Optimized Deployment of Cluster Head Nodes in Wireless Network for the Greenhouse

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Abstract: Applying wireless techniques in the greenhouse is one of the most important trends of the agricultural development. In the clustered wireless network with definite network level, the deployment of cluster head nodes has a great influence on the performance of the network. This paper discusses a three-level network model of the wireless monitoring and control system based on the multi-span in greenhouse. The cluster head nodes in network with traits of wireless sensor network and wireless motion network are designed with GPRS Module and Zigbee Module CC2430. Taking single multi-span greenhouse as an example, we adopt the improved LEACH clustering algorithm to analyze the influence of the cluster head nodes number on latency and energy consumption., The optimized cluster head nodes deployment strategy based on the multi-objective optimization method is given to ensure the highly efficient data transmission. We optimize the cluster head nodes deployment, determine the best number of the cluster head nodes in single multi-span greenhouse based on MATLAB and analyze the influence of the low lever cluster head nodes number on latency, energy consumption and the total nodes number. The network has great improvement on the real-time and lifetime with the optimized cluster head nodes deployment compared with one clustered network.

Index Terms: ***Wireless Network Cluster Node Disposition Optimization Greenhouse***

I. INTRODUCTION

Greenhouse is a typical facility of agriculture cultivation. The mechanization and automation of the production management can help people to prevent the environment from high temperature, high humidity and bad ventilation. The existed measuring and control system has poor adaptability disadvantages as follows: the difficulty in building the greenhouse with lots of wires, high cost and the restriction of the mobile device's application. With the development of the technology, not only the steady and reliable systems are required, but also the wireless and real-time measuring and control system are needed [1].

Testing and controlling technology of the greenhouses in Holland, Japan, America, and Israel etc has reached the world advanced level and has achieved the level of intelligent control, and they pay great attention to the researches and applications of the wireless network control and measuring technology [2]. Besides high reliability and low power consumption, the requirement of real-time is needed in realization of the wireless network observation. Three methods for realizing wireless network control and measuring are as follows:

First: The control and measuring technology of wireless sensor network. Wireless sensor network consists of many cheap sensor nodes deployed in the detection region. Different applications and objects have different requirements of latency, energy consumption and the robustness [3].Generally, wireless sensor network has the characters of high cost-performance, low power but large time-delay and weak real-time.

Second: Wireless mobile network GSM monitoring technology. Wireless mobile network monitoring technology is the combination of GSM network, automatic control technology, computer control technology and communication technology. It realizes the remote data collection, monitoring and controlling [4].

Third: Bluetooth wireless communication technology. The combination of Bluetooth wireless communication technology and field bus technology which used in greenhouse for monitoring was proposed by DU hui in 2005[5]. However, this technology is difficult to be applied because of the high cost and the short lifetime of the battery.

The modern greenhouses include control nodes, located nodes and actuators nodes with limited energy. Furthermore, the better performance such as the low cost, low latency and low energy consumption is required in the information

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transmission system. The present technology can not meet the requirements of wireless measurement and control system. In this paper, a three-level wireless network is established based on the characters of the greenhouse and the combination of the wireless sensor network and the wireless mobile network. The performance of the network is also improved by optimizing the number of the cluster head nodes.

II. THE EATABLISHMENT OF THE THREE- LEVEL WIRELESS NETWORK MODEL

A. The deployment and the characters of the Multi-span greenhouse

Take five-multi-span greenhouses as study object, the main structure of the greenhouse with arch structures and south-north remains is that: the standard span of single-span greenhouse is 10m, the width is 3.5m, and the average height is 5.3m. The total length of the five-multi-span greenhouse is 50m, the total width is 50m and the total area is 2500m2. We assume that ten five-multi-span greenhouses are included in the whole area. Each five-multi-span is divided into three levels, and 75 temperature and humidity sensors are deployed in the greenhouses.

The total area deployed 150 nodes including CO2 concentration sensors, light intensity sensors, controlling nodes, actuators nodes and environmental control equipment.

B Three-level wireless network model of greenhouse

For the high cost-performance and low power characters of the wireless sensor network and the large coverage and highly real-time characters of the wireless mobile network, a new network with more highly real-time, lower cost, more reliable performance is established based on them. The model is showed in Fig 1.

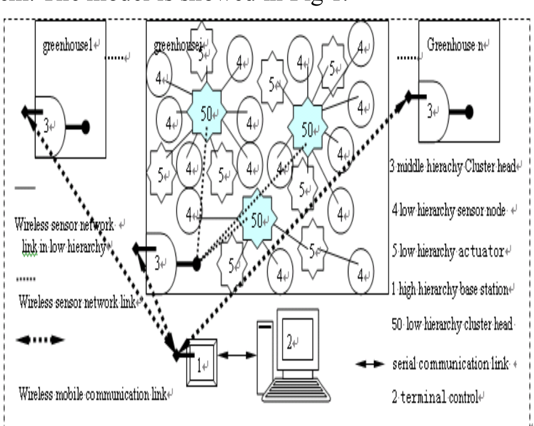

Fig 1: Three-level wireless sensor network model of greenhouse

The lowest level of wireless sensor network includes: sensor nodes 4 for collecting the information of the greenhouse, actuators nodes 5 for controlling the execution mechanism and nodes 50 which are the low level cluster head nodes. The cluster head nodes of the middle level are the crucial components of the hardware which consists of wireless mobile communications module 31(GPRS Module), Zigbee Module 32(CC2430 Module) and the battery module 33. The Zigbee Module and the wireless mobile communications module are connected by RS-232. The middle level cluster head node is showed in Fig 2. The battery module is solar cell (SW6060-8-2946) or the chargeable battery which has enough power. The middle level cluster head nodes communicate with their neighbor nodes and the base station 1. Highest level which is the base station 1 is connected with the terminal server by wired serial communication method. The monitoring and the management of the whole greenhouse are completed by the terminal server.

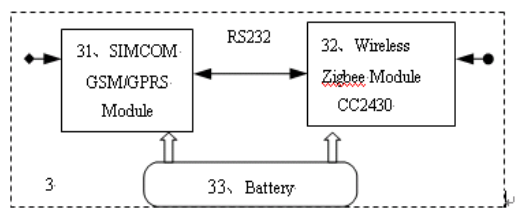

Fig 2: The hardware structure of the middle level cluster head node

The operation process of the three-level wireless network of greenhouse is : information is collected by the general sensor node in the lowest level, integrated by the cluster head nodes in middle level then transmitted to the base station. At last, the data arrives at the terminal server of the greenhouse for data management and control algorithm, then the control command is transmitted to the actuator nodes through the base station, middle level cluster head nodes, lowest level cluster head nodes, and finally drive the execution mechanism to control the environment of the greenhouse integrally and coordinately.

III. THE OPTIMIZED CLUSTER HEAD NODES OF THE LOWEST LEVEL IN THE WIRELESS SENSOR NETWORK

Wireless sensor network and Wireless mobile networks are integrated to establish three-level wireless network of greenhouse which can reduce the latency and the energy consumption of the network. Based on the analysis for the costs, the fewer cluster head nodes in middle level are needed, and the energy is enough for using the solar cell. In addition, the wireless mobile network has a characteristic of better real-time. So, the performance of data transmission is better between the middle level and the highest level. However, the clustering algorithm and the configuration of the cluster head nodes have impact on the performance of the data transmission between the middle level and the low level. Therefore, we study the method of optimizing the cluster head nodes based on the greenhouse's practical application to improve efficiency of the data transmission. In this paper, we assume that the sensors (actuators) are even-distributed.

A. Influence of cluster head nodes' configuration on latency and energy consumption of the data transmission.

Within a certain range, less cluster head nodes are allocated, so the distance between the cluster head node and the general node is farther. According to the energy model in [6], the times of the wireless communication energy consumption is in the direct ratio from two to four of the distance. If we use multi-hop wireless communication, the latency will increase for the limited communication band. If less cluster head nodes are allocated, the distance between the low level cluster head nodes and the middle level cluster head nodes will be farther which will increase the latency and the energy consumption of the data transmission. Moreover, the cluster head nodes of the low level are better-distributed which prolong the lifetime of the network. Hence we need an appropriate way to select the number of cluster head nodes.

B. Clustering Algorithms of LEACH and an improved method for selecting the cluster head nodes

LEACH is a self-organizing, adaptive clustering protocol that uses randomization to distribute the energy load evenly among the sensors in the network. In LEACH, the nodes organize themselves into local clusters, with one node acting as the local base station or cluster-head. However, if the cluster-heads were chosen prior and fixed throughout the system lifetime, as in conventional clustering algorithms, the cluster-heads would die quickly, and end the useful lifetime of all nodes belonging to those clusters.

In order to avoid such a result, clustering algorithms of LEACH is improved as follows: select just one cluster head node in a pre-set phase, and make sure the nodes are well-distributed. We select the actuators nodes with more power and near the middle node as cluster head nodes by turns in a same cluster and do not reorganize the cluster every time. In this way, the cluster head nodes are better-distributed to make the energy consumed more efficient, and prolong the lifetime of the network.

C. The energy consumption and latency model of the network communication

The low power transmission distance d0 of the wireless sensor node is about 20m, in order to reduce the energy consumption and the latency, the max region of every cluster is a circle of radius d0 and the cluster head node is located at the center. Based on the research in [8], the energy consumption model of the general (non-cluster) head nodes and the cluster head node are:

$$W_{non-ch} = L(E_{elec}) + L\varepsilon_{fs} * d1^2(J) \tag{1}$$

$$\begin{aligned} W_{ch} &= LE_{elec} * (N/m - 1) + Wf * N/m \\ &+ L * E_{elec} + L\varepsilon_{mp} * d2^4(J) \end{aligned} \tag{2}$$

Where L is the length of the packets; E_{elec} is the parameter of every packets energy consumption in the transmission and reception; ε_{fs} is the coefficient of the low power energy consumption; d1 is the average distance from non-cluster head nodes to the cluster head node, d1<d0, so the energy consumption is proportional to the square of d1; m is the cluster head nodes of the low hierarchy; N is the total number of the node; Wf is the energy consumption of every data aggregation. ε_{mp} is the coefficient of non low power energy consumption; d2 is the average distance from cluster head nodes to the sink node in the middle hierarchy. Generally, d2>>d0, so the energy consumption is proportional to 4of d1

The energy consumption of every cluster is:

$$W_{ch} + (N/m - 1) * W_{non-ch}(J),$$

and all nodes in each middle level energy consumption is:

$$W(m) = m * (W_{ch} + (N/m - 1)W_{non-ch}(J)) \tag{3}$$

The advantages of using the clustering method are the convenient management and the low latency. Assuming the delay time of every transmission is T0 (about 1ms), the nodes in different clusters can communicate at the same time. The number of the cluster is m, so the network completes a data collection costs:

$$T(m) = T_0 * (N/m + m) \tag{4}$$

D. Multi-objective optimization model for the cluster head nodes deployment of the low level in network

We assume that the deployment range, node number, and the location are already known and the number of the cluster heads is optimized. Our goal is to optimize the latency and the energy consumption. Based on (3) and (4), the optimized disposition model of cluster head nodes can be established using multi-objective optimization.

Because of the different dimension and unit as well as the magnitude between W(x) and T(x), normalization should be used to determine that the W(x) and T(x) are the same magnitude (both between 0 and 1). In this paper, the latency is four orders larger than the energy consumption, hence the whole optimization model is:

$$Z = 10^4 * w1 * f1(x) + w2 * f2(x) \tag{5}$$

Where $f1(x) = W(m)$, $f2(x) = T(m)$, w1 and w2 are weight parameter of the energy consumption and the latency respectively, and $w1 + w2 = 1$. According to the different application environment and requirements, the best number of cluster head nodes at the different weight parameter can be calculated by adjusting the w1 and w2.

E. Optimization and the result

The optimized model discussed above is the on nonlinear constrained optimization; Fmincon function is used in MATLAB for calculation. 120 sensors (actuators) are deployed in the five-span greenhouse [9], as showed in Fig 3.

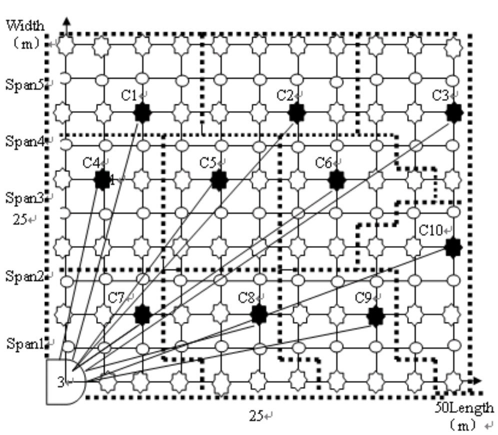

Fig 3 the number cluster head node of the five multi-span greenhouse

According to [7],The optimized parameters are set as follows: L= 25bytes, E_{elec} =50pJ, ε_{fs} =10pJ/bit/m², ε_{mp} =0.0013 pJ/bit/m4, Wf =5nJ/bit.

When w1 is set to 0.5, the result of the optimization showed in Fig 4 is that: the best cluster head node number is

about 10 that between 5 and 11. Five is the best number of the cluster head nodes when the weight w1=1, eleven is the

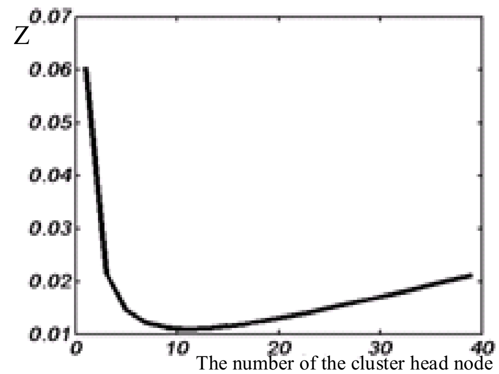

Fig 4 where w1=0.5, the optimized number of the cluster head node

best number of the cluster head nodes when the w1=0.

IV. ANALYSIS OF THE OPTIMIZED RESULT

A. Influence of the weight w1 and w2 on the best number of the cluster head nodes

Different demand of the energy consumption and the latency with different application environment, the best cluster head nodes number at the different weight parameters can be calculated by adjusting the w1 and w2, as showed Fig 5.

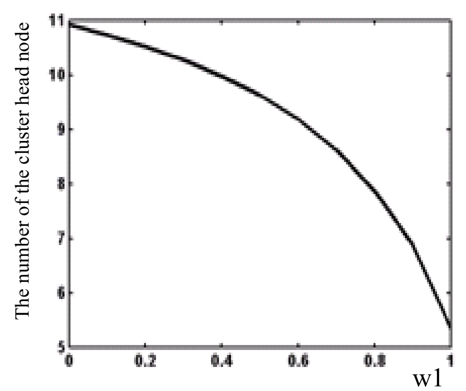

Fig 5: Influence of the weight w1 on the cluster head node number

When w1=0.9 and w2=0.1, the optimized cluster head number is seven. The number of the cluster head nodes is reduced with the weight of the energy consumption increase. Otherwise, the cluster head number is increased with the growth of latency.

B. When w1 and w2 are decided, the influence of the total node number on optimized cluster head number

When w1 and w2 are decided, for example, w1=0.5 and w2=0.5, we optimize the number of the cluster head with different number of the total nodes. The conclusion which showed in the Fig 6 is that: more nodes are deployed, more clusters will be clustered.

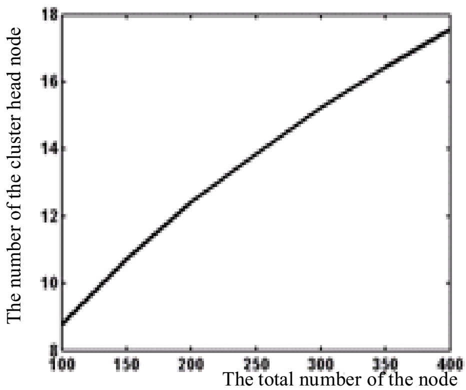

Fig 6: Influence of the total number on the cluster head node number

V. ANALYSIS ON SIMULATION TEST

In wireless sensor network, the appearance of the First Node Dead (FND) is an important parameter to measure the lifetime of the network. Therefore, the appearance time of FND should be delayed to improve the network performance. The simulation is run on NS-2, compared with the clustering algorithms of LEACH [10]. According to Fig 3, the middle level includes 55 sensor nodes and 65 actuators nodes. Some parameters are set as follows: every data packet is 25 bit, assume data is transmitted all the time. The node initial energy is 15J; 2J energy is supplemented to the actuators nodes every round, the energy doesn't increase beyond 20J. The interval periodic is set to 400 seconds. Every round continues 20 seconds. Simulation based on (1) and (2) and the clustering algorithms of LEACH, the FND appears at 2820 seconds, while the simulation based on the improved LEACH, the FND appears at 5750 seconds. The lifetime is increased because of the supplemented energy of actuators and the optimized number of cluster head node.

The simulation based on (4) and the LEACH suggest that the time of completing data collection once is imbalance in each cluster transmission, it varies from 8T0 to 24T0. The transmission time of low level is calculated with the longest interval, the transmission time between the low level and the middle level is about 10T0, and 34T0 is needed for the middle level to complete data collection once. However, only 22T0, which reduces 35%, is needed based on the improved LEACH and the optimized number of the cluster head nodes.

VI. CONCLUSION

Three-level wireless network measurement and control system is established based on the wireless sensor network and the mobile network technology. The energy consumption and the latency are reduced in term of the hardware. Multi-Objectives Optimization is applied to determine the best number of the cluster head nodes based on improved LEACH which can reduce the energy consumption and the latency. The further study of the paper is to establish the practical wireless network measurement and control system to verify the effects and the feasibility. The research of the mechanism and the communication protocol will continue to improve the transmission efficiency and realize the measurement and control with lower power, lower cost and lower latency.

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