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Industrial Internet Communication Architecture Based on Embedded IPv6 Fuzzy Control

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Abstract. In order to solve the problems of wrong device address, unreasonable network bandwidth setting and low level of automation control of industrial Internet, a standard verification platform and test system for industrial Internet based on IPv6 fuzzy control are designed. We determine the network architecture of the industrial Internet according to the demand analysis, and complete the design and implementation of the embedded IPv6 protocol stack. We design a fuzzy rule library to describe the relationship between input and output. The corresponding IPv6 communication protocol and mechanism are used to achieve communication between fuzzy control modules and other system components. This module is used to accurately predict the situation awareness within the industrial interconnection network to ensure the security and reliability of communication. A real environment is established to test and analyze the data path, and the correctness and compliance tests of the system are implemented, which provided ideas for the development of IPv6 based industrial Internet network construction and promotion of related applications.

Keywords. IPv6; fizzy control; industrial internet; protocol stack; data path

1. Introduction

With the continuous development and popularization of the Internet of Things technology, many new and advanced technologies such as big data technology and mobile Internet technology have also been effectively integrated with the energy industry, making the energy industry achieve major reform and innovation. By scientifically applying IPv6 standard to the construction field of industrial Internet, the problem of IPv6 address error of network equipment can be fundamentally solved IPv6 is a commonly used lightweight protocol. Its reasonable application can not only promote the healthy and sustainable development of wireless network technology in oilfield industry, but also form a systematic and standardized IPv6 standard to provide corresponding standard support for the interaction between various networks [1]. At present, based on the deep integration and development of the manufacturing industry with the Internet+, cloud computing, big data, artificial intelligence and other new generation information technologies, the construction and application of the industrial Internet platform to realize the optimal allocation of internal resources of manufacturing enterprises and cross enterprise socialized collaborative manufacturing has become a key to promote industrial transformation and upgrading. However, with the explosive growth of all kinds of sensors and intelligent industrial equipment, the IP

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resources under the traditional IPv4 protocol become more and more tense. In addition, industrial big data has the characteristics of real-time and high concurrency, which makes the traditional industrial control network unable to meet the practical needs of industrial Internet platform applications. IPv6 based industrial Internet platform provides a new solution to solve the above problems [2].

In industrial internet communication, fuzzy control can be applied in multiple aspects. Firstly, it can be used for automation control of industrial equipment. By collecting sensor data from the equipment and using fuzzy control algorithms to control the equipment, automatic adjustment and optimization of the equipment can be achieved, improving production efficiency and quality. Secondly, fuzzy control can be applied to load balancing and optimization of industrial internet communication networks. By real-time monitoring and analysis of network traffic, combined with fuzzy control algorithms, dynamic allocation and scheduling of network resources can be achieved, improving network performance and reliability. Thus, the application of IPv6 fuzzy control in industrial internet communication can improve the automation, performance, and security of the system, which is of great significance for achieving intelligent and efficient industrial production.

This paper first introduces the related concepts and basic principles of IPv6 and industrial Internet, and then, combined with the analysis of IPv6 protocol stack, puts forward the design framework of using embedded IPv6 protocol stack to complete industrial Internet data communication. In the process of system communication, 6LowPAN gateway, 6LowPAN node, field equipment, Modbus and other devices are used to conduct dual stack communication between server and client. The sensor data can be identified and transmitted through IPv6 addresses. Based on the designed fuzzy control system, the corresponding control output can be calculated based on the degree of fuzzification of input variables and the definition of fuzzy rules. The IPv6 protocol is used in the transmission of control commands to transmit the calculated control commands to the actuator, achieving control over industrial equipment. Finally, the scheme proposed in this paper is implemented and tested by establishing an actual environment. The test results show that the IPv6 based industrial Internet design conforms to the corresponding communication standards, and can better support key management, IPSec and other security policies, thus providing an ideal data path for intranet communication.

2. Related Work

2.1 Industrial Internet

Intelligent manufacturing is a new production mode based on the deep integration of the new generation information communication technology and advanced manufacturing technology, which runs through all aspects of manufacturing activities such as design, production, management and service, and has the functions of self perception, self-learning, self decision-making, self execution, and self adaptation. It is the main direction to promote the strategy of manufacturing power. Industrial Internet is the key enabling technology to realize intelligent manufacturing, which provides a key common infrastructure for intelligent manufacturing and an important support for the intelligent development of other industries. The Chinese government attaches great importance to the in-depth development of industrial Internet and IPv6, and has issued a series of policy documents to promote the healthy and rapid development of industrial Internet

The Ministry of industry and information technology of China issued the guiding opinions on deepening the development of industrial Internet through "Internet plus Advanced Manufacturing". Industrial Internet is the product of the deep integration of the new generation of information technology and manufacturing industry, which needs to be jointly promoted by the industrial field and the information communication field. The plan focuses on three tasks. First, promote industrial enterprises to carry out IP based network transformation based on IPv6, and realize wider and deeper interconnection from the entire manufacturing system to the Internet; Second, speed up the IPv6 transformation and upgrading of industrial enterprises' external networks, and make IPv6 a must for the construction of new networks such as NB IoT and 5G; Third, strengthen the technical research and development of intelligent industrial equipment, products and communication modules that support IPv6, and solve the problem of massive terminal access of industrial Internet.

2.2 Fuzzy Control Neural Theory

Fuzzy set theory forms the foundation of fuzzy computing systems. On this basis, people introduce the methods of knowledge representation and reasoning in artificial intelligence, or apply fuzzy set theory to knowledge engineering to form fuzzy logic and fuzzy reasoning. In order to overcome the shortcomings of knowledge acquisition and low learning ability in these fuzzy systems, neural computing is added to these fuzzy systems, forming fuzzy neural systems. Fuzzy control and neural networks each have their own advantages and disadvantages. Fuzzy technology emphasizes rules, which are the expression of human experience and knowledge: the knowledge of neural networks is implicit in their weight matrix, and their knowledge expression is implicit. Neural fuzzy network combines the learning mechanism of ANN (Artificial Neural Network) with the human thinking and reasoning of FLN (Fuzzy Logic Network) [3].

In fuzzy neural networks, the physical meaning of nodes can be explained through fuzzy system models. Each node represents a fuzzy set, and its inputs and outputs can be processed through fuzzification and de fuzzification methods. In this way, nodes in the network can be initialized based on the fuzzy knowledge of the system, so that the initial state of the network can meet the characteristics and requirements of the system. In addition, the parameters of fuzzy neural networks also have obvious physical significance. These parameters can represent the shape of fuzzy sets, parameters of membership functions, etc. By determining the initial values of these parameters based on fuzzy or qualitative knowledge of the system, the network can better approximate the behavior and characteristics of the system.

Assuming the input vector $X=[x_1, x_2, ..., x_n]$ and each weight is a fuzzy language variable, and we set

$$T(x_i) = \{A_{i1}, A_{i2}, ..., A_{im}\},\ i = 1, 2, ..., n$$

where A_{ij} is the j_{th} Language variable value of x_i and it is a fuzzy set on domain U_i. The corresponding membership function is $\mu A_{ij}(x_i)$. y is also Language variable and $T(y) = \{y_1, y_2, ..., y_n\}$. It is a fuzzy set defined on the domain U_y and the corresponding membership function is $\mu B_j(y)$.

Since the integral of the above is troublesome, the following approximate formula will be used instead in real computation:

$$y = \frac{\sum_{i=1}^{m} y_{c_i} \mu \mathrm{B}_i(y_{c_i})}{\sum_{i=1}^{m} \mu \mathrm{B}_i(y_{c_i})} \quad (1)$$

Based on the fuzzy model of the fuzzy system provided above, a fuzzy neural network structure can be designed as shown in Figure 1:

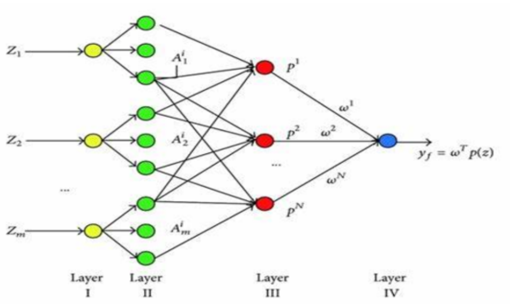


Figure 1. The structure of fuzzy neural networks.

2.3 IPv6 Address Assignment and Management Technology

The address format of IPv6 is different from IPv4. An IPv6 IP address consists of eight address sections, each section contains 16 address bits, written in four hexadecimal numbers, and sections are separated by colons. In addition to the 128 bit address space, IPv6 also designs an address with a hierarchical structure for point-to-point communication. This address is called an aggregated global unicast address, and its hierarchical structure is divided as shown in the figure. The first three address bits are address type prefixes used to distinguish other address types. The following 13 bit TLA ID, 32 bit NLA ID, 16 bit SLA ID, and 64 bit host interface ID are used to identify TLAs (Top Level Aggregator), NLAs (Next Level Aggregator), SLAs (Site Level Aggregator), and host interfaces arranged from top to bottom in the hierarchical structure. TLA is a public network access point connected to long-distance service providers and telephone companies. It obtains addresses from international Internet registrars such as IANA. NLA is usually a large ISP. It applies for an address from TLA and assigns an address to SLA.

The binary identification address type at the beginning of IPv6 address is shown in table 1.

Table 1. IPv6 binary identity

Address type	Format Prefix	IPv6 Prefix
Unspecified address	00…0	::/128
Loopback address	00…1	::1/128
Link Local Address	1111111010	FE80::/10
Unique local address	11111101	FD00::/8
Global Unicast Address	others	
Multicast address	11111111	FF00::/8
Anycast address	others	

3. Industrial Internet Data Path Design Based on Embedded IPv6 and Fuzzy Control

3.1 Network Architecture of Industrial Internet Based on IPv6

Based on the integration requirements of industrial network and IPv6 network, this paper proposes an IPv6 based industrial Internet network architecture. The network architecture of IPv6 based industrial Internet consists of network access layer, transmission layer and application layer. IPv6 industrial Internet consists of the network outside the factory and the network inside the factory. Among them, the network outside the factory includes the IPv6 network built between factories based on the Internet, mobile network or private network; The network in the factory is industrial field network, industrial backhaul network and IPv6 network in the factory, which is composed of multiple industrial wireless networks or industrial wired networks [4]. In the IPv6 based industrial Internet network architecture shown in figure 2, the networks inside and outside the factory are interconnected. The network in the factory is divided into network access layer, transmission layer and application layer.

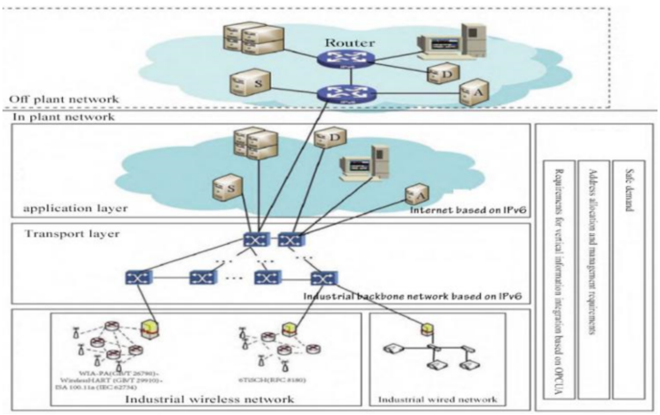


Figure 2. IPv6 based industrial Internet architecture

3.2 Embedded IPv6 Protocol Stack

Since wireless sensor network nodes are generally embedded devices, the design of embedded IPv6 protocol stack should focus on the idea of "miniaturization" This paper uses Mbuf technology to realize the management of buffer, and designs the system function module. According to the embedded application, the corresponding buffer management mechanism is designed, and the functions of ICMPv6 and neighbor discovery in IPv6 module are cut down [5]. The protocol stack software adopts memory protection, data verification, new forwarding algorithm and other measures to ensure the high reliability and stability of the software; The idea of separating the relevant and independent parts of the operating system is adopted, so that the protocol stack software has good portability and can run on VxWorks, Linux, BSD and other mainstream operating systems. The system also adopts a layered approach to realize the functions of each layer of the IPv6 protocol stack.

In IPv6 function design, the ipv6 we want to implement_ Input() function and ipv6_ The functions of the output() function are relatively simple, mainly including the addition and deletion of protocol headers and the verification of datagrams. We first provide the data header structure of IPv6 as follows:

```
typedef struct _IP6Hdr
{
uint32_t ip6_version:4;
uint32_t ip6_priority:8;
uint32_t ip6_flow_lbl:20;
uint16_t ip6_payload_len; /* PayLoad Length /
uint8_t ip6_nexthdr; / Next Header /
uint8_t ip6_hop_limit; / Hop Limit */
ipv6_addr ipv6_Saddr;
ipv6_addr ipv6_Daddr;
} IP6Hdr;
```

3.3 Fuzzy Control Module Based on Ipv6

In the research of industrial internet communication based on IPv6 fuzzy control, network management and optimization are important research directions. Researchers are committed to developing network management algorithms based on fuzzy control to improve network performance, reduce latency, and improve reliability. In industrial internet, device failures may lead to communication interruption or data loss. Fuzzy control can detect faults in a timely manner and take corresponding fault-tolerant measures by monitoring equipment status and communication quality indicators, to ensure the reliability and stability of communication

The workflow of the IPv6 fuzzy inference engine can be described as follows:

Step 1: Data collection: Firstly, collect sensor data from industrial internet communication systems. These data can include various environmental parameters such as temperature, pressure, humidity, as well as equipment status and performance indicators.

Step 2: Data preprocessing: Preprocessing the collected data, including data cleaning, denoising, normalization, and other operations. These preprocessing steps can improve the quality and reliability of data, preparing for subsequent fuzzy reasoning.

Step 3: Fuzzification: The pre processed data is fuzzified and transformed into a fuzzy set. The fuzzification process can use the membership function of fuzzy sets to describe the degree of fuzziness of data.

Step 4: Rule library matching: Match the fuzzified data with a pre defined fuzzy rule library. The fuzzy rule library contains a series of fuzzy rules that describe the relationship between input data and output results.

Step 5: Fuzzy inference: Perform fuzzy inference operations based on the matched fuzzy rules. Fuzzy reasoning can use fuzzy logic operations such as fuzzy AND, fuzzy OR, fuzzy NOT, etc. to calculate fuzzy output.

Step 6: Defragmentation: Transforming fuzzy output into specific numerical results. The process of defuzzification can use defuzzification functions, such as maximum membership method, average value method, etc., to map fuzzy outputs to specific output values.

Step 7: Control command generation: Generate corresponding control commands based on the results of deblurification. Control commands can include equipment adjustment, optimization, alarm, and other operations to achieve control and management of industrial equipment.

Step 8: Control command transmission: Transmit the generated control commands through the IPv6 network. IPv6 provides greater address space and better security, ensuring accurate transmission and real-time control commands.

Step 9: Control execution: The industrial equipment that receives control commands performs corresponding operations to achieve control and adjustment of the equipment.

3.4 Realization of System Communication Mode

The client/server system is a distributed computer system running in a new application mode Inter network process communication is completely asynchronous. When asynchronous communication sends characters, the time interval between characters can be arbitrary. The workflow of the server is depicted in figure 3.

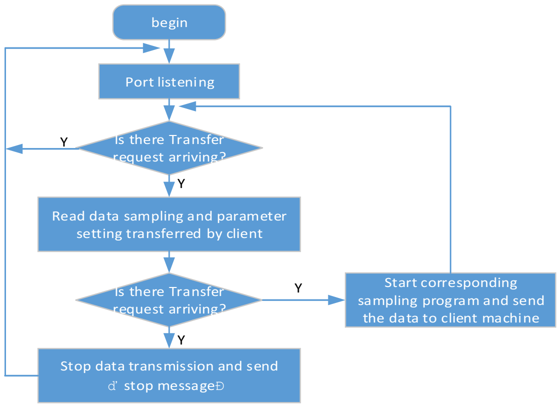


Figure 3. Workflow on the server side

In this design, the protocol based networked data acquisition system is used as the server in the client server mode, while the remote control center is used as the client. Use Internet search engine technology to achieve targeted, industrial and accurate data capture, and classify data according to certain rules and screening criteria [6-8 When the microcontroller enters the low power consumption working mode, the relevant data acquisition channels automatically conduct the corresponding data acquisition mode. When each channel collects the data, it will issue the acquisition completion interrupt to wake up the microcontroller.

4. System Implementation and Test Analysis

To test the embedded protocol stack, we establish a small Ethernet as the test environment. The ARM network platform takes Samsung ARM7TDMI CPU as the core and is embedded at the same time μ The embedded Web server hardware system of

Clinux system. The main chips used are 80C52, RTL8019AS, 93C46 (64 × 16bit EEPROM), 74HC573 (8-bit latch), 62256 (32K byte RAM), and the system runs the dual protocol stack of IPv4/IPv4. Host A, B, and C are all installed with Windows operating system. Set host A as the test server, install dual protocol stacks, and realize the communication test with ARM network platform. ND itself is implemented based on ICMPv6. The Ethernet protocol type is 0x86DD, that is, IPv6 message. The next header field value of IPv6 is 58, indicating ICMPv6 message Issue the ping6 command from the Windows system to the embedded system to view the operation of the protocol stack in the embedded system. The operation result is shown in figure 4.

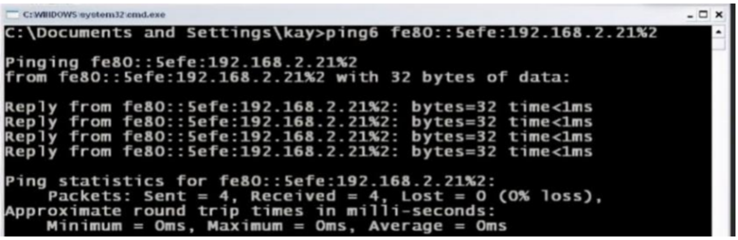
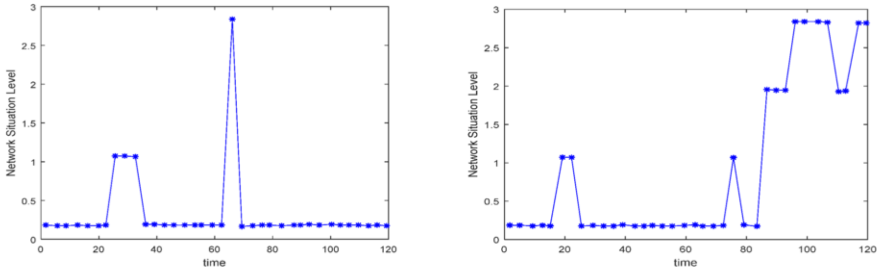


Figure 4. Reachability test of IPv6 protocol under Windows system

In the data module, use Wireshark software to capture real-time data traffic in the current LAN Fuzzify the parsed data and convert it into a fuzzy set. The fuzzification process can use the membership function of fuzzy sets to describe the degree of fuzziness of data. Data input network operation situational awareness model: Input the fuzzified data into the network operation situational awareness model for analysis. The network operational situational awareness model can analyze the state and trend of the network based on input data, and obtain network situational values. Due to the stable operation of the network in most cases, this article takes some of the network situation assessment results and visualizes them for analysis.

Figure 5 (a) shows the intercepted network operation situation assessment results for two consecutive hours. We divide the network situation into four levels. It can be seen that when abnormal traffic is injected, malicious attacks in the network, such as distributed denial of service (DDoS) attacks, network scans, or intrusion attempts, may cause drastic fluctuations in the network situation. The level of network operational situation is in good condition, but due to the prediction error of the network situational awareness model. The predictive performance of the model can be improved by adjusting the parameters of the model, such as the membership function of the fuzzy set and the weight of the rules.

Figure 5 (b) shows the trend of network operation trend in the second experiment. During the first hour, the network situation level continued to fluctuate. In the second hour, the load of the industrial interconnection network may gradually increase, such as an increase in the number of devices and data traffic. This may lead to a decrease in network performance, leading to a gradual increase in the network's situational level. When such changes occur, network administrators should analyze the business applications in the network in real-time and optimize the network in a timely manner, such as increasing bandwidth, optimizing network topology, adjusting network configuration, etc., in order to improve the performance and reliability of the network.



(a) 1st experiment (b) 2nd experiment

Figure 5. The experiments on situation awareness of industrial interconnection networks.

Intercept the data packets in the communication process. After the link lock address is configured, the duplicate address check message is sent to check whether other nodes in the link use the address. According to the experimental results, we can know that the basic protocols of the embedded system IPv6 protocol stack have run well. The compact IPv6 protocol stack in embedded system has the characteristics of less code, high running efficiency and good portability. The size of the compiled binary file is more than 70 KB. The packet capture screenshot obtained after running the above command is shown in figure 6:

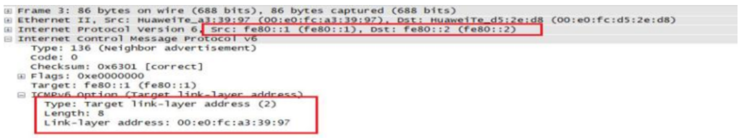


Figure 6. Screenshot of IPv6 protocol stack communication

In the internal network, an integrity verification mechanism suitable for the characteristics of the internal network of the factory shall be adopted to find out whether its integrity has been damaged. The MIC adopted in this paper_32 integrity check mechanism, using the Google code source package in the code. We use integrity levels and enforcement policies to evaluate access rights. The integrity level assigned by the security principal and security object to determine their protection or access level. For example, a principal with a low integrity level cannot write to an object with a medium integrity level, even though the DACL of the object allows write access to the principal. The test results in figure 7 show that the data is consistent with the original data during migration_32 The integrity verification was successful, meeting the requirements for data integrity in the overall requirements for industrial Internet security.

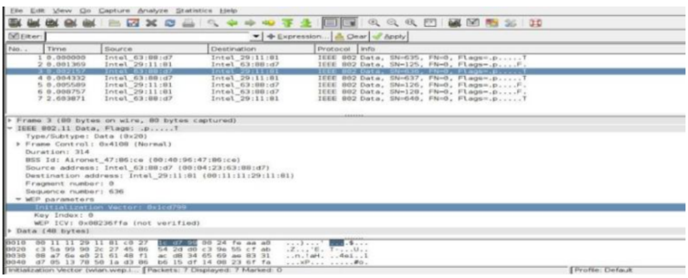


Figure 7. Integrity check packet capture graph

5. Conclusion

Under the application background of IPv6 standard, the intelligent and automatic control of Intranet devices, as well as the adjustment and improvement of industrial structure can be realized through the network upgrading, transformation and construction of the industrial Internet, which plays a role in improving quality and efficiency. Therefore, this paper proposes a data path design scheme for industrial interconnection based on IPv6 fuzzy control, to realize fast transmission and security inspection of internal data. The experimental results show that the scheme has important practical significance for the realization of industrial automation perception, remote monitoring, intelligent inspection and other comprehensive applications.

Acknowledgments

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