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Design of ZigBee IoT System in Smart Agricultural Greenhouses

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Abstract: Zigbee has been widely used by scholars and technicians in China, it's a currently circulating solution on digital agricultural technology. To tackle issues in traditional agricultural management methods and enhance supervision, data accuracy, and efficiency, a proposed smart agricultural monitoring system uses ZigBee wireless technology and the Internet of Things (IoT). This system employs a tree network topology, distributing monitoring nodes throughout fields and greenhouses. These nodes gather data through wireless sensors, transmitting it for real-time analysis on a central server. The design optimizes power usage, reduces costs, and ensures precise control, summarizing parameters like the maximum network capacity under varying network scan times. Ultimately, it significantly improves crop growth conditions. It is of great significance to regulate the growth environment of crops to meet the growth needs of crops, thereby improving the yield and quality of crops.

1. Introduction

Facing the challenges of global population growth and resource scarcity, modern agriculture urgently needs to achieve sustainable development by increasing crop yields and quality while protecting the environment. Smart agriculture, using Internet of Things (IoT) technology to optimize agricultural production, is becoming the key to solving this problem[1].

ZigBee technology is particularly important in this context. ZigBee is a new type of short-range, low-power consumption, low data transmission rate, low-cost, easy-to-implement wireless network transmission technology, it is very suitable for agricultural environment monitoring systems. Using ZigBee for real-time data collection and processing not only improves monitoring efficiency, but also enables remote management, which is crucial to improving agricultural production efficiency and crop quality. The advantages of Zigbee are shown in Figure 1.

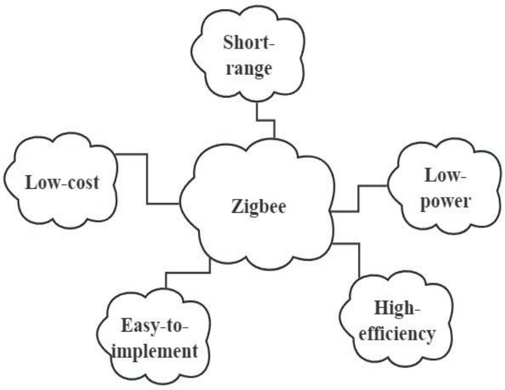

Figure 1: Adventure of Zigbee

This research aims to explore how to effectively use ZigBee technology to build an efficient IoT system in smart greenhouses to promote agricultural automation and intelligence and promote the sustainable development of agriculture.

2. Basic principles and design of Smart Agricultural Greenhouses

2.1 The structure of Smart Agricultural Greenhouses

The greenhouse remote environmental monitoring system adopts a ZigBee tree network topology. The system configures a ZigBee Router, and several ZigBee End Devices as sensor terminal and device execution terminal nodes for each greenhouse.[2] The sensors execution devices in each greenhouse work independently. ZigBee tree network topology is shown in Figure 2.

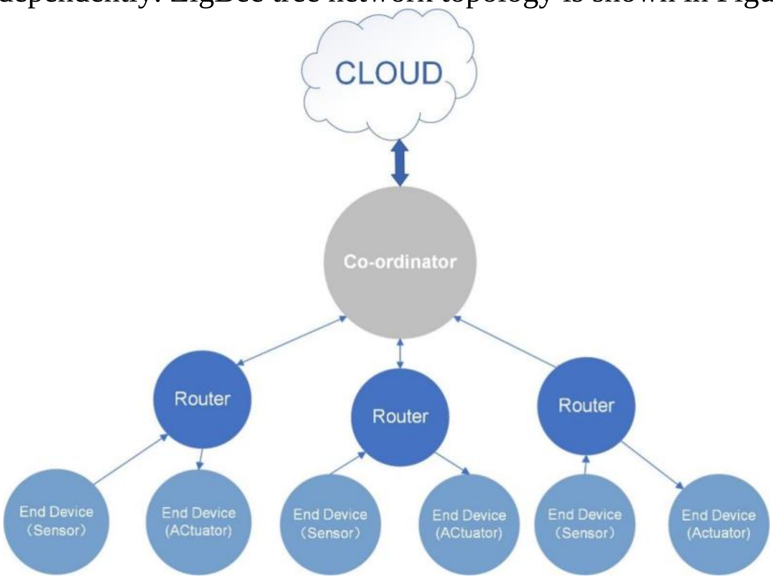

Figure 2: ZigBee tree network topology

The terminal monitoring nodes include sensing terminal nodes used to detect environmental parameter information in the greenhouse and start-stop execution terminal nodes used to control related equipment. Sensing acquisition devices and equipment execution devices are arranged in each greenhouse. The system transmits the data collected by the sensor on air temperature, air humidity, soil temperature, light intensity, pests and diseases, crop growth status, and disaster situation to the routing node through ZigBee wireless communication technology, and then the routing node transmits it to the ZigBee coordinator module. After receiving the data, the ZigBee coordinator module summarizes the information and transmits it to the host computer and mobile phone. The host computer queries, processes, and manages the data, compares it with the preset parameters, and issues corresponding control instructions based on the results. Each execution device terminal. After receiving the control instructions, the node starts and stops fans, roller shutters and other equipment. The control instructions are also sent by the ZigBee routing node to the terminal execution node, and then the switches of each device are controlled according to the instructions.

According to the principle of the Internet of Things system, it can be divided into four layers of structure [3]. They are shown in Figure 3.

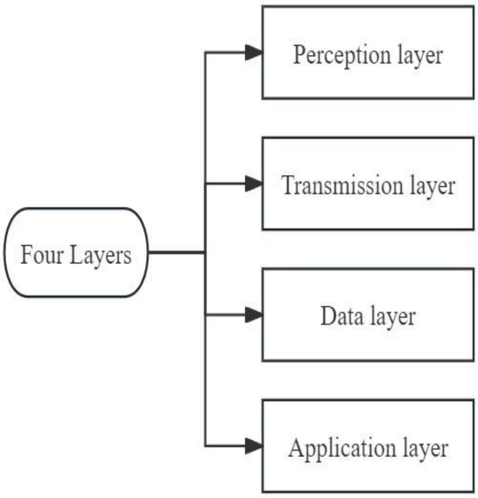

Figure 3: IOT layers

(1) Perception layer: The perception layer mainly includes hardware equipment such as environmental monitoring data, crop growth video images, and cameras, including air temperature and humidity, light intensity, rainfall, wind speed, wind direction, CO_2 concentration, soil temperature and humidity, soil pH, soil EC and other sensors and cameras.

(2) Transmission layer: The transmission layer mainly uploads data automatically collected by hardware devices and information entered by software systems to the cloud server, mainly including WiFi, 4G cellular network, NB-IoT and wired broadband networks.

(3) Data layer: The data layer refers to a data set composed of data involved in the system according to certain classifications, including metadata, catalogs, and attribute data used to manage data. Data is mainly stored in cloud servers.

(4) Application layer: The application layer is the web-side software and mobile APP application of the agricultural product quality and safety visual traceability system.

2.2 Mesh structure of ZigBee wireless sensor network nodes

The planar network structure applied to large farmland is relatively complex, and its complexity is related to the number of network paths; the scan time analysis is also more complicated.[4] This article uses the square one for a brief analysis. The ZigBee flat network structure diagram is shown in Figure 4.

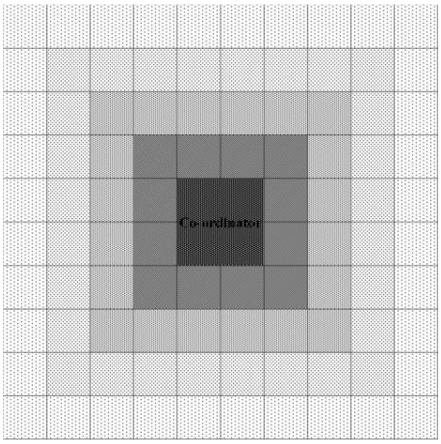

Figure 4: Illustrative Sketch Map of Plane network structure for ZigBee

Assume that a node is at the intersection of any two straight lines. The central node is at the center of the network. The 8 nodes surrounding the central node can communicate directly. 16 nodes require 2 relays. Nodes, 24 nodes require 3 relay nodes and the total network scanning time can be expressed as:

$$T_i = 8t\sum_{i=1}^{n} i^2 \tag{1}$$

$$N_i = 8\sum_{i=1}^{n} i \tag{2}$$

In the formula: T is the total network scanning time; n is the network layer; N is the capacity of the network node; t is the time required for each two adjacent nodes to complete a communication, as shown in Table 1.

Table 1: Meanings of variables

Variable	Meaning
T	Total network scanning time
n	Network layer
N	Capacity of the network node

3. Results

3.1 The establishment of model

In the overall planning and design process, it's crucial to factor in network terminal capacity and latency. While the ZigBee standard allows for a network capacity supporting up to 65,000 terminal nodes, there's a 15 ms communication delay between every two adjacent nodes.[5] However, real-world applications necessitate considerations beyond just capacity and delay. It's essential to contemplate terminal coverage and response time. Simply boosting single-point capacity might not significantly expand coverage, and increasing response time could impede application services.[6] Consequently, designing efficient network terminal topology combinations becomes imperative to cater to diverse applications within varying environments. Ultimately, calculating and analyzing the final network capacity is contingent upon different network scan cycles under ideal conditions, as applied in the smart greenhouse based on a mesh system.

3.2 Analysis of experimental results

If the central node is located at the edge of the entire network topology, it will obviously increase the number of network layers, thereby prolonging the scanning time of the system and reducing the capacity of the entire network, as shown in Table 2 and Figure 5.

Table 2: The relationship between scanning time and network layer capacity

T	n	N
10s	6	168
20s	7	224
30s	8	268
40s	10	440

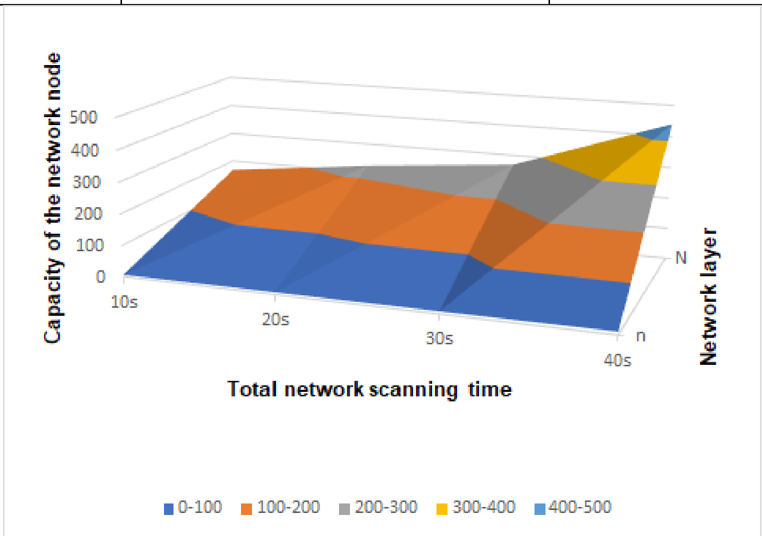

Figure 5: The relationship between scanning time and network layer capacity

The central node of the mesh network should be placed in the center of the network topology as much as possible. The closer it is to the edge, the longer the scanning time of the system will be. Under the limit of the scanning time, the capacity of the entire network will also become smaller. For example, the situation where network scanning is closer to the edge is shown in Figure 6.

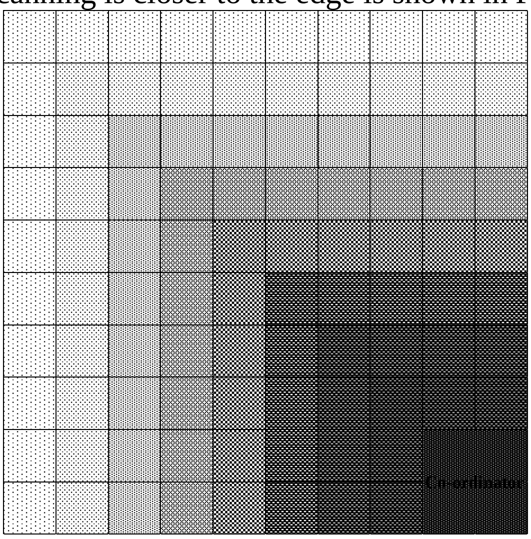

Figure 6: Illustrative Sketch Map of Network Scanning Approaches at the Edge

4. Conclusions

This study reveals that deploying ZigBee network nodes is crucial in constructing an agricultural digital information collection network. This network can optimize deployment, utilizing flexible networking methods to create topologies based on site environment and usage requirements. This article provides a research idea and framework for a greenhouse remote monitoring system based on ZigBee technology. It collects environmental parameter data in each greenhouse through multiple different sensor nodes and uploads it to the host computer or mobile phone through the ZigBee network. The host computer or mobile phone issues control instructions based on the data to control the start and stop of each execution device, thereby ensuring that the crop growth environment is within a suitable range. This system has important practical significance for smart agriculture.

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