realize the registration management and real-time monitoring of the operation status of all smart devices, as well as the effective evaluation of project progress and process quality through monitoring. The principle of the cloud platform of intelligent equipment management for railway engineering is shown in Figure 5.

There are many types of equipment used in the construction of railway projects. Some equipment has the ability to be intelligent, and some equipment is capable of information monitoring and transmission after networked and intelligent transformation. According to incomplete statistics, there are more than 200 professional tooling machines for railway bridges, tunnels, subgrades, tracks, four power stations, and station buildings. Through this equipment, the on-site real-time data is collected, basically achieving a complete overview of on-site production elements and engineering entities.

5.2 Transmission system based on MQTT Protocol

MQTT protocol is an information transmission protocol based on a TCP/IP network connection, using a publish/subscribe model. It is open, simple, lightweight, and easy to implement, making it suitable for various restricted environments such as low bandwidth, unreliable networks, embedded processors and insufficient memory. It is an ideal choice for IoT framework [7].

Due to the publish/subscribe model, the MQTT protocol releases the coupling between the applications of the two parties, and at the same time, there are three levels of QoS (Quality of Service) information delivery quality levels:

(1) “0” indicates that the information is only sent once at most, and the reliability of it is not guaranteed, and it may also be lost;

(2) “1” indicates that the information is sent at least once, and the client or server confirms the receipt of it, but it may be repeated;

(3) “2” means that the information is sent exactly once to ensure that the client or server receives the message only once. It can be reasonably selected according to the application scenario and the importance of the published information. And the protocol exchange cost can be minimized when the transmission is reliable [8-9].

Although the MQTT protocol guarantees transmission quality, the protocol itself does not provide information encryption and verification, and there is a possibility of tampering and attacks during the transmission process. Therefore, a security scheme based on HASH encryption is proposed to meet the network security requirements of Equal Guarantee 2.0.

The information of the MQTT protocol is composed of at most three parts: a fixed header, a variable header, and a payload (see Figure 6).

The fixed length occupies 2 bytes (16 bits), of which bits 4-7 of the first byte indicate the type of control

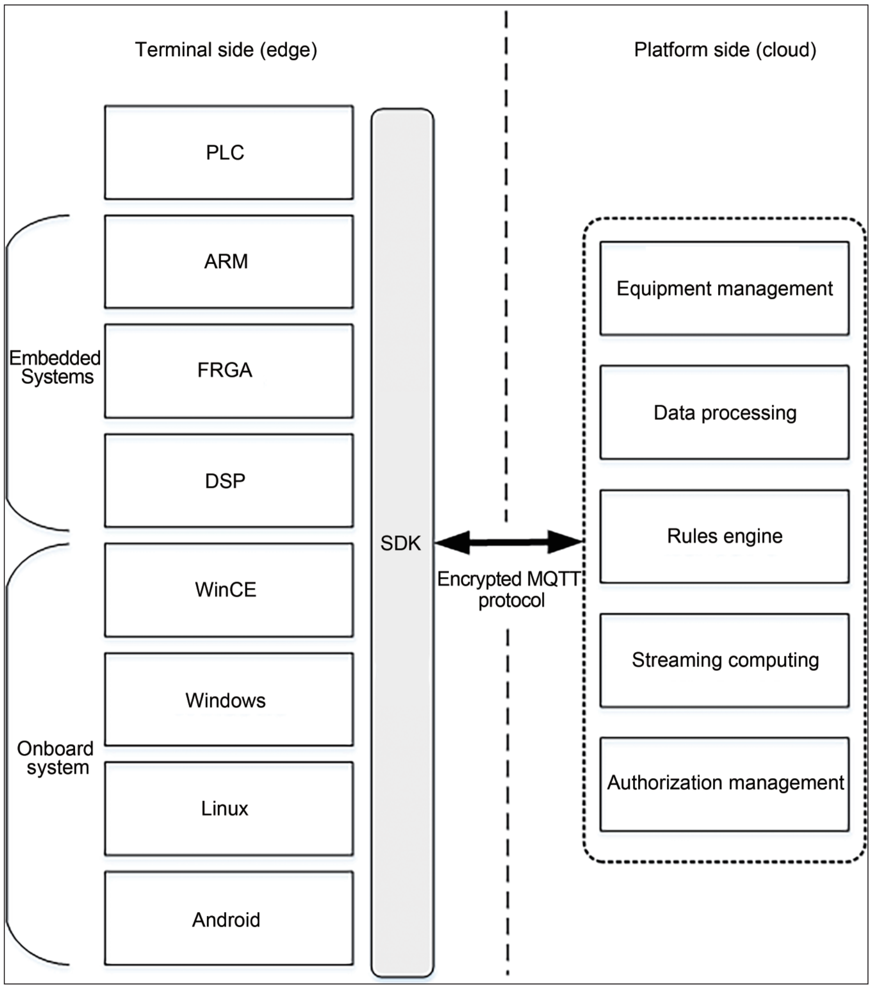

Fig. 5 Schematic diagram of the principle of the intelligent equipment management cloud platform for railway engineering

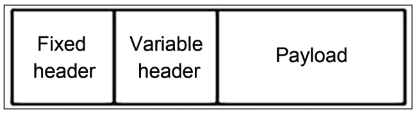

Fig. 6 MQTT message structure

message, and bits 0-3 indicate the specific flags of each MQTT control message type, including DUP flag, QoS Level, and RETAIN field. The other 1 byte represents the Remaining Length field, which calculates the total length of the variable header and message body. As the minimum length is 1 byte and the maximum is 4 bytes, the maximum length of the Remaining Length is: 128*4=256 Mbit. The MQTT fixed header format is shown in Figure 7.

Before the smart device terminal sends the MQTT message, the message is spliced with a 32-bit string for salting encryption. Different message modules have different Salt values, and the spliced message is encrypted by the HASH algorithm to generate a 128-bit message verification code. The signature verification is then spliced at the end of the message to be sent for message transmission, and at the same time the value of the Remaining Length field in the fixed header of the MQTT message is modified to complete the assembly of the encrypted message to be sent, and then send it.

When the platform receives a message, it verifies the received message. First, slice the received message and divide it into “MQTT original message+128-bit message verification code”, and change the value of the Remaining Length; then, encrypt it by the HASH algorithm after the use of Salt string splicing at the end of the original message, the make comparison between the encrypted value and the 128-bit message verification code extracted by segmentation. If the comparison is consistent, the message is reliable and has not been tampered with, and the message is received normally; if the comparison fails, the message is rejected.

5.3 Equipment and user-oriented certification system

As an important component of the security design (see Figure 8), the unified certification system of the railway IoT cloud platform includes the following three parts:

(1) Unified login. A consistent login entry for each application is provided, including login based on account and password, login based on mobile phone number and SMS verification code, global logout (users who log out from one system will log out from all systems at the same time) and access log records;

(2) Unified gateway. Controlled IT resource access authorization for all types of terminals is provided to

Bit	7	6	5	4	3	2	1	0
byte1	MQTT Control Packet type(3)				DUP flag	QoS level		Retain
	0	0	1	1	X	X	X	X
byte2	Remaining Length							

Fig. 7 Format of MQTT fixed header

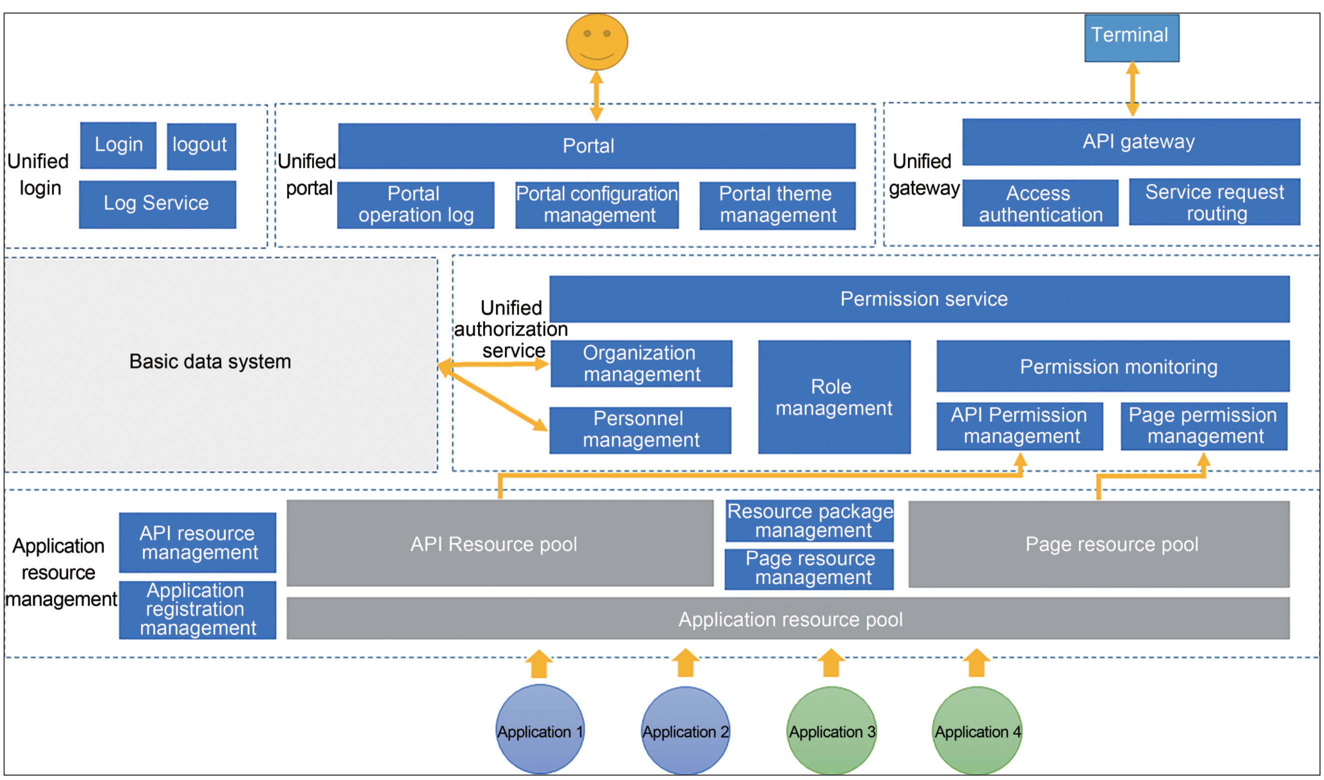

Fig. 8 Schematic diagram of the unified certification system framework of the railway IoT cloud platform

comprehensively manage all data and service access permissions on the platform, and display the authorization status of all terminals and applications in the entire platform in a unified view. Its functions include: role group and role management, authorization management, authorization monitoring, authorization service, resource package management, hierarchical authorization, etc;

(3) Unified portal. Users are provided with a unified access entrance with page embedding functions. Meanwhile a unified integrated display portal for each application is provided for API solutions for integrated display, so that the functional pages of other applications are shown in the portal with functions such as theme management, menus management, operation log, etc.

5.4 Quality control system of cloud collaborative identification

The calculation modes of big data include batch computing and streaming computing. Batch computing is to first statically store the data, and then perform calculation operations on the stored data; streaming computing does not need to store data directly, but provides continuous and dynamic services for the data flowing into the system dynamically, and performs real-time calculations on the data [10-11].

According to the data framework of the railway engineering IoT cloud platform, a built-in streaming computing engine and a rule engine will be established in the platform, and the quality control technology based on the “cloud + terminal” collaborative identification of “edge computing + streaming computing” is adopted. A unified quality research and assessment base is then formed, and real-time identification of the collected data is performed through the streaming computing engine. After that, the data will be sent to the data queue for classified persistent storage.

At the same time, smart devices have certain edge computing capabilities to build their own quality rule base in each terminal device. The terminal rule base maintains data communication with the platform rule base. After the platform rule base is updated, it can uniformly distribute data to various collections and control equipment on-site, and all kinds of terminal systems carry out automatic judgment and real-time reminders according to the rules. Due to the limited computing power of the terminal, it can only carry out the quality judgment and control of a single profession and a specific process. At the same time, relying on the powerful processing capabilities of the cloud platform, it can carry out multi-disciplinary integrated quality research and judgment and multi-dimensional trend research and judgment based on big data, forming a quality control technology for cloud collaborative judgment.

5.5 Security early warning technology based on big data analysis

In the construction of railway engineering, on-site monitoring information is widely distributed and equipment is diverse. It has the characteristics of real-time, cross-domain, massive size, multi-source, multi-dimensional, and multi-granularity. It adopts massive data abnormal event extraction technology to effectively aggregate multi-source heterogeneous data resources. Through quick identification of redundancy and error correction, data preprocessing is performed and interference and noise data in the collection process is filtered, forming effective data for calculation and analysis. A metadata-based catalog is established based on the attribute identification and classification of the collected quality data. With that, the integrated analysis of massive multi-source data is achieved, providing the technical foundation for the quality control system based on comprehensive IoT perception.

Based on the massive safety data of the construction site, combined with cross-regional, cross-departmental, and cross-business information requirements, big data analysis models such as hazard identification, safety hazard warning, deformation monitoring, and critical engineering identification have been constructed, which use algorithms such as cluster analysis, linear and non-linear regression, Douglas-Puck thinning, similar matching, frequent item sets to predict the risks that may occur in the engineering entity, and deduct the final value and the range of influence that may occur. By doing so, pre-judgement of the risk source is achieved, effectively solving problems such as inadequate monitoring of hazard sources and inadequate investigation of hidden dangers.

6 Application

Since the promotion of a railway engineering construction information platform in 2014, a railway engineering IoT cloud platform has been gradually built to realize the management and control of various construction projects. A hierarchical structure is adopted to provide project-oriented monitoring and management decision-making for CHINA RAILWAY, construction enterprise, and participating units. it has been fully applied in 21, 000 km of new railways such as Xian—Chengdu high-speed railway, Liaoning section of Beijing—Shenyang high-speed railway, Henan section of Zhengzhou—Chongqing high-speed railway, Beijing—Zhangjiakou high-speed railway, Beijing-Xiong’an high-speed railway, and 129 engineering projects and 79 construction units. It has included 17, 452 working faces of 4 066 tunnels; 350 million rounds of 7, 817 mixers, about 650 million cubic meters of concrete; 19.16 million raw material tests on 4, 214 universal machines and 3, 510 presses; line settlement observation of 13 987 km; linear monitoring of 1, 398 continuous beams; production process of 128 beam yards; collection and monitoring of multi-source information such as 10 million concealed project image information collections, forming a data resource lake for railway construction. Through real-time data collection and analysis, the quality control of key procedures in the construction process and dynamic management of project progress is achieved, improving the level of refined management of railway engineering construction groups, supporting the improvement of the physical quality of the entire road project, and effectively reducing on-site safety accident rate.

7 Conclusion

Combined with the development trend of railway IoT technology and the development needs of informatization of railway engineering, the application and key technology research of the railway engineering IoT cloud platform were carried out, and the following conclusions were reached:

(1) Having analyzing the development situation at home and abroad and the development needs of informatization of railway engineering construction, the definition of railway engineering IoT was put forward for the first time, proposing the goal of railway engineering IoT platform construction to realize more convenient equipment access and more comprehensive site perception, support comprehensive analysis of railways engineering big data, and provide decision-making basis for engineering project management;

(2) The technical framework, data processing framework and functional framework of the railway engineering IoT cloud platform was proposed, describing in detail the functional composition of the platform;

(3) Through the analysis of the key technologies of IoT in railway engineering, and the access of various intelligent equipment of railway engineering at any time through SDK, the diversity of terminal equipment is shielded, facilitating the process of the equipment entering the cloud; through the HASH encryption algorithm, MQTT-based secure data transmission of the protocol provides a secure channel for the secure data transmission is achieved; in terms of collaborative processing between the end and the cloud, the end-side computing power is used to carry out real-time data identification, and the cloud-side streaming computing and rule engine are used to achieve multi-professional collaborative analysis and calculation; the data preprocessing model is used to filter the noise and interference of the original data to ensure the effectiveness of the collected data, providing high-quality data samples for the analysis of massive data. And the big data analysis model is used to guide the identification of risk sources and early warning of potential safety hazards to improve engineering safety management capabilities.

At present, there are still problems in railway engineering IoT data collection, such as incomplete process coverage, incomplete data analysis, and insufficient use of data value. With the further development and improvement of the railway engineering IoT cloud platform, the support value for railway intelligent construction will be much more prominent.

(Translated by Qian Jun)

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