Research on Wireless Ad Hoc Network Technology for Building Monitoring

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Abstract—Aiming at the difficulties of equipment expansion, high data collection cost, and difficulty in data sharing faced by traditional building monitoring systems, this paper proposes a wireless ad hoc network technology for building monitoring. This method establishes a wireless ad hoc network through wireless network structure selection, wireless network self-organization and dynamic maintenance. Experimental results show that the wireless ad hoc network technology greatly reduces the cost of networking and debugging of intelligent systems, and can well meet the needs of intelligent monitoring of existing traditional buildings.

1. INTRODUCTION

As the third wave of development of the information technology industry, the Internet of Things is a major development and change in the information field. Once proposed, it has been paid attention to by academia and industry around the world, and has played an active role in all aspects of social life [1-3]. As a typical application of Internet of things technology in construction industry, building intelligence has developed rapidly in recent years. However, the structure of intelligent building system is complex, and the system involves many types of equipment, interfaces and protocols [4]. In the face of a variety of application scenarios, the construction process of building intelligent system involves a lot of system configuration, software configuration and other work, and the professional requirements of construction personnel are extremely high, and the installation and maintenance cost of the system is high. Especially in the process of transforming the intelligent system of traditional buildings, there are often changes in the spatial pattern, changes in room functions, and increases or decreases in monitoring points. At the same time, the operation control personnel may propose new control systems during use. Requirements, and traditional monitoring methods are often difficult to expand [5]. Data sharing between different platforms and systems also plays a key role in intelligent monitoring, but traditional monitoring methods are difficult to achieve[6-7].

The intelligent transformation of traditional buildings faces the difficulties of equipment expansion, data collection, and data sharing, which greatly restricts the promotion of Internet of things technology. In view of the above problems, scholars have carried out a lot of research work. Literature [8] proposed a self-organizing intelligent system architecture based on the Internet of things, which has the characteristics of flat self-organization, and solves the problem that the current intelligent building system does not adapt to the era of Internet of things. Literature [9] proposes a self-organized group intelligent control building intelligent system platform technology to realize distributed control and global optimization coordination.; Wireless network is involved in the above solutions, and the wireless ad hoc network technology is the premise of realizing self-organization and extensible architecture. At present,
many literatures have carried out research on wireless ad hoc network, and have done a lot of work in anti-collision mechanism [10], wireless [12] relay and routing [11], but there is a lack of global practical solutions for building characteristics.

In order to adapt to the increasingly high requirements of data collection for intelligent building control, the article proposes a wireless ad hoc network technology for building monitoring, which is selected from the wireless network structure, wireless network self-organization and dynamic maintenance [13]. In all aspects, a complete wireless ad hoc network has been established. Experimental results show that the method proposed in this paper greatly reduces the cost of networking and debugging of intelligent systems, and solves the problems of data sharing, equipment deployment and expansion, and life-cycle maintenance problems in building intelligent systems.

2. STRUCTURE SELECTION OF WIRELESS NETWORK

Compared with wired network, wireless network is dynamic and uncertain due to the randomness of location and the limitation of wireless node transmission distance. If the nodes in the network work with fixed maximum power, it is very easy to produce dense network areas, resulting in network performance degradation, or even network congestion, reducing the utilization of network resources. The randomness and mobility of node locations in the network will cause random and dynamic changes in the network topology, affecting network performance [14-15], causing problems such as network capacity decline, routing path complexity, and network energy consumption increase, and even increase network communication packet loss rate and network throughput capacity decline [16-17]. Therefore, the selection, control, maintenance and optimization of network topology are of great significance to the realization of network self-organization.

The current common wireless network topologies mainly include tree topologies, mesh topologies, star topologies and clustered topologies [18-19]. Each has its own characteristics and adapts to specific applications.

The wireless network uses a mesh topology, as shown in Figure 1:

The red circle represents the DDC controller, including the process DDC controller and the lighting DDC controller, which is the core of the entire wireless network; The blue circle represents the periodic single-zone intelligent terminal, and only one DDC controller can communicate with the server; The green circle represents the intelligent terminal in the overlapping area, which can realize the connection between multiple DDC controllers and servers. As for which DDC controller is selected as the routing node, the factors such as signal strength, load quantity, network status of DDC controller and server should be considered comprehensively, which is a key point of the whole wireless network design. The entire wireless network intelligent terminal and DDC controller are built by themselves, without the help of manpower, which is convenient and fast.

3. WIRELESS NETWORK SELF-ORGANIZATION AND DYNAMIC MAINTENANCE

3.1. Wireless Ad Hoc Networking Process

Wireless ad hoc network is a system function that can not be completed by a single device independently, which needs the coordination of intelligent terminal and DDC controller. The whole ad hoc network function can be divided into three parts: ad hoc scheme process, intelligent terminal and DDC controller.
The wireless ad hoc network scheme is shown in Figure 2:

![Flow chart of wireless ad hoc network solution](image)

After the smart terminal is turned on, it first uploads the broadcast data packet to the surrounding controller and waits for the response packet. The surrounding controller responds to the smart terminal after receiving the broadcast data packet, and then the smart terminal processes the response packet to form routing information and store it in the routing table, finally the routing table is sent to the server through the controller, and the networking is completed. After networking, the channel is switched to private channel, and the data is exchanged in the private channel negotiated by the controller and the intelligent terminal, so as to reduce the mutual interference between adjacent controllers.

The wireless ad hoc network flow of intelligent terminal is shown in Figure 3:
The core function of smart terminal work is mainly composed of three parts: application to join the network, selection of sending data through channel switching and multi-route [20], and dynamic monitoring and maintenance of the network. After the intelligent terminal is powered on, it first applies to join the network, and then judges whether it successfully joins the network. If joining the network fails, it will continue to apply until the joining is successful; After judging to join the network, perform other normal data processing procedures, including network status monitoring, sending data, and receiving data. The network status monitoring is triggered regularly; If the network is abnormal, the network will be reconnected. On the contrary, data transmission and data receiving are processed. Channel negotiation is conducted with the controller before data transmission, and the actual data is sent after channel negotiation. The flow chart of wireless ad hoc network receiving channel reception through common channel is shown in Figure 4:
3.2. Intelligent Terminal Automatically Join the Network after Power-on

After the smart terminal is turned on, it must first join the wireless network. The algorithm flow chart for joining the network is shown in Figure 5:
After the smart terminal is turned on, it first sends a broadcast data packet to the DDC, and then it is in a waiting state. The controller receives the broadcast packet and makes response information such as the controller ID number and the number of smart terminals it carries. The smart terminal receives the response data packet from the controller, and then the sorting algorithm is called to update the routing table according to the signal strength and the number of intelligent terminals carried by the controller. The intelligent terminal judges that it has joined the network and immediately switches to the normal state to perform other data processing.

Note: the key point of joining the network is to ensure that the intelligent terminal can join successfully. The state lock is set. When it is judged that the intelligent terminal has not joined the network, it will send broadcast packets to request joining the network until the network is successfully joined, and the state is switched from the joined network state to the normal state.

3.3. Channel Allocation Strategy Based on Pseudorandom Sequences
In order to solve the problem of mutual interference between adjacent controllers, frequency hopping technology is used to support DDC controller to send data through its private channel. The most important thing is that the adjacent DDC controller can use a channel allocation strategy based on random sequence [21-23] to allocate different channels for data transmission. The algorithm flow chart is shown in Figure 6:
The last byte of the controller ID number is used as a seed. A string of pseudo-random sequences is generated through the selected seed, and then the random sequence is generated by taking the remainder of 10 to generate a number between 0-9, corresponding to a private channel of 0-9. The intelligent terminal carries out channel negotiation before sending data each time, so as to reduce the mutual interference between adjacent controllers during data transmission. Since the probability that the last byte of the ID number between adjacent controllers is the same is relatively small, different random sequences will be generated, as shown in Figure 7; Each smart terminal will generate a random sequence, and use a pointer to point to this random sequence. After each channel negotiation, the pointer takes out the sequence number as a private channel for communication, and realizes movement by adding one to the pointer. This method can effectively avoid adjacent controller communication of mutual interference.

Figure 6. Flow Chart of Generating Private Channels

Figure 7. Pseudo-random sequence diagram

3.4. Multi-Route Controller Selection Based on Signal Strength and Load Balancing
Since the wireless network based on LoRa modulation technology has the advantages of long communication distance and wide coverage, an intelligent terminal may be within the communication range of multiple DDC controllers around. The wireless ad hoc network makes full use of this feature to strengthen reliability of data transmission. In this paper, a multi-route selection strategy based on signal strength and load balance [24] is adopted. By obtaining the signal strength of each intelligent terminal communicating with surrounding controllers and the number of intelligent terminals in the controller, the
controllers are scored and ranked. Finally, a multi-route controller is formed. The algorithm flow chart is shown in Figure 8:

![Algorithm Flowchart]

After receiving the broadcast response packet from the controller, the smart terminal immediately reads the signal strength at this time (set to $x_1$), and analyzes the number of terminal modules responded by the controller (set to $x_2$). The actual test signal strength ranges from 0-180, and the number of terminal modules is 0-80. The signal strength (60% of the total) and the number of terminal modules (40% of the total) affect the final score. The full score is 100. Finally, the signal strength $x_1$ and the number of terminal modules $x_2$ are normalized to score data $x_1'$ and $x_2'$, and the final score formula is used to calculate the result:

![Table 1 Example of Routing Table Scoring Process]

The corresponding relationship between the signal strength and the number of terminal modules and the standard signal strength and the number of standard terminal modules is as follows: signal strength 0-180 linearly corresponds to signal strength score 0-60, and the number of terminal modules 0-80 corresponds to the number of terminal modules score 0-0. The signal strength score and the terminal modulus score are added to obtain the final score of the controller, and the final score of the controller is ranked to obtain routing table information.

### 3.5 Multi-route Information Transmission Strategy

In order to strengthen the reliable transmission of data between the smart terminal and the DDC controller, avoid the situation that all the smart terminals under it cannot communicate when the controller is abnormal, and improve the utilization of the controller, we propose a multi-route information
transmission strategy. When the selected highest-scoring routing controller fails to communicate, then other routing controllers are selected for communication. The algorithm flow chart is shown in Figure 9:

![Flow chart of multi-route information transmission algorithm](image)

The intelligent terminal first selects route controller No.1 with the highest score to send information. If the transmission is successful, the data transmission is completed. If the transmission fails, the intelligent terminal will select route controller No.2 to send data immediately, and so on until the data transmission is successful. If all the sending fails, the data transmission is failed. N is the number of routing controllers selected by each smart terminal. Each smart terminal has a fixed value, up to 10. The maximum limit has been set in the program. When it is greater than 10, the routing table will no longer be updated.

### 3.6 Dynamic Maintenance of Wireless Networks

The key task of the wireless network is the dynamic maintenance and use of the routing table. The dynamic maintenance of the routing table is the foundation. Only the timely and reliable maintenance of the routing table information can ensure reliable data transmission. Dynamic maintenance is mainly composed of three parts: smart terminal heartbeat maintenance, controller heartbeat maintenance, and controller event triggered maintenance. The flow chart of the wireless network dynamic maintenance algorithm is shown in Figure 10:
Intelligent terminal heartbeat maintenance: the intelligent terminal will regularly send heartbeat packet to the selected optimal routing controller. When the heartbeat packet sent does not receive a reply within the specified time, it will send it again quickly twice. If the subsequent two times of sending do not receive the response information from the controller, it will judge that the network is disconnected, and the intelligent terminal will send broadcast information to update the routing table information.

Controller heartbeat maintenance: The timer will send broadcast data packets at regular intervals, and the smart terminals within the range will read the signal strength and the number of terminal modules to update the routing table after receiving it. This cycle is generally longer and is a dynamic network maintenance backup protection.

Controller event triggering: when the controller judges that it is disconnected from the server or the network cable is disconnected, it will broadcast the fault packet immediately. After the intelligent terminal receives it, it will delete the ID information of the faulty controller in the routing table. The controller can judge the connection status between itself and the server through the heartbeat packet.

4. EXPERIMENTAL TESTS

4.1. Wireless Networking Time Test
A test environment was set up in the school experimental building, and multiple controllers and intelligent terminals were placed in the experimental building. The experimental test controller and terminal are shown in Figure 11:
Turn on a controller, gradually increase the number of smart terminals and record the networking time; Then turn on the two controllers, gradually increase the number of intelligent terminals and record the networking time; Then continue to increase the number of controllers and smart terminals and record the networking time. The test results under fixed power (13dB), fixed communication rate (2kbps), and indoor domain are shown in the table below. As the number of terminal modules increases, the networking time is increasing; as the number of controllers increases, that is, the network complexity increases, the networking time also increases; The results show that, in the case of meeting building coverage terminals (3 controllers, 100 terminals), all networking can be completed in 0.8 seconds.

**TABLE 2** TEST RESULTS OF WIRELESS NETWORKING TIME

| Experimental environment | Number of controllers | Number of terminal modules | Networking Time (s) |
|--------------------------|-----------------------|---------------------------|---------------------|
| Open areas in buildings   | 1                     | 30                        | 0.3                 |
|                          |                       | 50                        | 0.4                 |
|                          |                       | 100                       | 0.6                 |
|                          | 2                     | 30                        | 0.3                 |
|                          |                       | 50                        | 0.4                 |
|                          |                       | 100                       | 0.7                 |
|                          | 3                     | 30                        | 0.4                 |
|                          |                       | 50                        | 0.5                 |
|                          |                       | 100                       | 0.8                 |

4.2. Frame Transfer Success Rate Test

Fix the number of controllers and smart terminals, and then continuously increase the length of data packets to test the complete and correct rate of data transmission. In the case of fixed communication distance, communication rate, and power, the test results are shown in the following table:

**TABLE 3** TEST RESULTS FOR RADIO FRAME SUCCESS

| Experimental environment | Packet length (byte) | Transmission success rate |
|--------------------------|----------------------|---------------------------|
| Open areas in buildings   | 10                   | 100%                      |
|                          | 30                   | 100%                      |
|                          | 70                   | 100%                      |
|                          | 100                  | 99%                       |
|                          | 150                  | 97%                       |
The results show that the communication success rate is 100% when the data frame length is less than 70 bytes, which can ensure reliable transmission.

5. CONCLUSION
This paper studies a wireless ad hoc network technology for building monitoring. Firstly, the mesh wireless network topology is selected, and then the algorithm of the whole wireless ad hoc network is proposed, including how to ensure that the terminal can join the network, how to generate private channel, how to select multiple routing controllers, information transmission strategy based on multi routing controllers and dynamic maintenance of wireless network; finally, the experiments show that the proposed wireless ad hoc network technology can meet the needs of intelligent monitoring of buildings.

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