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Research Article

Interoperability Structure of Smart Water Conservancy Based on Internet of Things

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Massive smart water conservancy object (WCO) need to be connected for real-time monitoring and control, which produces massive data. Unfortunately, heterogeneous data structures and semantics lead to low interoperability between WCO and management systems. To address this challenge, we propose a novel interoperability structure for a smart water conservancy system based on the Internet of Things (IoT), and the key design includes a smart WCO terminal, interoperability network, special interoperability protocol, WCO information model, and cloud platform. Universal terminal and network are the base of interoperability hardware, and special interoperability protocol and information model for interconnection of WCO are designed for smart water conservancy management system. WCO can be connected to a water conservancy Big Data processing cloud platform for interoperability applications. The application results demonstrate that our proposed WCO's interoperability structure has obvious advantages than the general IoT at WCO interoperability. The interoperability protocol is reliable, the information model can ease interoperability and security, and the semantic dictionary is very rich and covers all semantic services of WCO.

1. Introduction

Water conservancy object (WCO) includes hydrometric station (point), water conservancy equipment (sluice and pump), and management systems (smart systems and data twins). WCO can be connected and managed by the Internet of Things (IoT) [1] and water conservancy system, and interoperability can be considered a key for efficient management of smart water networks (SWN) [2]. The heterogeneous IoT devices may operate over diverse protocols, which have different data formats and structures but require smooth cooperation and coordination. Interoperability facilitates smooth cooperation and coordination between heterogeneous devices in an IoT environment. However, interoperability is a challenge for such IoT applications [3, 4], which is preventing the wide acceptance of the IoT ecosystem [5].

The rapid development and wide application of smart information technologies, such as the IoT, Cloud Computing, Big Data, and artificial intelligence (AI), provide new opportunities for WCO, such as real-time monitoring [6] and accurate early warning of mountain torrent disasters [7]. The water conservancy Big Data can be real-time processed by IoT and Cloud Computing platforms, and on this basis, AI applications, digital twins, etc. are generated [8, 9].

In this paper, we aim to improve the interconnection and interoperability of WCO. First, we design a base smart water conservancy system based on IoT and Cloud Computing. Next, we design the interoperability's key structure to ensure the reliability of information and the correct execution of instructions required and build a water conservancy cloud platform for unifying the interoperability structure. Finally, this interoperability structure is used in water conservancy management for experiments, and the application results demonstrate that our proposed WCO's interoperability structure has obvious advantages than the general IoT at WCO's interoperability. The interoperability protocol is reliable, the information model can ease interoperability and security, and the semantic dictionary is very rich and covers all semantic services of WCO.

About the paper's structure, Section 2 is the related works about IoT, interoperability structure, and smart water. Section 3 is the structure of smart water conservancy's interoperability. Section 4 is the key design of WCO's interoperability structure. Section 5 is the case study for the experiment, and we give the discussion and conclusion in Sections 6 and 7.

2. Related Works

IoT architecture can be described as an environment that supports data acquisition, data storage, and data application [10, 11]. Recently, IoT architectures have received great attention for smooth data acquisition and analysis [12, 13]. In the context of SWN, IoT architecture facilitates smooth data acquisition from heterogeneous sensors online, including layered architecture and cloud-based architecture [14, 15].

The low-level layer, also known as the perception layer, is composed of distributed and heterogeneous sensors to collect the data. This layer senses physical and object parameters to obtain observations representing the state of the environment [16, 17]. The medium-level layer, also termed as network layer, directs the data from the low-level layer to the platform layer [18]. The medium-level layer determines the path of data transfer using devices (such as gateways, routing devices, and hubs), which are connected through various networks (such as wireless, fourth-generation (4G), and twisted pair and cable) [19].

The platform layer consists of mainly databases, data, and data preprocessing modules [20]. This layer accumulates and processes the data streams acquired from the low-level layer. Generally, this layer is composed of two major stages: data accumulation and data abstraction. The data accumulation stage captures real-time data from various sources (such as IoT sensors, device controllers, and application programming interfaces) in a structured manner. The high-level layer, also known as the application layer, is responsible for data visualization and analytics [21]. This layer consists of a user interface and a data analytics section. The user interface displays the time-series information of sensor data and subsequently presents an analysis in a user-friendly way [20]. The data analytics section performs computing over the dataset and may consist of an advanced statistical algorithm for data analysis and anomaly detection [9]. It is expected that this layer should have high computational capabilities to address the challenges posed by the high volume of dataset [22].

Cloud architectures are composed of integrating different elements, which work together to achieve a specific goal [23], and they are scalable and flexible system-based architectures [24], where the cloud refers to the host server over the Internet. The elements of a Cloud Computing server are data storage [25], software tools, and user interfaces. In cloud-based architectures, WCO can connect to the cloud, and the cloud performs the data processing and analytics tasks [26]. Unfortunately, such an approach may be slow and not interoperable for large-scale water conservancy systems. Instead, one can process the dataset locally and transfer only the relevant WCO data to the central server [27]. Fog-based architectures are designed to process the dataset locally, where WCO and gateways can be used to perform part of the data processing and communicate only relevant sensor data to the cloud [28]. More importantly, this design can achieve an upper management system which can control devices.

About the interoperability structure's security, novel methods were proposed, such as the cryptographic techniques used in scalable and secure cloud architecture, the intelligent buffalo-based secure edge-enabled computing framework which improved communication efficiency and reliability, the bee-foraging learning used to acquire high security, and the whale-based attribute encryption scheme used to encrypt and decrypt data [29]. The management systems' data quality, security, and privacy need to be taken seriously [30]. Some intelligent methods can also be introduced. In general, the IoT in the industry should not only ensure its interoperability but also ensure its security, and reasonable data algorithm and protocol can effectively improve the security of data.

In the smart water conservancy field, monitoring layer monitor the hydrometric information and object status [31, 32], preprocessing layer filter and analytics of data; storage layer temporary storage of data, remote control, and security layer is to ensure privacy and data integrity [33]. However, at present, between the differences between WCO and Cloud Computing platforms, the obstacles are the heterogeneous data structures and semantics in data decoding and information, and the advantages of Big Data and AI functions have not been fully exploited [34]. It is clear that the problem could be tackled by interpretation-interoperability structure. The device layer provides a method for data interconnection and interoperability, which can be extended and used throughout the entire water conservancy IoT, providing partial solutions for this study.

Overall, there is a lack of specialized research and design on the interoperability of WCO. The relevant technologies of the IoT provide a technical framework for the interoperability of WCO, and some improved technologies provide detailed references for enhancing the interoperability of WCO.

3. Smart Water Conservancy's Interoperability Structure

The water conservancy's interoperability structure is based on an IoT structure system and meets the information management application scenario as the premise in order to monitor and remote control WCO. The interoperability structure is shown in Figure 1. It is based on flow data between various levels as the core of the network and is transmitted based on various network foundations. As a kind of social security object, security guarantee runs through the ubiquitous connection layer, communication layer, interconnection protocol layer, cloud platform layer, and application layer of WCO.

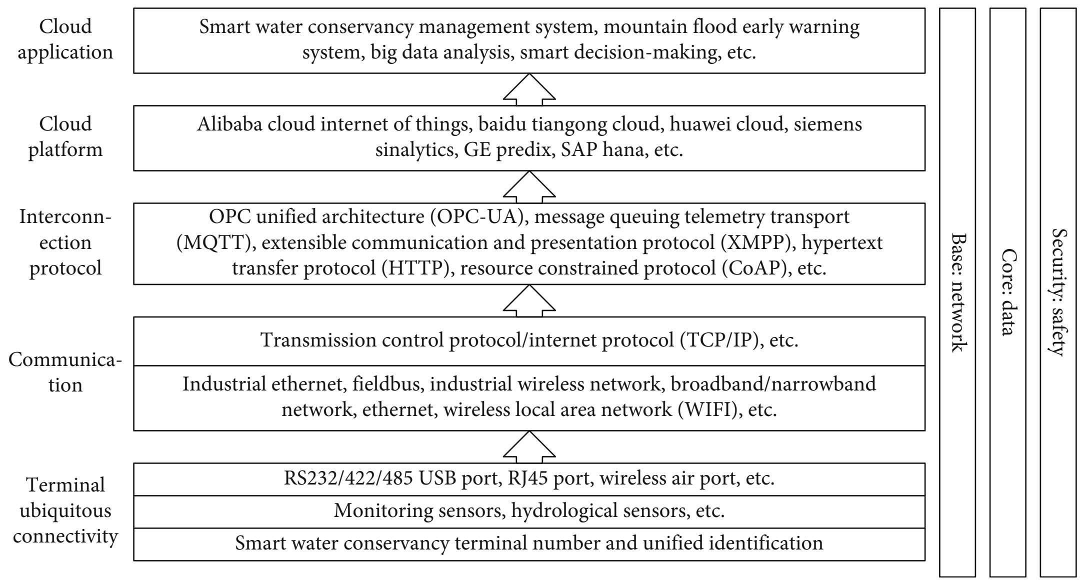

Figure 1: Smart water conservancy's base interoperability structure.

The main function of the ubiquitous connection layer is to connect WCO to the management network. There should be a unified object identification and physical communication interface, such as RS232/422/485 USB port, RJ45 port, and wireless airport; the monitoring sensors or hydrological sensors should be independent from WCO in some cases. The identification analysis system is the key infrastructure for realizing network interconnection. The WCO of each object manufacturer should have a unified and standardized physical communication interface.

The main function of the network communication layer is to realize the interconnection and intercommunication of the network layer. Ethernet, fieldbus, and WIFI are the main functions inside the local station system, and the Transmission Control Protocol/Internet Protocol (TCP/IP) interconnection network is mainly used outside the local station system.

The interconnection protocol layer reflects the interworking of message semantics of WCO. In the field of Industrial Internet, there are general standards such as OPC Unified Architecture (OPC-UA), Message Queuing Telemetry Transport (MQTT), Extensible Communication and Presentation Protocol (XMPP), Hypertext Transfer Protocol (HTTP), and Resource Constrained Protocol (CoAP). Designing special standards for the interconnection of WCO can improve communication efficiency and information security.

At the cloud platform, the large commercial Cloud Computing platforms provide convenient resources for data storage and processing for WCO, such as Alibaba Cloud Internet of Things, Baidu Tiangong Cloud, Huawei Cloud, Siemens Sinalytics, GE Predix, and SAP Hana.

At the top of this interoperability structure, we can operate the cloud application through data interaction, such as a smart water conservancy management system, mountain flood early warning system, Big Data analysis, and smart decision-making.

4. Key Design of WCO's Interoperability Structure

4.1. Smart WCO Terminal. Many smart WCO terminals do not have a unified physical interface and only have direct connection interfaces such as RS232 and USB. They are used for debugging and setting up the electronic control system. At present, wired and wireless industrial network modules are widely used in the IoT. The main interface types are shown in Table 1. The direct interface of an active object needs to be converted into wired and wireless interfaces of the network through the gateway, such as the twisted pair interface and the WIFI air interface. In addition, the control system of some smart WCO terminals is limited in storage and communication capabilities, which also restricts the direct access of device nodes to the point network, so the network conversion gateway should be configured.

Generally, the water conservancy network conforms to general network architecture, and the network level is shown in Table 2. The smart WCO terminal networking system includes basic modules such as object access, network communication, data processing, and information services.

The smart WCO terminal provider needs to configure a unified network interface, and the terminal can access the network through the data gateway. We make up for the lack of network scheduling through high bandwidth to meet the needs of information monitoring.

4.2. Interoperability Network. The network is the basis for the interconnection of WCO. The network structure reflects the reliability of interconnection. We formulate a unified smart WCO terminal interconnection and interoperability to achieve unified access to data, use a unified cloud platform to replace the traditional model of each management's self-built server, and develop service functions on the cloud platform, which reduces the cost of network construction and maintenance for managers, as shown in Figure 2. The

Table 1: Types of communication interfaces of smart WCO terminals.

Program	Interface type
Direct connection	RS232, USB, etc.
Wired	Twisted pair, optical cable, ordinary cable, coaxial cable, power line interface, etc.
Wireless	WIFI air interface, ZigBee air interface, Bluetooth, etc.

Table 2: IoT communication protocol stack of smart WCO terminal.

Network layer	Protocol stack
Application	Smart WCO terminal interconnection standard
Transport	TCP/UDP
Network	IPv4/IPv6
Data link	IEEE802.3/IEEE802.11, DLL protocol/RTU frame, CAN, CTDMA/cc-link/EtherCAT/EPA, etc.
Physical	Wired: twisted pair, optical cable, ordinary cable, coaxial cable, power line, etc. Wireless: ZigBee, WIFI, RFID, etc.

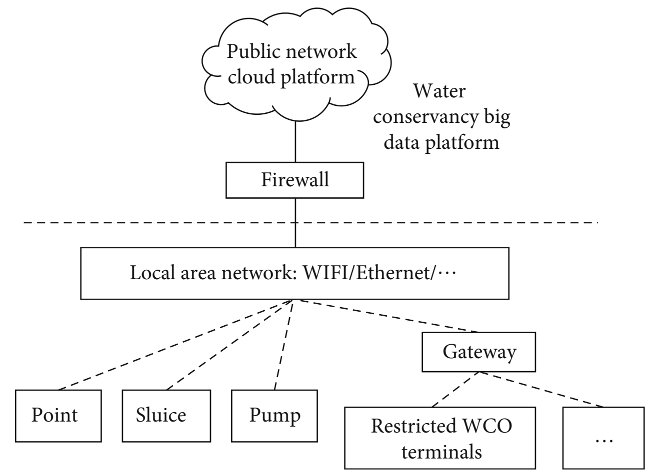

Figure 2: System structure of smart WCO interoperability network.

point, sluice, and pump are connected by the unified smart WCO terminal interconnection and interoperability network, and the restricted WCO terminals or others need the gateway.

We consider the large area of the hydrometric points, the high cost of arranging wired connections for each object, and hindering the placement of the bobbins above the object, which constructs platform object networking. Considering signal stability, it ensures full coverage of wireless signals, avoids wireless channel conflicts, solves communication congestion with high bandwidth, and uses wireless point arrays to lay out the network. The central node is wired to the access hydrometric points and finally accesses the cloud through the external network.

The convenient and low-cost interconnection network is easily accepted by water conservancy management. From the perspective of the current main industrial network structure, it is mainly in the form of a local communication network connecting WCO to systems data communication networks and terminals, but it is gradually transitioning to a simple network. The development will be more suitable for the interconnection needs of WCO. So, the problems and solutions of the application of "Internet +" and the future network in WCO are studied to improve the convenience of the network.

4.2.1. "Internet +" WCO Network. With the development of "Internet +," water conservancy management, which is a traditional field, is gradually connected to the Internet field. The overall structure of the WCO network is based on the Internet layout and directly connects to the Internet. The network structure is simple, but the premise is that the Internet has sufficient security, and WCO's upper-layer network application system can accept a certain network delay. On the other hand, it is also necessary that the motion control of water conservancy management does not depend on the network, and direct use of the Internet does not cause production failures to the equipment running. It uses Ethernet, WIFI, and other common methods to connect to the point's local area network, then connects to the general cloud service platform through the Internet, and realizes interconnection and intercommunication of WCO data through the cloud service platform. In short, the "Internet +" model has a simple network structure, low costs, and easy promotion.

However, Internet data transmission lacks a scheduling mechanism, resulting in a large number of parallel network packets and data packets. Network routing often solves the parallel problem in packet loss mode. When the cloud platform processes the communication transactions of each connected terminal, due to the lack of IP datagrams, it cannot be completed. Each connection terminal data transaction leads to service congestion and delay, which requires high bandwidth in exchange for the high efficiency of the Internet. We consider that the amount of data sent and received per second by WCO does not exceed 1 kilobyte (kb). According to the above specifications, the throughput rate (T) of the full-duplex switched network system cannot be lower than 70%, and the network load rate (B_r) should not be higher than 70%, packet loss rate (L) less than 0.1%, and error rate (E) less than 1%. Considering network redundancy (ψ) and concurrency of multiple (n) WCO, the minimum bandwidth empirical formula of a private network for $B_{\min}$ is as follows:

$$B_{\min} = \frac{1 * n}{T_{\min} * B_r * (1 - L_{\max}) * (1 - E_{\max}) * ((1 - \psi)}. \quad (1)$$

Although the bandwidth of the Internet is sufficient at present, with the increase of the WCO access, to ensure the reliability of data transmission, such as in flood control and disaster reduction, it is necessary to pay attention to the change in the minimum bandwidth and ensure its demand. On the other hand, we lead the Internet into the water conservancy system and also face a series of problems with many uncertainties in the Internet system, such as limited network address space, weak network performance, carrying capacity, and network security challenges. When the network integrator builds the network of a water conservancy management system, the number of access layer interfaces should not be less than the number of WCO and should be separated from other functional networks to avoid the blockage of the large data volume of the office network, which can affect the network communication of the WCO. The wide-area Internet network accessed by the enterprise can refer to empirical formula (1) to determine the bandwidth of the peer-to-peer Internet network, apply a fixed IP and domain name, and enhance the security of the network.

4.2.2. Future Network of WCO. Due to the sixth-generation (6G) communication technology's characteristics of massive, large-scale connection to the IoT and low-latency and high-reliability network scenarios and the software-defined network's (SDN) optimization technology to promote the industrial application of the Internet, the adoption of 6G mode will become the main industrial network structure.

All types of WCO use unified identification and independent IPv6 addressing to access 6G networks with high performance and high bearing capacity; use SDN for network transmission scheduling, which improves network reliability; and use TCP-based WCO for interconnection and interoperability protocols, which can maximize communication efficiency and information security. In addition, as a wireless network, 6G solves the problems of difficult network wiring due to the space occupied by the water conservancy points and also reduces the cost of unit network deployment.

4.3. Interoperability Protocol for Smart WCO. The network communication protocol is part of interconnection. In the industrial network protocol application, whether it is a heavyweight protocol or a lightweight protocol, it is difficult to directly realize the functional semantics and data semantics of discrete WCO. Therefore, on the basis of reliable TCP transmission based on the Internet, aiming at the difference of data processing capability of WCO, an application layer special protocol is designed, which is adapted to the network business function of WCO.

4.3.1. Heavyweight Protocols. OPC-UA is widely used in communication between devices and systems, systems and systems, because of its strong real-time performance, high reliability, and security. Its protocol cluster can ensure that all levels of the Industrial Internet can be interconnected. It adopts the communication redundancy mechanism based on UA-TCP, based on the multilevel security architecture, and has rich authentication and authorization mechanisms to ensure system security. Industrial control requirements are high reliability, data services are abundant, and the OPC-UA interconnection protocol is effective.

In view of the fact that the electronic control system of WCO on the market is mainly based on a single-chip microcomputer and embedded system, it can basically meet the interconnection and intercommunication functions of data monitoring and remote setting. However, the space for configuring OPC-UA in the electronic control system is small, and the cost of configuring the OPC-UA server alone is high, even higher than the cost of the electronic control system itself, and the promotion is difficult. But, the communication guarantee and security guarantee mechanism of OPC-UA can be designed into the WCO interconnection protocol, which can improve the interconnection performance of WCO.

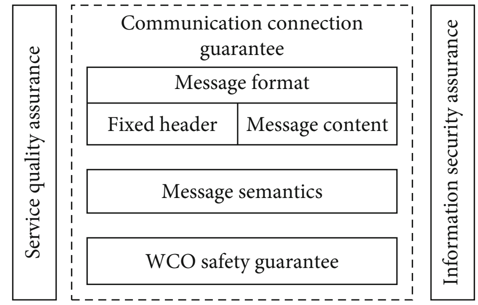

Figure 3: Design mechanism of WCO interconnection protocol.

4.3.2. Lightweight Protocol. Lightweight protocols such as MQTT and Presentation Protocol (XMPP) are widely used in generalized IoT networks and Cloud Computing platforms. With the central proxy server as the core, IoT terminals can publish and subscribe information to the proxy server. We use quality of service (QoS) to distinguish the importance of information through service authentication, key information encryption, abnormal detection, and other measures to protect the normal operation of the proxy server.

It is feasible for WCO to publish information to the Cloud Computing platform, but the lightweight mode is a one-way protocol mode, and there is no mandatory specification for the semantics and security of the IoT terminal. The fixed header semantics lack rich semantics such as MQTT, and it cannot meet the water conservancy's reliability of device interconnection.

4.3.3. Key Design of Special Protocol of WCO. The interconnection protocol of WCO should not only have the communication guarantee and information security performance of OPC-UA but also have the ease of implementation of MQTT and other modes. The overall design is shown in Figure 3. The agreement takes the safety of WCO as the core, reflects the target function of the interconnection of WCO, and establishes a communication connection guarantee, service quality guarantee, and information security guarantee mechanism.

The single WCO automatic electronic control system ensures the high-speed operation of the pump and other components. Once the command error occurs, it will cause serious failures and damage to moving parts. This structure can resist the uncertainty brought by the Internet setting permissions for WCO, establish an instruction verification mechanism, set a motion state matching mechanism to filter instructions that can conform to the motion of WCO transport parts, and add manual review functions to reliable setting instructions. The interconnection protocol cannot affect the normal

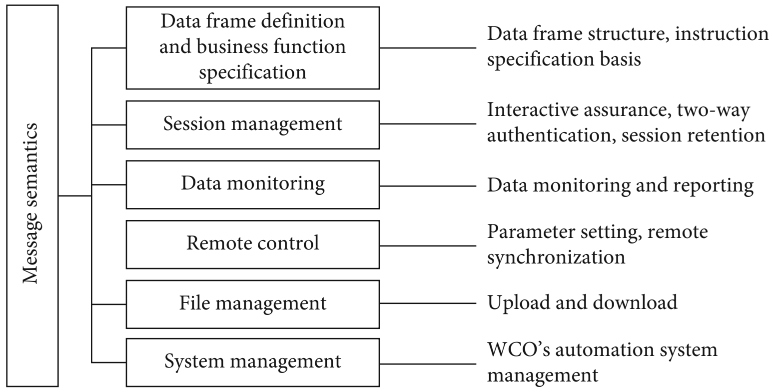

FIGURE 4: Function semantic structure of WCO message.

operation of WCO. The electrical control system of WCO needs to have a strong ability to process communication messages and reduce network attacks through a dedicated connection with the Cloud Computing platform.

The content of the message reflects the functional semantics and data semantics of information to achieve the interconnection and interoperability of WCO. The business functions mainly include data monitoring, remote control, file management, and system management of WCO. The semantic structure function is shown in Figure 4. The data frame definition and business function specification include the data frame structure and instruction specification basis. Session management is the interoperability security mechanism, which includes interactive assurance, two-way authentication, and session retention. As shown in Figure 5, the session process includes communication request, authentication, information interaction, disconnection, session end, and other processes. The whole process includes necessary sequential processes such as identity authentication, information interaction, and heart-beating maintenance.

Data monitoring is data monitoring and reporting. Remote control includes WCO's parameter setting and remote synchronization. File management includes upload and download. System management is WCO's automation system management. From the perspective of usage frequency, data monitoring and remote control are the most commonly used, which are the focus of business functions and important reference parts for the function semantic structure of WCO messages' structural design.

4.4. WCO's Information Model. The message packet for transport includes a packet header and packet content, and the packet structure is shown in Table 3. The fixed-length message header is easy to decode and contains a timestamp, requester ID, responder ID, and the total length of the message content in turn. The communication sequence number ensures one-to-one correspondence between the request and the response sequence of both parties in the communication, and the time stamp clarifies the time of message sending and receiving, the synchronization semantic time, and prevents communication denial. The ID numbers of the two communicating parties specify where the message comes from to prevent bit errors. The total length of the message content

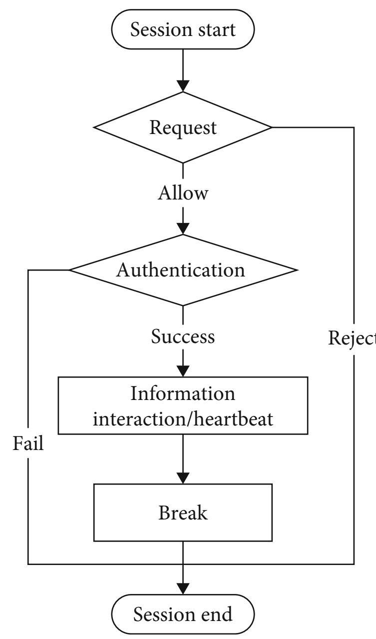

FIGURE 5: Session management's flow chart.

regulates the length of the codec and solves the problem of adhesion between messages.

The content of the message includes function code and parameter (code). The byte-type message can support multiple data type structures, as shown in Table 4.

WCO data collecting is supported by the server, which subscribes to the WCO terminal data service. WCO terminal regularly publishes service data to the cloud platform. The remote control of WCO reflects the function of the remote setting parameters of WCO, and WCO establishes a corresponding review mechanism for this type of instruction. The file management of WCO is mainly about the sending and receiving of system management files and system upgrades, so as to realize the remote maintenance of WCO.

The low coupling between messages and the strong cohesion within the messages result in strong anti-interference ability. Each message is independent of each other without contextual semantic interference, reducing decoding errors of later arriving messages caused by a priori errors. The typical parameter structure of WCO's

Table 3: Message structure.

Message structure	Type	Meaning
Fixed header	UInt16	Communication serial number
	DateTime	Timestamp
	Guid	Requester ID
	Guid	Responder ID
	UInt32	Total length of the message content
Function code	1Byte	Function type code
	1Byte	Subfunction code
Parameter (code)	variable length	Parameter (code)

Table 4: Data types of WCO.

No.	Type	Bytes	Describe
1	Boolean	1	A two-state logical value (true or false)
2	SByte	1	An integer value between -128 and 127
3	Byte	1	Integer value between 0 and 256
4	Int16	2	An integer value between -32768 and 32767
5	UInt16	2	Integer value between 0 and 65535
6	Int32	4	An integer value between -2147483648 and 2147483647
7	UInt32	4	Integer value between 0 and 4294967295
8	Float	4	IEEE single-precision (32-bit) floating-point value
9	Double	8	IEEE double-precision (64-bit) floating-point value
10	String		A sequence of Unicode characters
11	DateTime	8	Time instance
12	Guid	16	16-byte value that can be used as a globally unique identifier
13	XmlElement		XML element

information model is constructed, which mainly includes static, dynamic, environmental, etc., and covers the parameters required by WCO in equipment and management, such as Figure 6, and the parameters are encoded, the data type and range are standardized, and an extensible mechanism is formed.

4.5. Water Conservancy Cloud Platform. After WCO data is connected to the cloud platform, it involves business functions such as Big Data cleaning, transformation, analysis, and storage. The server cluster mode is used to divide labor and cooperate to process data to ensure the stable operation of the Cloud Computing server. Its structure is shown in Figure 7. The Cloud Computing platform provides reliable service functions for cloud applications and quickly processes the communication data of WCO.

It is a fast and stable solution to develop a WCO processing server on an existing cloud platform. At present, the market has general cloud servers, such as Alibaba Cloud, Baidu Tiangong Cloud, and China Mobile cloud platform, and proprietary clouds, such as Siemens and Alibaba IoT Suite, which provide platform as a service (PAAS) functional platforms and dedicated database servers.

WCO is connected to the cloud platform for data acquisition and data processing, and a management server is constructed on the cloud platform to provide services and promote the cloudification, sharing, and optimal configuration of various resources so as to promote the value-added and efficiency of resources. The unified cloud platform shields the heterogeneity of resources and uses resources on demand so that water conservancy management services are interconnected on the cloud platform.

4.5.1. Data Interaction and Processing Mechanism. The data acquisition server structure is shown in Figure 8. Considering the large scale of WCO and high data concurrency, it is necessary to give full play to the performance of the server's multicore CPU, and the water conservancy data collection server needs to support multiprocessing and multitasking and open a main process and multiple subprocesses to provide services to the WCO terminal. The main process is responsible for monitoring the subprocesses, and subprocesses monitor network connections and send and receive process data independently. The process model is simple, making server software more stable and efficient.

The water conservancy interconnection protocol has many types of instructions, and the operating status is switched in real time. The information received under the conditions of parking, running, alarming and communication abnormalities, file transmission, and object locking have different meanings, and the server needs to be discriminated and processed. In addition, due to differences in protocol

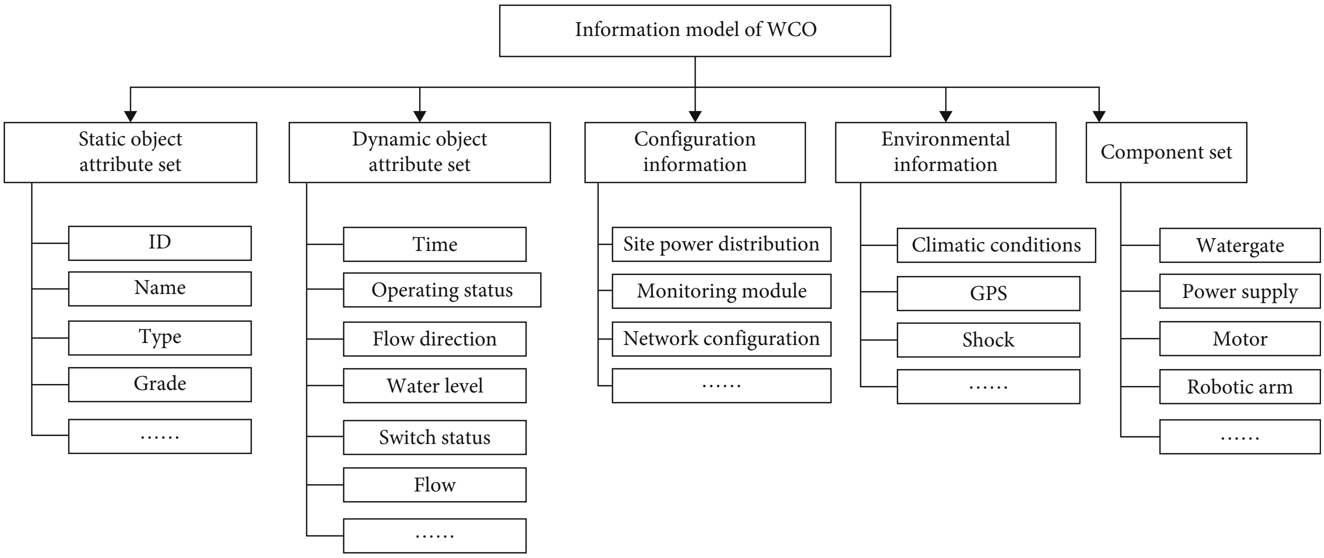

Figure 6: Information model's parameter structure of WCO.

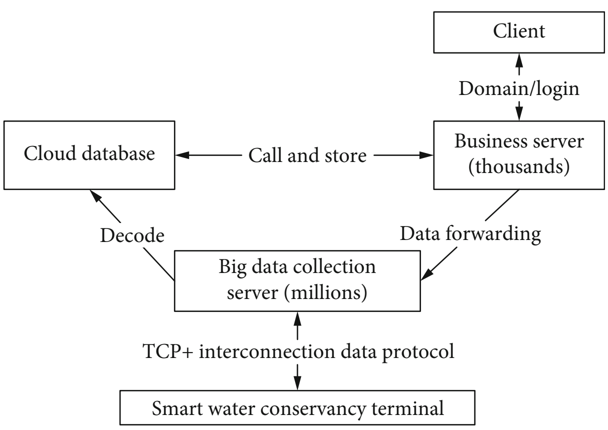

Figure 7: Cluster structure of water conservancy server.

conversion between heterogeneous networks, network interference, and intrusion, data needs to be cleaned and converted in advance, and business preprocessing is also required for upper-level management system.

4.5.2. Cloud Platform. The cloud storage database is the data core needed to realize the function of WCO networking, which involves many management departments, various types of WCO, and a large amount of data. The status, warning, and parameter changes of WCO are nonlinear changes, and there is no direct relationship between data parameter changes. For this reason, the Hadoop cluster Big Data database is used as the root database of the WCO cloud platform to store nonrelational data on the WCO terminal. However, user application databases such as management system mainly use real-time query functions, which require high real-time data. For this reason, the data service part of a cloud database uses a relational database to store the sorted business relationship data to reduce store duplicate data to improve utilization; we consider query speed when designing data tables for query functions, set up necessary indexes and temporary tables, build databases in a distributed type, and establish a grading mechanism according to functional characteristics.

The cloud database's attribute table is static data, which can be stored in the cloud database system once the WCO is online without repeated storage; for the data that needs to be quickly queried, the cloud database records the status, speed, etc. The data is updated in real time, and the historical data is shielded to improve the viewing speed of the cloud platform application services. The historical database is mainly used for the cloud platform to do Big Data statistics and analysis applications; the business class is used for the cloud platform application to complete related management services. The design of the data table achieves the separation of dynamic, static, and real-time query priority scheduling.

For the water conservancy management department, data separation is separate, including the object attribute table, temporary query table, historical data table, and business and class table. There are one-to-one, one-to-many, and many-to-many relationships between entities in the WCO relational database.

5. Case Study

Typical cloud services are mainly based on the water conservancy management system, and their functions and efficiency directly reflect the system users' evaluation of the efficiency of the WCO cloud platform. We design practical and reliable water conservancy management system functions. That is the focus of cloud service platform development. The WCO terminal transmits the status and operating parameters to the cloud server in time for processing. During the test, WCO operation monitoring status, speed, output, and other information are rich, and the user experience is not stuck. This service can be used by WCO manufacturers on a large scale to be extended to water conservancy management systems. The experiment of smart water conservancy management structure, WCO's

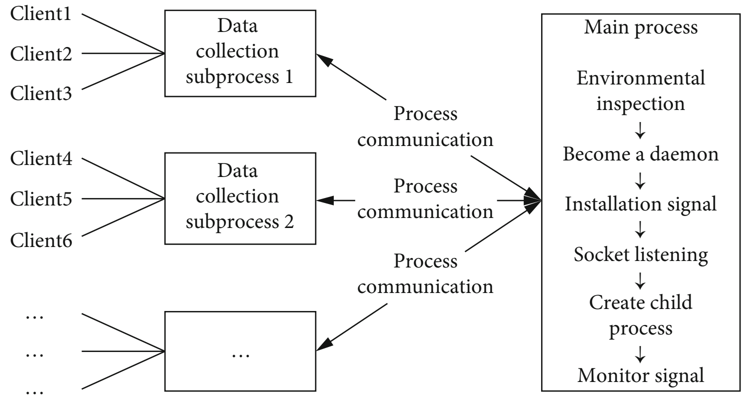

Figure 8: The structure of the WCO data collection server.

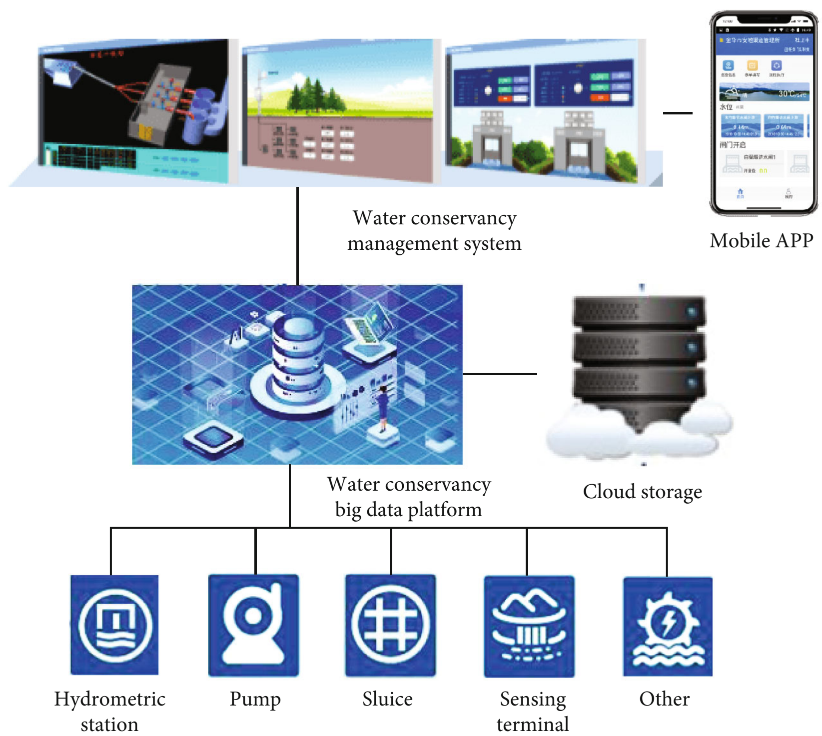

Figure 9: Smart water conservancy management structure.

interoperability data, and management system could prove that the key design of the interoperability protocol is reliable, the information model can ease interoperability and security, and the semantic dictionary is very rich and covers all semantic services of WCO.

5.1. Smart Water Conservancy Management Structure. The smart WCO terminal transmits the status and operation parameters to the platform for processing in time. During the test, the status, speed, output, and other information of smart WCO operation monitoring are rich, and the user experience is not sticky. This service can be widely promoted for smart water conservancy management. Figure 9 shows the functional structure of a smart water management system, including kinds of WCO which connect the water conservancy Big Data platform and cloud storage, and the management information is shown on the WEB management system and mobile applications. The smart water conservancy management system includes access terminals, data accessed today, new storage data today, total stored data, etc., and monitoring their data in real time proves the effectiveness of water conservancy management by the interoperability structure of the smart water conservancy system based on IoT.

5.2. WCO's Interoperability Data. Alibaba Cloud Computing platform is adopted to develop smart water conservancy cloud service data interaction and processing service software, and MySQL database software is used as the cloud database system. We develop the browser/server to monitor, control, and test the user's experience of Internet applications. The concurrency performance of the test server can

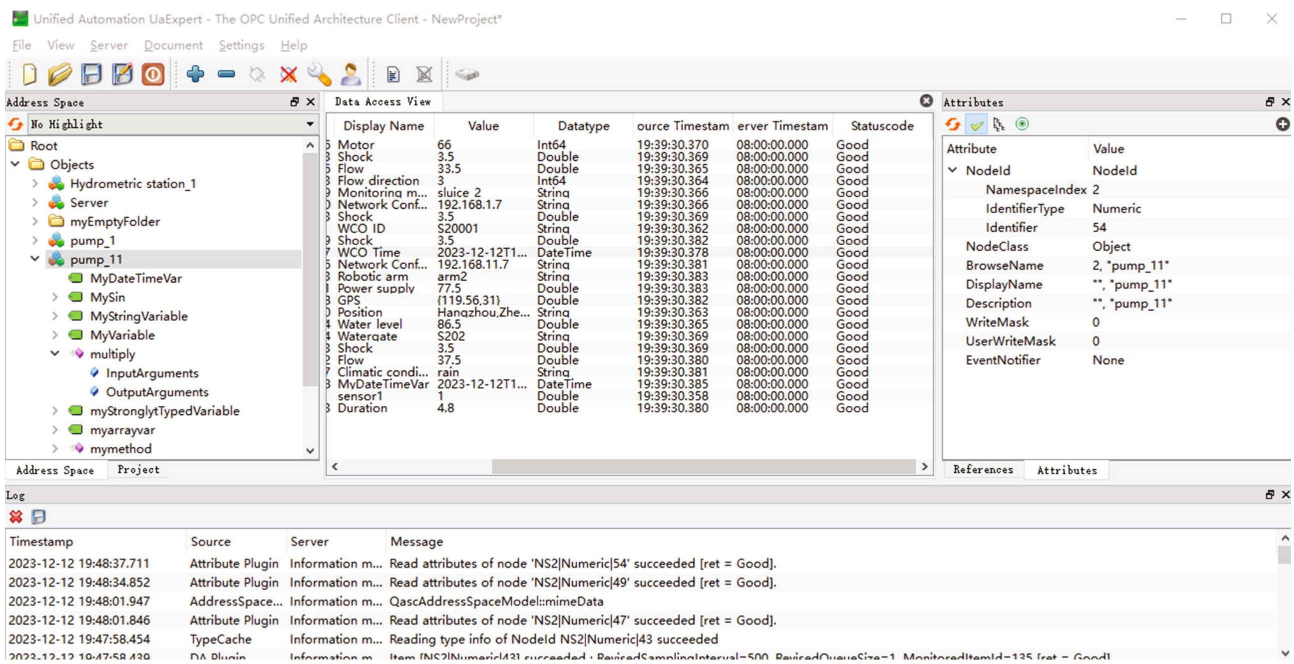

Figure 10: Unified OPC-UA client for data operating.

be measured by the TCP/UDP performance stress test tool, which can simulate multiterminal sending of data to the server and display the number of data transmission and the number of receiving through a graphical interface. Each terminal can encode and send about 2500 instructions per second, accept more than 300 service instructions, and decode them, and the effect meets the interoperability needs of the terminal and the server. It proves the feasibility and real-time performance of smart WCO terminal and interoperability network. It is consistent with the bandwidth evaluation of formula (1).

OPC-UA is commonly used for interoperability verification. In WCO's special interoperability protocol and information model, Figure 10 shows a water pump's OPC-UA server for the special protocol and information model test, which was developed by Python's OPC-UA module. Then, we can use the OPC-UA client to access the information model of the water pump on the OPC-UA server, including attribute sets such as WCO ID, flow, water level, shock, and other element structures, which proves the feasibility and interoperability reliability of WCO's interoperability protocol and information model. It can correctly analyze the semantics of information and the implementation value of data. This experiment proves the effectiveness of data interoperability.

5.3. WCO's Management System. At the application layer of the smart water conservancy management system, Figure 11 shows the real-time data display of the smart water conservancy management system, including WCO terminals, number of dadas, tasks, and average flow trend. The Big Data platform's real-time is reliable and connects with the 3146 WCO terminals. The structure of the WCO data collection server storage system's Hdfs (Hadoop distributed file system), Rdbms (relational database management system), and Rdies (remote dictionary server) has more than half of the processing capacity. The interoperability structure of a smart water conservancy system based on IoT has numerous advantages as the WCO information model is used in this system.

6. Discussions

The interoperability structure of the smart water conservancy system in this paper has obvious advantages than the general IoT. Table 5 shows the feature comparison between the interoperability structure of the smart water conservancy system and IoT. The interoperability protocol is as reliable as the abundant and multilevel interoperability protocols. The information model structure has a tree structure and mesh structure (attribute element implementation) which can ease interoperability and security. The semantic dictionary is very rich and covers all the semantic services of WCO. The number of interoperability functions and information transmission directions is richer, and the interoperability instructions can be transmitted up or down.

The diversity of interoperable hardware foundations and the uncertainty of system bandwidth are complemented by key-designed interoperable protocols and information models. Semantic interoperability was originally a big problem. Although the network has been interconnected or is easy to interoperate, it is difficult to achieve semantic interoperability for any terminal device due to the combination of the attributes and functions of each terminal device. However, in the field of WCO, it is feasible to design the interoperability structure of smart water conservation based on IoT because of the relatively standardized interoperability requirements, controllable data size, and achievable security level.

The whole architecture transmits not only data but structured information based on the unified language

Figure 11: Smart water conservancy management system.

Table 5: Feature comparison between interoperability structure of smart water conservancy system and IoT.

Interoperability factor	Basic IoT	Interoperability structure of smart water conservancy system
Interoperability protocol	Extensive	Extensive and reliable
Information model structure	None	Tree structure, mesh structure (attribute element implementation)
Semantic dictionary	None	Very semantically rich
Model semantic completeness	Fragmented, incomplete	Covers all semantic services of WCO
Number of interoperability functions	1	6
Information transmission direction	1 (only monitor)	2 (monitor and remote control)

model of WCO. Of course, when processing data, it needs a more professional data cloud platform and codec system, as well as programs that can analyze interoperable functions. The reliability, security, and convenience of an interoperable system are often a pair of contradictions. In order to reduce the complexity of the system and improve reliability and security of the system, it is necessary to obtain a unified design on the interoperable structure, interoperable protocol, and WCO information model, especially when the entire IoT infrastructure tends to be finalized, to design an interoperable protocol and information model suitable for WCO industry application scenarios. It can significantly improve the overall interoperability performance and get better application in data and storage of the cloud platform.

In total, the interoperability structure of the smart water conservancy system promoted the interoperability of the WCO and management systems. The key factors include the WCO information model and the water conservancy cloud platform of Big Data, which can be built into this paper. Also, note that the WCO needs a rule-based information model building ability to adapt to more types of systems or other objects.

7. Conclusions

This paper researches the interoperability structure of smart water conservancy based on IoT. The interoperability structure is designed to provide support for smart management and smart application. The main conclusions of the paper are as follows.

(1) An interoperability network of WCO is proposed, which can connect with the characteristics of multiple models and diversified access ports. It is compatible with various ports of existing smart WCO terminals and is a convenient and low-cost networking solution for network deployment

(2) An interoperability protocol for smart WCO is designed, including data acquisition, semantic analysis, and remote control. The interoperation protocol has the characteristics of comprehensive function, simple implementation, and security. In addition, the proposed information model of WCO in this paper ensures the reliability of interoperability and

has comprehensive information and data security, which is suitable for interconnection on the cloud platform based on Big Data

(3) A cloud platform for WCO has been established, and WCO is interconnected through the commercial Cloud Computing platform, realizing Cloud Computing services mainly based on a smart water conservancy management system. The test example proves the reliability and excellent performance of the interoperable structure of WCO, and the interoperability structure of the smart water conservancy system promotes the interoperability of WCO and management system. The key factors include the WCO information model and water conservancy platform which can be built into this paper

In future work, we plan to combine semantic and structural information, optimize the factorization rules and more extensive security certification, and establish WCO information model construction theories and methods. We will make full use of the advanced technology of the IoT to further improve the concurrency performance of interoperable systems and cloud platforms and widely apply it to the interoperability of the intelligent water conservancy industry, laying the foundation for advanced intelligent technologies such as water conservancy digital twin and digital water network.

Data Availability

The interoperability data used to support the findings of this study have not been made available because the data is generated in real time by the experimental platform and are only used for testing performance.

Conflicts of Interest

The authors declare no conflict of interest.

Authors' Contributions

Songsong Wang was responsible for the research design, experiment and analysis, and drafting of the manuscript, and Ouguan Xu revised the manuscript. All authors reviewed the manuscript.

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