



An Investigation of Data Relationships and Planning Strategies in Multi-Layer Industrial Networks

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Abstract

This study examines data relationships and planning methods within multi-layer industrial networks, beginning with a three-layer control network model as the foundational framework. A systematic method for representing data within a single network layer is introduced, providing a structured approach for analyzing interactions and dependencies across different layers of industrial communication systems. The concept of data relationships is developed to describe the connections and information flow among network layers. Two primary forms of data relationships are identified: the mapping relationship from lower network layers to higher layers, which facilitates data aggregation and interpretation, and the control relationship from upper layers to lower layers, which enables command transmission and operational coordination. These bidirectional relationships are essential for ensuring efficient communication, synchronization, and intelligent decision-making within complex industrial environments. Additionally, the study defines the principles governing the validity of control words used in network communication and emphasizes the importance of selecting appropriate property principles based on specific application requirements. By establishing these planning principles, the proposed framework enhances the reliability and effectiveness of multi-layer industrial network design and management. An illustrative example is presented to demonstrate the feasibility and practical applicability of the proposed planning method. The results confirm the validity of the approach and highlight its potential for improving data organization, network coordination, and operational efficiency in modern industrial systems. This research provides valuable insights for the development and optimization of advanced industrial communication networks.

Keywords: Data Planning Method, Data Relationships, Monitoring and Control Systems, Fieldbus Networks, Multi-Layer Industrial Networks.

Introduction

In industrial control systems, various communication networks are widely utilized to support automation, monitoring, and management functions. Common examples include EIA-485-based fieldbus systems and industrial Ethernet networks that rely on switching technology for high-speed data transmission and reliable connectivity between devices [1–3]. These communication infrastructures form the backbone of modern industrial environments, enabling efficient coordination between sensors, controllers, and supervisory systems. In practical applications, multiple networks are often integrated to form multi-layer industrial network architectures. From a functional perspective, such systems can be structured into a hierarchical network control model [4]. This model is typically divided into three layers: the field equipment layer, which handles data acquisition and direct device interaction; the monitoring layer, which oversees system supervision and data processing; and the management layer, which is responsible for decision-making, planning, and overall system coordination [5]. This layered structure improves scalability, flexibility, and control efficiency in complex industrial environments.

Recent developments have further expanded the capabilities of industrial network systems. For instance, Wu [6] designed an intelligent remote control system based on the Industrial Internet of Things (IIoT) to enable data collection, cloud-based analysis, and remote intelligent management of industrial equipment. Similarly, other studies have proposed programmable logic controller (PLC)-based remote monitoring systems using Internet technologies to enhance real-time data acquisition and remote management, thereby improving the efficiency and convenience of industrial automation. The focus of this paper is on data interactions within the monitoring network layer of multi-layer industrial systems. Starting from a three-layer control network model, this study describes how data is represented and exchanged within the monitoring framework. It introduces the concept of data relationships in multi-layer networks and investigates the interaction mechanisms between different network layers. Furthermore, this work establishes the correspondence between data transmission in both top-down (control-oriented) and bottom-up (feedback-oriented) directions. Based on this analysis, the rules governing data relationships across multi-layer networks are summarized, providing a structured foundation for improved data planning and system coordination in industrial network environments. On the basis of theoretical research, a dehumidifier monitoring system is given as an example.

1.Data and data relationships in industrial networks

The data of the industrial network is mainly the real-time parameters of the industrial site. Common real-time parameters are bool, integer or real. Each bool data is 1 / 8 bytes, the integer is two bytes, while the real number is 4 bytes.

In a certain layer of network, the data of a certain site includes bool, integer, a number of bytes, forming a collection

$$x_i(t) \quad (1)$$

$$x_i(t) \sqsubseteq [x_i(t_1), x_i(t_2), \dots, x_i(t_k)] \dots \quad (1)$$

Among them, they are determined according to the needs of filing. At the current moment, the real-time data in this site is. The data for all other elements in the set are combined data types, which are completely consistent in type composition.

$$t_1 \ t_2 \ \sqsubseteq \ t_k \ x_i(t_k) \ x_i(t) \ x_i(t_1) \ x_i(t_2) \ x_i(t_k)$$

Data in the first site can be divided into two categories: one local data and one remote data. Remote data is data related to communication, including input data and output data. Take the moment as an example,

$$i \ D_L \ D_R$$

$$t_k$$

$$\sqsubseteq D^L \ \sqsubseteq \ x_i \ (t_k) \ \sqsubseteq \ \sqsubseteq \dots \dots \dots (2)$$

$$\sqsubseteq D_R \ \sqsubseteq$$

Although the local data is not directly related to the communication, its value may also change with the communication and the execution of the program.

$$D_L$$

For the multi-layer network control system, set only one bus network in each layer. For a bus network in one of the layers, its data consists of data from all sites on the network in that layer. Let the total number of sites be, then the data set of a layer network be, where 1,2 or 3.

$$m \ FB_{jj} \ \sqsubseteq$$

$$FB^j(t) \ \sqsubseteq \ \sqsubseteq \ x_1^j(t), x_2^j(t), \dots, x_m^j(t) \ \sqsubseteq \dots \dots \dots (3)$$

At the present moment, the

$$Not_{kj}$$

$$FB^j(t_k) \cap x_1^j(t_k), x_2^j(t_k), \dots, x_m^j(t_k) \dots \dots \dots (4)$$

The purpose of communication is to exchange data. Multi-layer networks realize communication through gateway or routing technology, and data exists between each other. The exchange of data between multi-layer networks is not a one-to-one mapping, and there is some relationship between them.

Defining the data relationship of a 1 multi-layer network refers to the relationship between the data associated with each layer network in the multi-layer network.

The data relationship between layer and layer refers to the relationship between and, represented by symbols; when the network is a 3-layer network, 1 or 2. $j (j \in 1) FB^j(t) \cap FB^{j+1}(t) R_{j,j+1} j \in$

$$R_{j,j+1} : FB^j(t) \cap FB^{j+1}(t) \dots \dots \dots (5)$$

The network of data in each layer can be divided into two categories from the functions of the data itself: process data and state parameters. Process data is the data representing the amount of process, such as the value of temperature, pressure, etc. The status parameter is the parameter that sets how the system works. In general, the data relationship of the multilayer network will determine how the system acts as a whole.

2. Bottom-up mapping of data in multi-layer networks

2.1 Overview of the bottom-up data relationships in multi-layer networks

Multi-layer network is the most typical of 3-layer network. This section takes 3-layer networks as an example to study bottom-up data relationships in multi-layer networks. In the 3-layer network, any network has its corresponding data. On any layer of the network, the data in the site is exchanged, that is, there is a mapping relationship between the data of some different sites. Therefore, the data in the data set of each layer is repeated. The data relationship of the single-layer network is not detailed here, but only the cross-layer relationship

2.2 Data relationships of the network in layer 1 and 2

The first layer is the equipment layer, and the data of this layer is various field data, mainly for the output data of various sensor data and controller. In the 3-layer network, the main feature of the device-layer data is the strong real-time performance. Therefore, in its data set, the role of historical data is not big, only the latest data in each station is useful, their collection is. $FB^1(t) \cap x_1^1(t_k), x_2^1(t_k), \dots, x_m^1(t_k) \cap$

Site m is the main station or the gateway. The data set of this site is, at time moment, site m uploads some of the data to layer 2. $x_m^1(t) \cap x_m^1(t_k)$

From Figure 1, the data set of the layer 1 and 2 networks has a mapping relationship. At any moment, part of the data is equal to part of the data, so there is an intersection between the data set of the two networks. t_k

$FB^2(t) \cap FB^1(t)$ In the moment, t_k

$$FB^1(t) \cap FB^2(t) = \{\text{Uploaded data in } x_m^1(t_k)\} = \{\text{data uploaded in layer 1 in } x_m^2(t_k)\} \dots \dots \dots (6)$$

2.3 Data relationships of the network in layer 2 and 3

The data mapping between layer 2 and layer 3 is a special relationship. Depending on the application, at most all the data from the second layer can be uploaded to the third layer. If required by layer 3 (management), layers 2 and 3 can form the following data relationships:

$$FB^2(t) \cap FB^3(t) \dots \dots \dots (7)$$

3 Top-down control relationships of data in multi-layer networks

3.1 Overview of top-down data relationships in multi-layer networks

Unlike the bottom-up case, top-down data are mainly various running parameters used for setting. In general, the topdown data relationship is a control relationship.

This section also takes 3-layer networks as an example to study the top-down data relationships in multi-layer networks.

3.2 Top-down data relationships

As shown in Figure 2, layer 3 can control the operation mode of layer 1 and layer 2, generally by setting the control words. The third layer may set the control word of the second layer or by the second layer as the intermediary; the second layer may set the control word of the first layer. In addition, the control words of layers 2 and 3 can also be set by initialization, or through the human-machine interface (HMI).

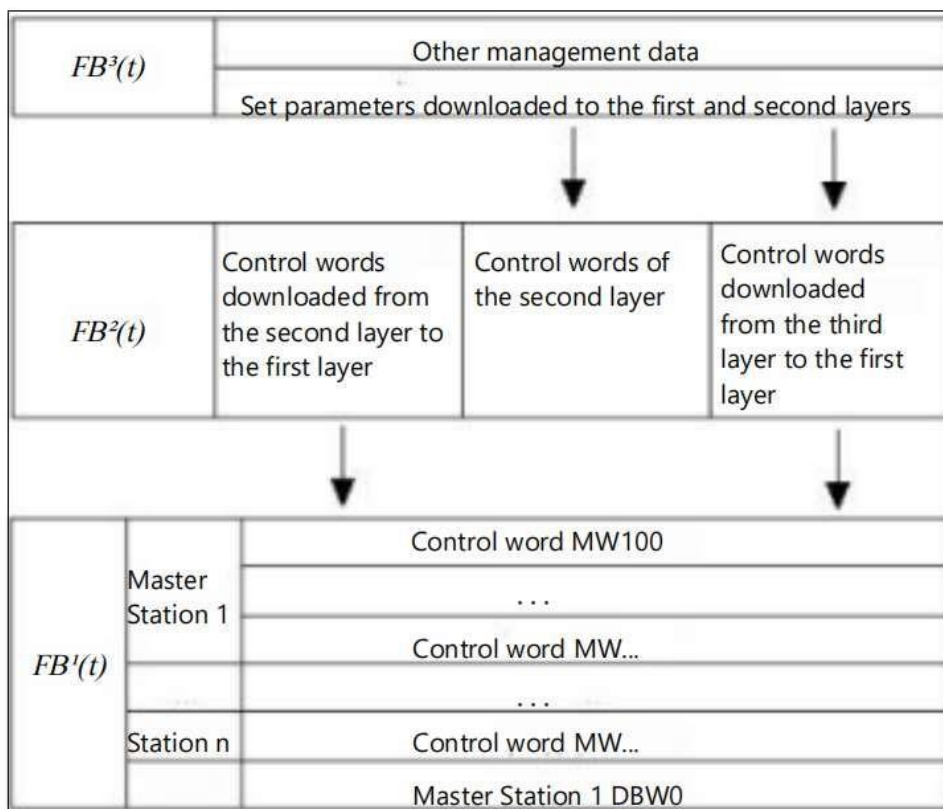


Figure 2: Top-down data relationships in multi-layer networks

Take layer 1 as an example, layer 1 includes multiple sites, which have a master station (master station 1) and a touch screen (HMI), the control word of the main station 1 is MW100, etc.

The control word MW100 of the main station 1 can be set and modified in four ways: one is the initialization setting and the initial value before modification in other ways; the second is the setting of the second layer and the monitoring layer through the network; the third is the management and the setting of HMI and the operation of the main station 1 by the touch screen in the first layer.

3.3 Valid rules set by the control words

When there are multiple ways or ways of control word setting, it is necessary to determine which way the setting is an effective setting.

There are three common multi-way setting effectiveness: effective setting, effective setting first and selective effective. **Definition 2** The post-setting valid means that the last setting is the current valid setting when the control word can be set in a variety of ways.

Definition 3 First setting effective means that the first setting is the current effective setting when the control word can be set in various ways; only after the effective setting is cleared.

Definition 4 selectivity means that when the control word can be set in various ways, the current control word is determined according to the set priority, and the high priority setting will replace the low priority setting.

4. Application examples

4.1 Network composition of the system

This section takes the multi-node dehumidifier monitoring system as an example to introduce the design and application of the structure planning and data relation of multi-layer networks.

The system design of this section requires to control 3 sets of dehumidifiers with a maximum of 48 each. The system is able to monitor the operation of 3 groups of up to 144 dehumidifiers. In the design, the whole system is divided into group and group levels, 48 dehumidifiers are connected by group bus; group by group bus. According to the industrial control network model, the group bus is the field equipment level; the group bus is the monitoring layer.

The bus in the group adopts the serial fieldbus communication mode, such as the PROFIBUS bus⁹⁻¹⁰, the group bus connects three protocol conversion gateways and the monitoring computer, using Ethernet. The network structure of the dehumidifier monitoring system is shown in Figure 3.

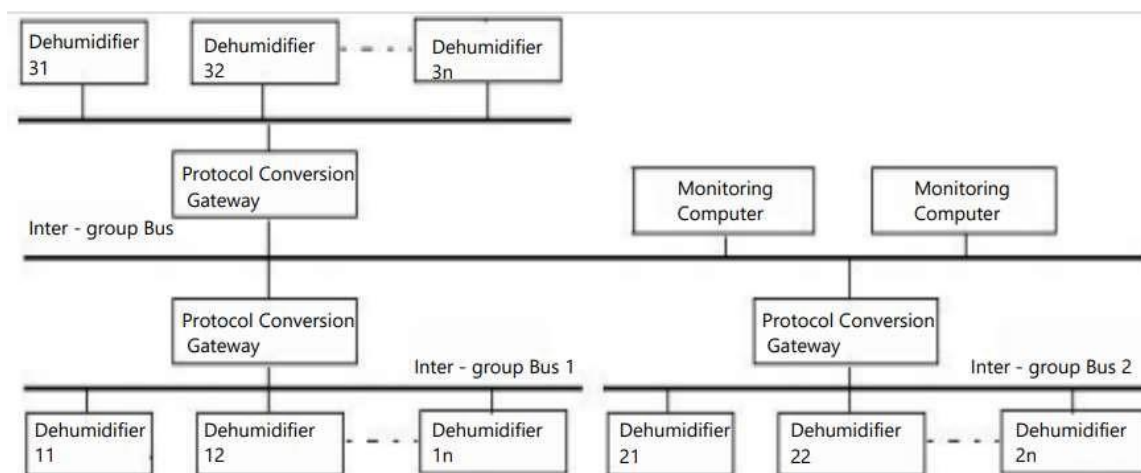


Figure 3: The network structure of the dehumidifier monitoring system

4.2 Variables in the dehumidifier monitoring system

The data in each dehumidifier are represented by a data block, the composition of which is shown in Table 1. Each dehumidifier has the same data block, and a similar data block structure is also used in the monitoring computer. Table 1: Data block of the dehumidifier monitoring system.

Variable	Data Type	Explanatory Note
DB.DBW0	WORD	Group number and machine number setting
DB.DBW2	WORD	Control Word
DB.DBW4	WORD	Humidity Setting
DB.DBW6	WORD	Temperature setting
DB.DBW8	WORD	Wet difference setting
DB.DBW34	WORD	Status Word
DB.DBW36	WORD	Humidity
DB.DBW38	WORD	Temperature
DB.DBW40	WORD	Evaporator temperature
DB.DBX28.0	BOOL	Upper computer setting flag

4.3 Bottom-up data relationship of the dehumidifier monitoring system

The main task of the dehumidifier monitoring system is to monitor the operation of each dehumidifier in the system. The data in the system must be transmitted in the multi-layer network, and there is a certain relationship between the data in the multi-layer network system

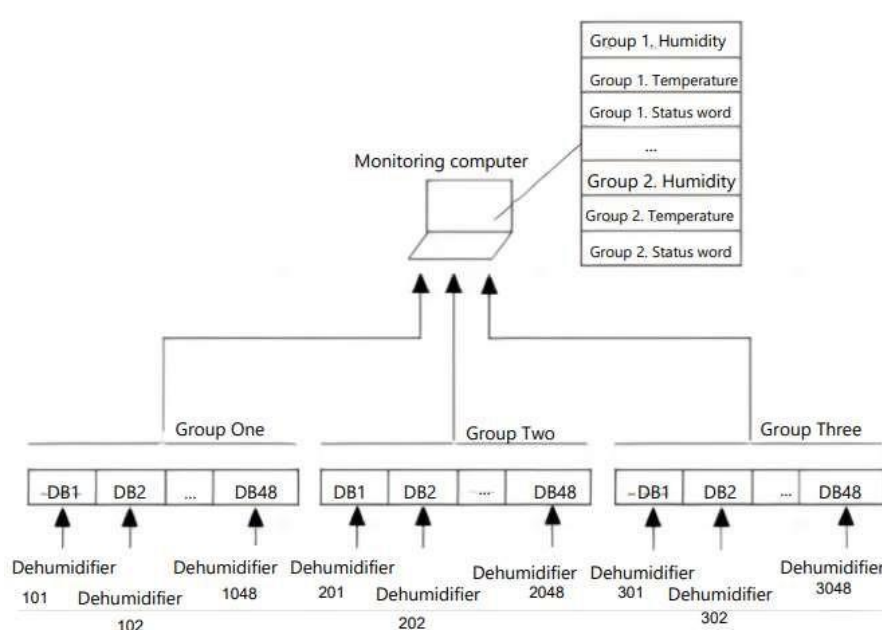


Figure 4: Bottom-up mapping relationship of the system data

The bottom-up data relationship of the dehumidifier monitoring system is shown in Figure 4. The dehumidifiers in the whole system are divided into 3 groups, each with a maximum of 48 dehumidifiers. In each group, one Siemens S7-300

PLC, 48 data blocks in the PLC DB 1 to DB 48 correspond to all dehumidifiers in this group, which is completed on the Intra - group Bus by S7-1500 PLC and S7-1200 PLC in each dehumidifier.

The monitoring computer can obtain the DB 1 to DB 48 data blocks from all 3 groups of S7-1500 PLC through Ethernet. Thus, the operating parameters and operating status of all dehumidifiers in the system can be monitored.

4.4 Top-down data relationship of the dehumidifier monitoring system

The dehumidifier monitoring system can determine the control parameters and control modes of each dehumidifier from top down. For the top-down data relationship, as shown in Figure 5. Taking the first group 101 dehumidifier, the control parameters and operation mode can be set in three ways: first, the dehumidifier system will automatically load the default setting; the second way can be set through the touch screen on the bus in the group in the field layer; third, the control parameters can be set in the monitoring computer.

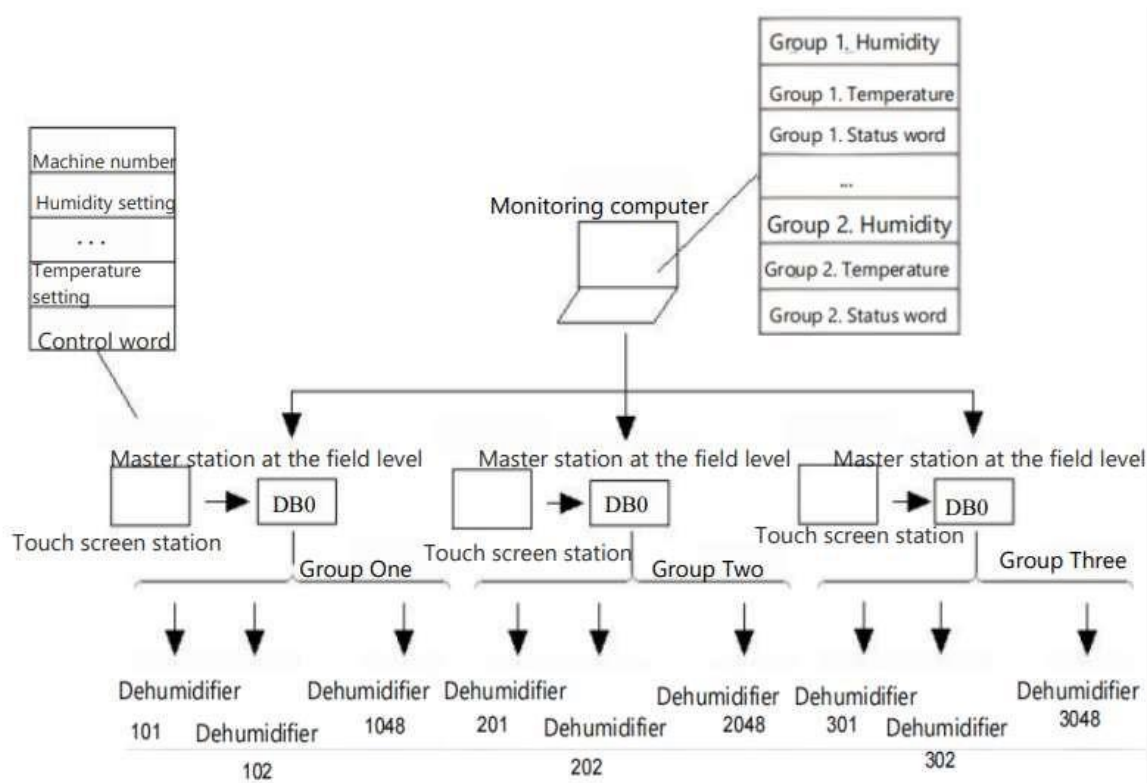


Figure 5: Top-down control relationship of the system data

As a whole, the monitoring system is a control relationship from top to bottom. The monitoring computer can control and set the operation mode of all the field layer dehumidifier, and can also set the working mode of S7-1500 PLC, which functions as the main station in the field layer. Since the control parameters are set in many ways, the validity rules are set in many ways here. According to the previous discussion, the validity rules are set effectively here. Both the touch screen mode setting and the monitoring computer setting can modify the control parameters, subject to the last modification of any one of them.

Conclusions

In this paper, we start with the 3-layer model of the industrial control network and represent the data of the single-layer network by sets. We propose the concept of data relations in multi-layer networks. Based on this analysis, the data relationships between the multi-layer monitoring networks are analyzed. Multi-layer monitoring network, bottom-up mapping relationship; some or all of the data in the lower network. In the multi-layer monitoring network, the top-down is reflected as the control relationship. The upper layer

network controls the operation of the equipment in the lower layer network by setting the control words. This paper also introduces the effective rules of the control word setting, and the appropriate effective rules should be selected according to the actual situation.

The research content of this paper focuses on the basic theory and practical research of data relations in the multi-layer monitoring network, and aims to explore the key mechanisms of data flow, association and optimization in the multi-layer network structure. This study not only provides a theoretical basis for the efficient data management and planning of multi-layer monitoring network, but also provides important reference value for the data architecture design, transmission optimization and resource allocation strategy of different types of monitoring networks in practical application scenarios.

Reference

- Junhui Z, Celimuge W, Wenjun X, et al. Intelligent Internet of Things with reliable communication and collaboration technologies[J]. China Communications, 2024, 21(8): iii-vii.
- W. DeVan, S. Hicks, G. Lawson etc. Using a control system Ethernet networks as a field bus. Proceedings of 2005 Particle Accelerator Conference, Knoxville, Tennessee, IEEE, 2005, 3961-3963
- Wang Liping. Research on Siemens S7-1200 PLC and ABB Industrial Robot Ethernet Communication [J]. Mechanical and Electronic Control Engineering, 2023,5 (6): 1-3.
- Shi Xiaoyan. Application of Siemens communication technology in industrial process control [J]. Mechanical and Electronic Control Engineering, 2023,5 (8): 261-264.
- Ji Shunping, Sun Chengzhi, Sun Shufang, etc. Principles and application of Siemens fieldbus communication [M]. Beijing: Machinery Press, 2009
- Wu B, Shi C, Jiang W, et al. Enterprise Digital Intelligent Remote Control System Based on Industrial Internet of Things[J].
- Liu L, Qi H. Design of programmable logic controller remote monitoring system based on industrial internet[C]//2024 International Conference on Artificial Intelligence and Power Systems (AIPS). IEEE, 2024: 11-14.
- Huang Liangwen, Zeng Wuyi. Principles of Statistics [M]. Beijing: China Statistics Press, 20 00
- Shaikh M, Shah P, Sekhar R. Communication Protocols in Industry 4.0[C]//2023 International Conference on Sustainable Emerging Innovations in Engineering and Technology (ICSEIET). IEEE, 2023: 709-714.
- Sun H, Zhe Q, Rao Z, et al. Research on Communication Simulation of PROFIBUS Multi-master System[J]. International Journal of Mechanical and Electrical Engineering, 2024, 2(2): 10-15.