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Edge Control Monitoring System Based on Heterogeneous Networks

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Abstract: *This paper proposes an edge control and monitoring system based on heterogeneous networks, which comprises edge IoT gateways, IoT terminals, unmanned vehicle-mounted terminals, unmanned aerial vehicle (UAV)-mounted terminals, and edge IoT pipes.Aiming at the problems of diversity, heterogeneity, and inconsistent access protocols among terminals in the network, the system enhances the intelligence of the edge side to reduce the computational pressure on the server side, supporting ubiquitous access and interconnection of multiple heterogeneous networks and terminal devices. It boasts the ability to quickly and uniformly access various heterogeneous devices, capable of shielding the differences in heterogeneous protocols to achieve unified control and management of various devices in the network, optimizing communication and response among devices within and across networks, and providing efficient and convenient system services.*

Keywords: *heterogeneous network; edge intelligence; monitoring system; Edge-End collaboration*

1. Introduction

With the continuous development of modern logistics, new technologies such as mobile internet, big data, cloud computing, and Internet of Things (IoT) have been widely applied in the logistics sector. However, there exists a structural imbalance in regional logistics hub network facilities, manifested in issues like "strong east and weak west" and "strong urban and weak rural." The primary challenges facing logistics transportation lie in the significant disparity in network throughput demand between holidays and weekdays on the temporal dimension, and diverse requirements for logistics networks on the spatial dimension. Consequently, constructing a heterogeneous network system that can flexibly adjust network throughput on the temporal dimension while satisfying various scenario needs on the spatial dimension is of great significance for enhancing the overall operational efficiency and service quality of the logistics industry [1] .

The heterogeneous network resource integration technology is an effective approach to seamlessly connect diversified logistics channels. In the construction of logistics hubs, various types of networks are applied to different network service technologies, including the Internet of Things (IoT), mobile networks, cloud computing networks, etc [2] . The Internet of Things (IoT) harnesses embedded technology and computing power to transform simple physical devices into intelligent ones. Heterogeneous networks enable the sharing of information among devices and facilitate their collaborative efforts to improve user experience [3] .Collins Aerospace released a white paper outlining a framework architecture proposed by the company for heterogeneous network networking services, known as Resilient Autonomous Networking (RAN). Its goal is to provide autonomous heterogeneous network convergence layer capabilities, leveraging this capability to integrate individual networking services into a holistic whole, thereby achieving resilience, reliability, and robustness for next-generation network services.

2. Scheme Design

The system comprises an ad hoc network formed by edge IoT gateways, fixed IoT terminals, mobile IoT terminals, and edge IoT pipes. To address issues such as timeliness, punctuality, and transportation matching in logistics networks, a prototype system for heterogeneous network-based edge IoT gateway access is designed. By enhancing the intelligence at the edge of the system, the prototype reduces computational pressure on the server side, supports ubiquitous access and interconnection of multiple heterogeneous networks and terminal devices, and possesses the capability for rapid and uniform access to various heterogeneous devices. It can shield the differences in heterogeneous protocols to achieve

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unified control and management of devices in the network, optimize communication and response between devices across networks, and provide efficient and convenient system services. The system is composed of a perception layer, an edge layer, and an application service layer, as illustrated in Figure 1 for the prototype system's architecture.

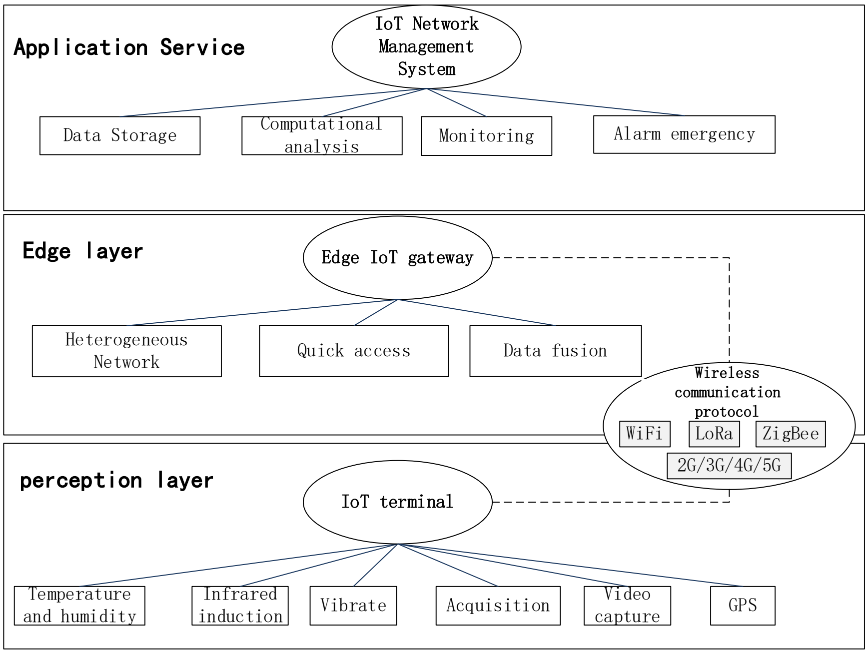

Figure 1: System composition diagram

Given the diverse functional requirements of logistics warehousing and transportation scenarios, different communication methods are typically selected, leading to application systems characterized by diverse access devices and heterogeneous communication networks. This, in turn, results in poor data interoperability between network nodes and difficulties in network management. Gateways serve as fundamental components for data integration and protocol conversion in network systems. However, traditional gateway devices have limitations such as relatively simple network conversion capabilities and high deployment costs, making them unable to meet the extensive device access demands in current logistics warehousing and transportation scenarios. Efficiently addressing network standard issues and data integration challenges posed by heterogeneous objects is a crucial problem that IoT gateways urgently need to solve.

By studying the multi-interface and multi-protocol conversion capabilities of edge IoT gateways, this paper proposes a solution for edge IoT gateways that integrates multiple wireless communication methods. Furthermore, a logistics control and monitoring system software is developed to rapidly monitor various heterogeneous IoT terminals, display the network organization status of corresponding warehousing areas and parameter information of stored objects, and realize various comprehensive management functions to meet data acquisition and integration needs across different scenarios.

3. Information Process

IoT terminals will be distributed across multiple locations within the logistics management and control area. These terminals support various wireless communication protocols and can autonomously select a communication method based on the distance and data transmission requirements to achieve rapid networking. Multiple sensors are employed to monitor the attributes (such as location, temperature, and other device status information) of each IoT terminal in real-time. The acquired diverse data (including images, videos, infrared, temperature and humidity, vibration, and other business-related information) is transmitted through different communication technologies and aggregated at the gateway for classification. The logistics management and monitoring system then integrates and presents this data. According to management needs, the logistics management and monitoring system issues instructions, which are executed by the corresponding terminals. The edge IoT gateway packages these instructions into different protocols based on real-time registration information and distributes them to terminals connected via different communication protocols. The terminals receive the instructions and proceed with data collection. The collected data is then aggregated by the terminals at the edge IoT gateway based on their respective communication protocols. The gateway sends the corresponding data to the host computer in sequence according to the set priorities, where it is displayed in the network management system. Any abnormal data triggers the corresponding actions.

4. System Design

4.1 Edge IoT Gateway

In real-world logistics scenarios, the Internet of Things (IoT) faces multiple heterogeneous networks, where a large number of terminal devices often support only one wireless technology and exist in different access networks, leading to poor interoperability among devices. Driven by application requirements, an edge IoT gateway supporting multi-source data integration and heterogeneous multi-mode network access has been designed. Its functional structure is illustrated in Figure 2.

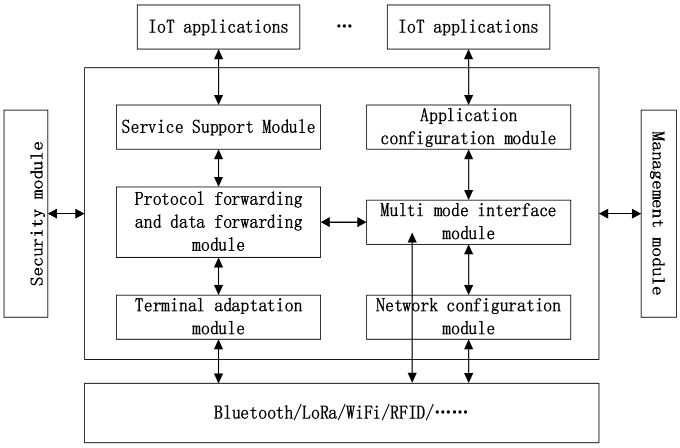

Figure 2: Gateway architecture diagram

The edge IoT gateway is designed with a hierarchical structure. Under this structure, the edge IoT gateway system accesses a wide range of heterogeneous terminals, aggregates sensory data from multiple subnets, and adapts and converts the multi-data within the edge IoT gateway system to form uniform and standardized data frames that can be recognized by different terminal devices. These data can then be transmitted to corresponding network nodes or management platform systems. This hierarchical model, as shown in Figure 3, consists of device access layer, protocol adaptation layer, data synchronization layer, and platform communication layer, from bottom to top.

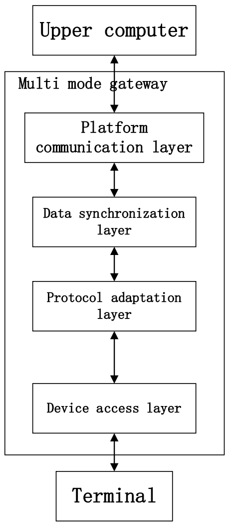

Figure 3: Hierarchical structure diagram

4.2 IoT Terminal

The hardware block diagram of the IoT terminal is shown in Figure 4. The IoT terminal supports networking through ZigBee, LoRa, and WiFi, allowing users to specify the network type by sending commands based on their requirements. By default, the system establishes networks in the order of WiFi, ZigBee, and LoRa. The system also incorporates a relay function to enhance network coverage and stability. Additionally, it provides a network status map, which visually displays the entire network state, assisting users in understanding network connections. The system supports the collection of various sensor data, enabling real-time access to data from different sensors.

The system features a sensor linkage function. For instance, upon detecting the presence of a human body, the system can automatically push relevant video data, facilitating users' timely access to information. Furthermore, users can configure different sensors to transmit data through different networks as needed, optimizing the utilization efficiency of network resources.

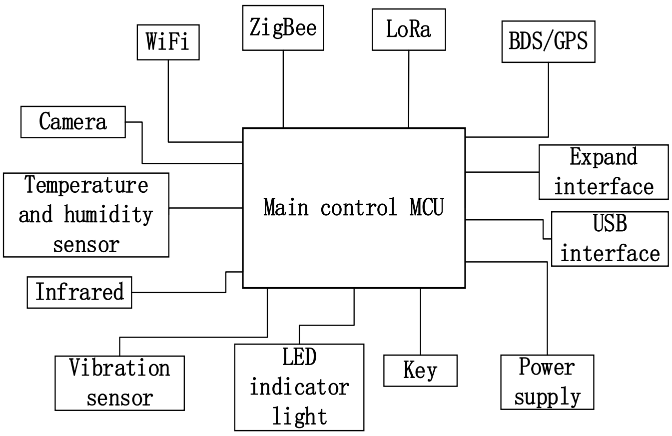

Figure 4: Terminal hardware diagram

4.3 Edge Control and Monitoring System

The Edge Logistics Management and Monitoring System is deployed on the host computer, where the Edge IoT Gateway communicates with it via the MQTT protocol for data exchange. Depending on various network application scenarios, it connects and supports various end-side IoT terminals and edge-side IoT gateways, forming an integrated Edge IoT Access System Management Center. This center provides supporting functions such as communication management, interface protocols, parameter configuration, device authentication, device management, network topology, data aggregation, operational status monitoring, data analysis, service switching, and real-time monitoring. It enables applications like rapid networking, mobile trajectory tracking, data aggregation, dynamic network switching, data relaying, UAV-mounted terminal cruising, and long-distance multi-hop transmission. The functional architecture of the edge control and monitoring system is shown in Figure 5.

The MQTT protocol is a message transmission protocol based on the publish/subscribe model, employing a client/server architecture for communication. The system utilizes an MQTT communication module to enable data communication between the Edge Logistics Management and Monitoring System and the Edge IoT Gateway. The Edge IoT Gateway maintains a persistent connection with the system, and they interact and transmit various types of sensory information through an MQTT broker server. In the MQTT protocol, communication information is represented in the form of "topic + payload," where the topic indicates the communication type, encompassing critical information such as the source, destination, and data type of the transmitted information, while the payload represents the specific content of the communication. Since IoT terminals perceive different data, different communication messages correspond to different payload types. The system adopts the JSON format to describe all message payloads, with each JSON object corresponding to a specific payload type object.

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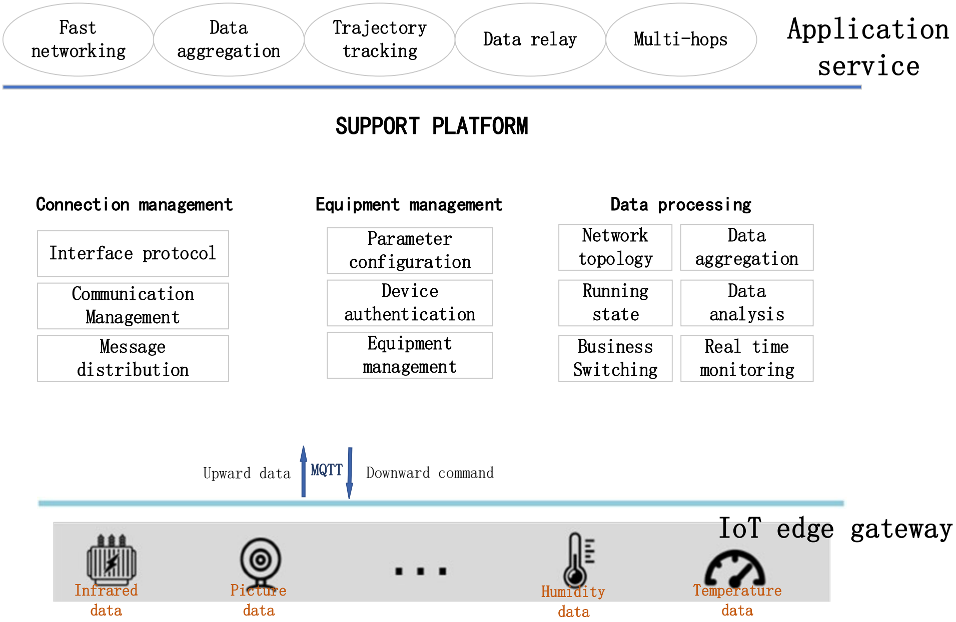

Figure 5: Functional architecture of edge control monitoring system

4.3.1 Unified description of data structure on the device side

This structure represents the attribute set of IoT terminal devices, and the transmission of IoT terminal data needs to follow this format. Its data structure contains key elements such as DeviceID, HostID, and PropertyList. The specific contents are shown in Table 1.

Table 1: Unified description of device end

Field name	Value Type
DeviceID	string
HostID	string
PropertyList	List

Among them, DeviceID and HostID are both static attributes, representing the uniqueness of the device. PropertyList, on the other hand, is a collection of properties and belongs to dynamic attributes.

4.3.2 Equipment Management Data Structure

This structure is applicable to scenarios where a user issues control commands to a specific IoT terminal, modifies attribute information of a device, or deletes device information. Its data structure encompasses key elements such as command source, command target, and command parameters. The specific fields are detailed in Table 2.

Table 2: Equipment Management Data Structure

Field name	Value Type
GUID	string
DeviceID	string
HostID	string
SourceUserID	string
PropertyList	list

In this context, GUID represents the unique ID of the operation, SourceUserID indicates the source of the command, DeviceID and HostID serve as identifiers for the target of the command, and the command parameters are stored in the PropertyList array. After the IoT terminal acquires this type of data, it parses the command parameter array to obtain the corresponding control parameters.

4.3.3 Data structure of online device list

This structure is frequently used as the system will push real-time information about online IoT terminals and edge gateways. When a device goes offline, the edge logistics management and monitoring system will immediately update the corresponding device list and synchronize it to the user end. The specific fields are shown in Table 3.

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Table 3: Data structure of online device list

Field name	Value Type
GUID	string
DeviceID	string
DeviceList	list
PropertyList	list

Wherein, DeviceList represents the device information array, containing specific details such as device location information, device description, device registration time, device network access time, and so on.

5. Conclusions

This paper designs an edge management and monitoring system based on heterogeneous networks. Compared to existing solutions, the heterogeneous network-based logistics management and monitoring system possesses unique advantages in warehouse environmental monitoring and cold chain transportation. By integrating various sensors, the system collects real-time multi-dimensional data such as temperature, humidity, vibration, and light intensity, providing comprehensive environmental monitoring to ensure that all aspects of storage and transportation are maintained in optimal conditions. The system employs multiple communication protocols (ZigBee, WiFi, LoRa) for data transmission, minimizing the impact of a single module failure on the entire system and enhancing the reliability of data transmission and the stability of the monitoring system.

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