A Chain-type Wireless Sensor Network in Greenhouse Agriculture

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***Abstract*—Wireless sensor networks are useful complements to monitoring systems in greenhouse agriculture. Based on the requirements of this system, we design and implement one chine-type wireless sensor network (C-WSN) to monitor crops' growing environment. In the hardware, CC2420RF are applied in sensor nodes as the wireless transceiver, and the MCU, MSP430F149, is used in sensor nodes and sink nodes, which has high performance and ultra Low-Power. In the communication protocol, we propose one novel chain-type MAC protocol based on token (CMAC-T) according to traditional one and the sink node's characteristic of unlimited energy. Experiments prove that this C-WSN has long life cycle and good stability. It is competent for monitoring the environment of greenhouse agriculture.**

***Index Terms*—greenhouse agriculture, wireless sensor network, token, MAC protocol, low power**

I. Introduction

Agriculture plays a pivotal role in the development of countries, especially China, a typical big agricultural country. For a nation with 1.3 billion populations, the health and rapid development of agriculture is the essential guarantee of economic development and social stability. Greenhouse agriculture has become one of the most important components in agriculture. Therefore, it is a very important strategic decision to accelerate research-ing and developing the greenhouse agriculture.

Currently, main researches in this field focus on how to measure and transmit crops' environmental variables to famers, who can make decisions based on the data to improve yields and quality. This is one important issue in this field, and has important significance in Chinese modern greenhouse agriculture.

Traditional monitoring system in greenhouse agricul-ture (MSGA) generally collects data by wire. This method has some shortcomings, such as complicated wiring, inconvenient using, and difficult maintenance. Wireless sensor network (WSN) can not only meet the application requirements in MSGA, but also is recognize-ed as the best solution of replacing traditional wired connection[1].

Among various topologies of WSNs, the C-WSN is the most suitable for MSGA[2]. It adopts wireless communication to avoid the drawbacks brought by wiring[3], and takes MSP430F149 to design nodes. Combined with the improved communication protocol, not only can the C-WSN meet the requirements of MSGA, but also reduce the nodes' power consumption greatly and prolong C-WSN's life cycle.

II. The Proposed Method

At first, MSGA adopted wired communication, such as the artificial plants climate laboratory in America, CECS computer control system in Netherlands. Both of them achieved the purpose of monitoring environment in greenhouse agriculture[4]. However, there are weak points which are addressed above.

Later, wireless network were applied in this field. In 2002, Intel established the world's first wireless vineyard in Oregon. Sensors were deployed in the yard, which collected data frequently. From those data, researchers can acquire the relationship between grape and environmental variables[5]. From then on, lots of MSGA used the wireless network[6]. The typical system is shown in Fig.1.

In the system, GPRS network is used to transmit data.

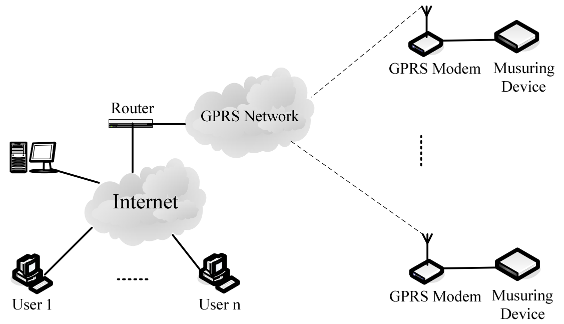

Figure 1. Structure of typical system

A monitoring point must use a GPRS module. Thus, its cost of design and maintenance is very high in large system. To reduce the cost, C-WSN is used, in which GPRS module is only used to design the sink node that transmits data to information center.

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III. RESERCH METHOD

A. System Overview

Aim at the requirements of MSGA, there are some principles when design the C-WSN: the sensor node should be low power, low cost and small; the network can guarantee the stability and real-time; the network can be used in large scale. These principles must be obeyed when design the system structure and communication protocol.

Similar to traditional WSN, the C-WSN is composed of sensor nodes, sink nodes and management node (information center)[7]. Besides, this system monitors temperature, humidity and light intensity among various environmental variables in agriculture. Thus, the system structure of C-WSN applied in MSGA is designed as following figure. In Fig. 2, each node has its own responsibilities.

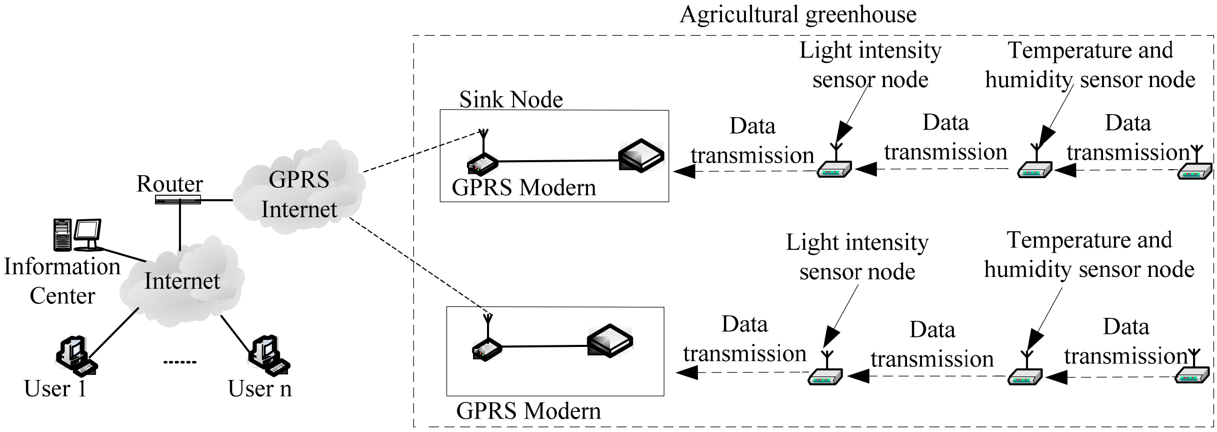


Figure 2. Structure of monitoring system

1) Management node: It is the upper layer of the system, which can receive data from sink nodes via GPRS network, and offering some Web services, which can be useful to users.

2) Sink node: It is the center of the monitoring system, which has multiple functions, including synchronizing nodes in network by sending beacon frames, collecting and processing data measured by sensor node by wireless transmission, and communication with upper layer network. Because its heave responsibilities cost lots of energy, it is powered by electric-power line.

3) Sensor node: Measure environmental data, including temperature, humidity and light intensity, and send data to sink node. It is the bottom of the monitoring system. It is powered by battery with energy limit. Thus, the nodes should be in sleeping mode in most time to reduce the power consumption.

Based on above principles, we implement C-WSN in two steps. One is hardware, which considers low power and stability in the design of circuits and choice of chips. The other one is communication protocol. Since typical layer protocols are not suitable for this system, we should design one new protocol, which should concern sleeping mode to reduce power consumption and synchronization to increase the stability of network.

B. Hardware Implementation

1. Hardware of sensor nodes

Sensor nodes are responsible for collecting environmental data in the network. Since temperature, humidity, and light intensity are the three main factors that influence crops, we monitor those three variables in this system. Low-Power is the key index in the design of sensor nodes. With characteristics of ultra Low-Power, high speed of data processing and stability[8], MSP430F149 is widely applied in sensor nodes. So we choose MSP430F149 and CC2420 RF[9] as the controller and wireless module.

1) Hardware of temperature and humidity sensor nodes

SHT10 can measure both temperature and humidity[9]. Fig. 3 is the hardware diagram of temperature & humidity sensor node.

MCU collocate SHT10 through P3.2 and P3.3 which are connected to the DATA and SCK of SHT10 respectively. Meanwhile, MCU uses simulation serial mode to configure CC2420's wireless characteristics, including sending and receiving frequency, sending power, and data rate.

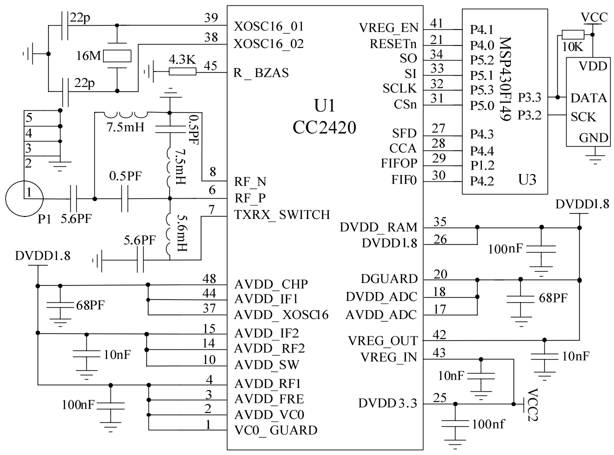


Figure 3. Hardware diagram of temperature & humidity sensor node

2) Hardware of light intensity sensor node

To monitor light intensity, choose TSL230B as the sensor. The hardware diagram of light intensity sensor node is shown in Fig. 4.

MCU can configure TSL230B by I/O ports which are connected to TSL230B's four configuration pins, S0, S1, S2 and S3. Besides, MCU can read the output signal through P1.1 connected to the OUT of TSL230B. Then it calculates the value of frequency and figures out the light intensity finally.

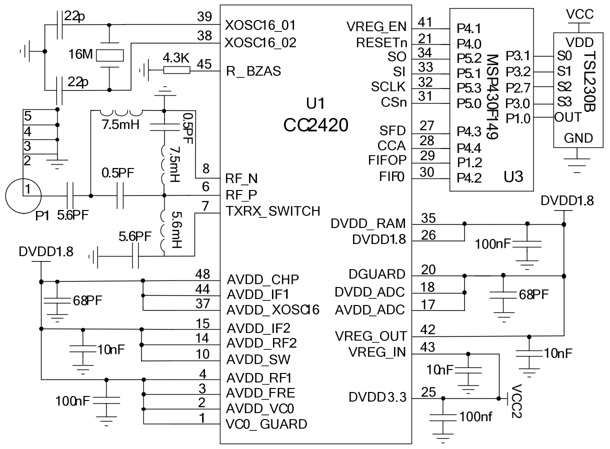


Figure 4. Hardware diagram of light intensity sensor node

2. Hardware of sink nodes

The sink node is different from sensor nodes. It is powered by electric-power line and has the responsibilities of processing and storing data. Thus, it has memory Flash module, real-time module, LCD, serial port, and GPRS. The hardware structure of sink node is shown in Fig. 5.

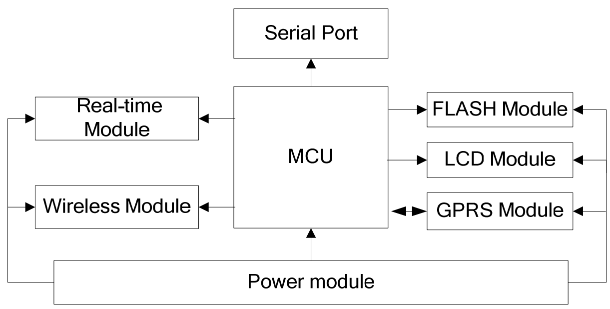


Figure 5. Hardware structure diagram of sink node

The responsibility of GPRS module is sending data from sink nodes to information centers. It is consist of SIM card, antenna, and G24 MOTOROLA module. The MCU and real-time module adopt chip MSP430F149 and PCF8563. Besides, the Flash module uses memory M25P23 which has large memory capacity. Sink node provides one RS232 to connect with GPRS module. Meanwhile, power management is quite important. First, it converts 220V AV in electric-power line to 12V DV by adapter. Then, conversion circuits of LM2576 and LM1117 change 12V into 5V and 3.3V, which can be directly used by above modules. LCD module uses LCD12864 because of its Low-Power, and simple external circuit.

C. Communication Protocol

1. The MAC protocol based on the token

According to the MAC protocols based on demand assignment[11] and TDMA[12], the CMAC-T is an improved protocol combined with access on demand and stationary distribution of time slot.

1) Format of Frames

There are two main types of frames, beacon frame and data frame.

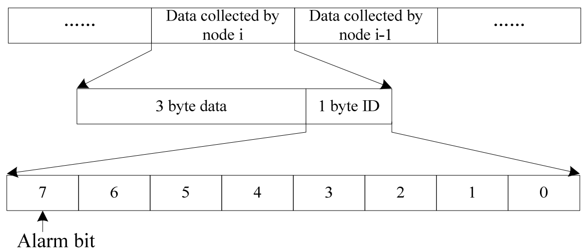
- *Beacon frame*

Beacon frames are responsible for the synchronization between adjacent nodes and assigning channel permission. Frame's length is stable. It includes two bytes. The first one stores token information, the other one stores the number of nodes in network. Token is different in different period.

Token information	number of nodes in network

- *Data frame*

Except uploading its own data, sensor node has to transmit other nodes' data. So the length is changeable for different node. Besides, the data frame should include node's ID and alarm information. Thus, the frame format is as below.



2) Synchronization algorithm and communication

Coarse-grained time synchronization algorithm is adopted in the CMAC-T. Sink node periodically sends a certain number of beacon frames. After waking up from sleeping state, sensor nodes in the network randomly receive a beacon frame containing time slice and token information, which can determine whether nodes get the communication authority. If get the authority, they finish synchronization, and later complete data transmission between adjacent nodes. Otherwise, they will continue to sleep. In this way, the network can not only avoid the data collision in data transmission, but also can reduce the power consumption.

Assume the whole chain contains N child nodes (except node 0). During one completed data transmission, the sink node has to broadcast N periods of synchronization information. Each period contains M ($0<M<256$) beacon frames, whose token information is the same in one period. The relationship between token information and the nodes' state can be seen in table 1.

TABLE I.
RELATIONSHIP BETWEEN TOKEN INFORMATION AND THE NODES' STATE

Period	Token	Synchronize working nodes	State after synchronization	Beacon frames
1	N	Node N: sending state	Node N-1: recieveing state	M
2	N-1	Node N-1: sending state	Node N-2: recieveing state	M
j	N-j+1	Node N-j+1: sending state	Node N-j: recieveing state	M
N	1	Node 1: sending state	Node 0: recieveing state	M
1	N	Node N: sending data	Node N-1: recieveing data	M
…	…	…	…	…

Beacon frames' token information in period 1 is N, which can synchronize node N and node N-1 to transmit data. Beacon frames' token information in period N is 1, which is used for data transmission between node 1 and node 0.

Assume the time of period j is T_{aj}, whose components are shown in Fig. 6. $\Delta\tau$ is set by users to adjust receiving time of period N based on time for processing, uploading and storing data.

When node i receives beacon frame k in period j, the specific synchronization and communication process of node i is as follows:

- $j \neq N$:

  a). $i > N - j + 1$ or $i < N - j$: Node i switches to sleeping state which lasts for $(M-k)t_1 + t$, then intercepts beacon frames after waking up.

  b). $i = N - j$: Node i switches to sleeping state which lasts for $(M-k)t_1 + \tau$, then switches to receiving state. After receiving data or out of receiving time, it switches to sleeping state which lasts for *t*, and then intercepts beacon frames after waking up.

  c). $i = N - j + 1$: Node *i* switches to sleeping state. If there is data waiting for transmitting, it sleeps for $(M-k)t_1 + \tau$, and then switches to transmitting state. After transmission, the node sleeps for $(N-1)T_{ai} + t + \Delta\tau$ or $(N-2)T_{ai} + t + \Delta\tau$ when $i = N$ or not, and then intercepts beacon frames after sleeping. If there is no data to transmit, the node sleeps for $(M-k)t_1 + t + (N-1)T_{ai} + t + \Delta\tau$ or $(M-k)t_1 + t + (N-2)T_{ai} + t + \Delta\tau$ when $i = N$ or not, and intercepts beacon frame after sleeping.

The scheduling figure is shown in Fig. 6 (a).

- $j = N$:

Node 1 switches to sleeping state which lasts for $(M-k)t_1 + \tau$, then transmits data, later switches to sleeping state. After $(N-2)T_{ai} + t + \Delta\tau$, it wakes up and intercepts beacon frames. Meanwhile, other nodes switch to sleeping state which lasts for $(M-k)t_1 + \tau + \Delta\tau$, and intercept beacon frames when wake up. The scheduling figure is shown in Fig. 6 (b).

3) Example of chain with 4 nodes

Take a C-WSN with 4 nodes for example. K_i means the No. of beacon frame acquired by nodes. t_1 is the time for sending one beacon frame. τ is buffer time to avoid intercepting the last frames in period. Since τ and time for sending and receiving data are far less than t， τ can not affect the next period. The communication processes

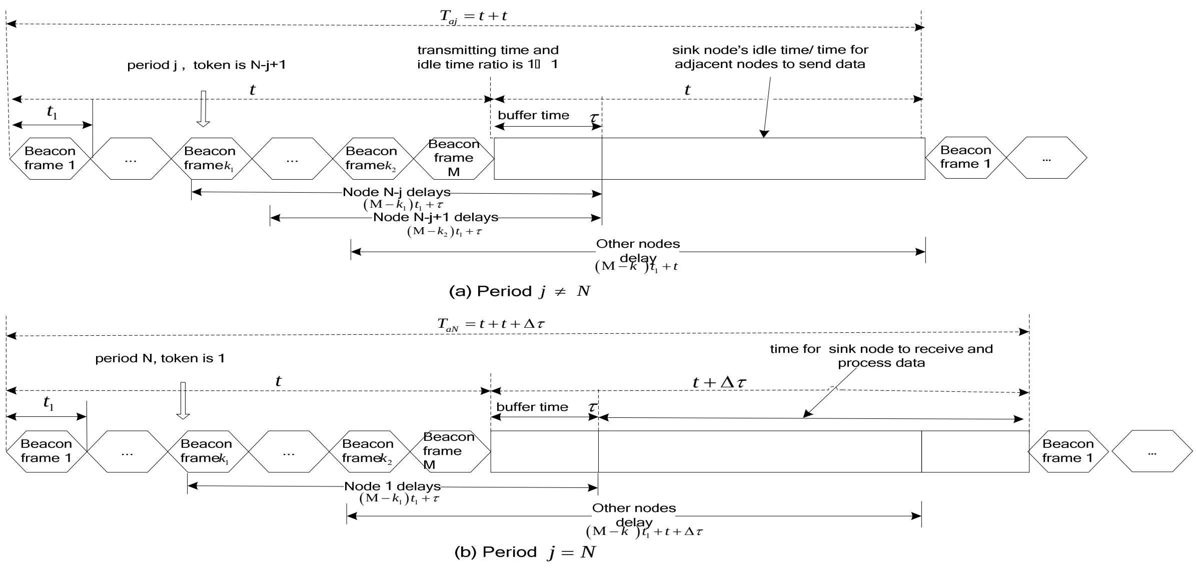


Figure 6.Synchronization and communication process of node i

of four nodes are shown in Fig. 7. communication.

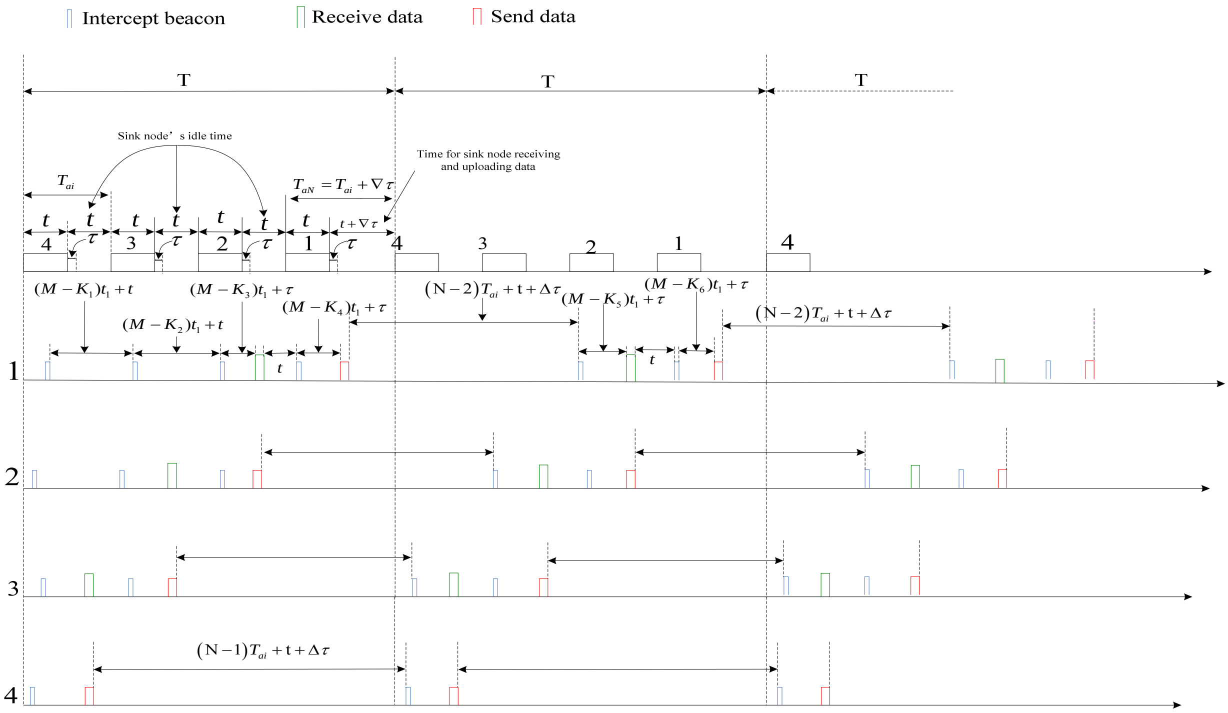


Figure 7. Communication example for 4 nodes

4) Scheme for low power

Since sensor nodes are powered by battery, power management is quite important. To prolong network's life cycle, it is important to reduce the power consumption. We should optimize the time of active and sleeping to cut down the average current, which is the node's energy consumption cost within a unit. The current distribution is shown in Fig. 8, and formula (1) is the calculation method [13].

$$I_{avg} = \frac{(I_{active} * T_{active}) + (I_{idle} * T_{idle})}{T_{total}} \quad (1)$$

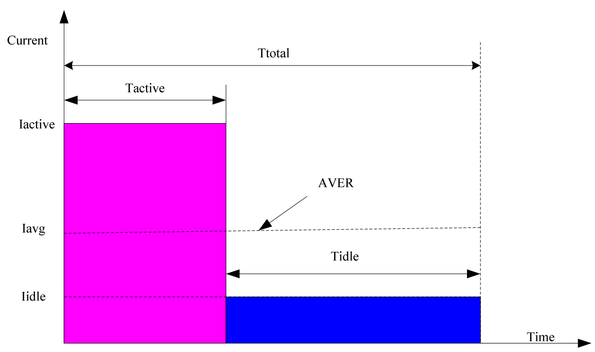


Figure 8. The current distribution

From above coordinate, we should try our best to reduce the colorful area. In conclusion, we lower the power consumption by following aspects [14]:

1) Close unused modules and circuits.

2) Reduce the load of hardware.

3) Lower the transmitting power on the basis of

2. Implement of software

1) Software of sink node

Sink node is responsible for receiving data from sensor nodes, processing and uploading data. Besides, it is powered by electric-power line without energy limit. Therefore, according to above protocol, the main flow chart of sink node in one cycle is shown in Fig. 9.

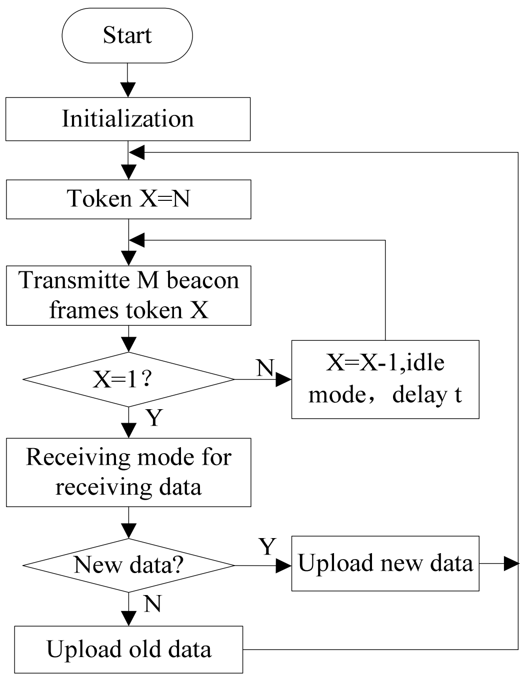


Figure 9. The main program flow chart of sink node

2) Software of sensor nodes

Sensor nodes have to collect environmental data, and transmit to sink nodes. Based on the CMAC-T, the software of sensor nodes can be described by Fig. 10. After being powered on, the sensor node starts initializing the system, including clock, timer, ports, interface SPI, wireless transmission module and sensor's working mode. After initialization, it enters sleeping state.

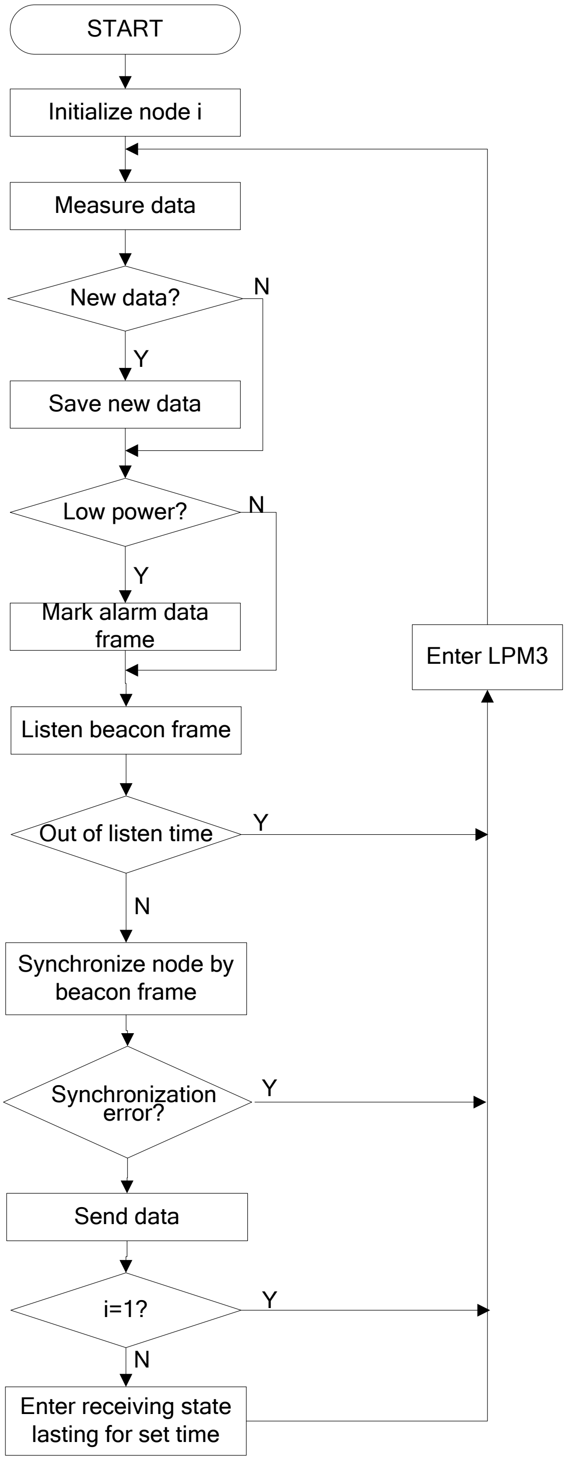


Figure 10. Main program flow chat of sensor nodes

IV. System Test

A. Power Consumption Test

Measured by experiments, the sensor node's current of transmitting, receiving and active state are 27.43mA, 30.23mA and 2.53mA. When the temperature & humidity or light intensity sensor node is collecting data, the current is 1.28mA or 1.51mA. The current in sleeping state is 49μA.

It takes RF 1325μs and 1526μs to turn sleeping state into receiving and transmitting state. Sensor nodes need 1004μs to receive beacon frames. Node 1 needs to receive and transmit up to 26 bytes and 30 bytes of data, which cost 1068μs and 1256μs at most. Meanwhile, it takes 4.1ms and 100μs to collect one completed data for temperature & humidity sensor and light sensor. Specific current change in one period is shown following.

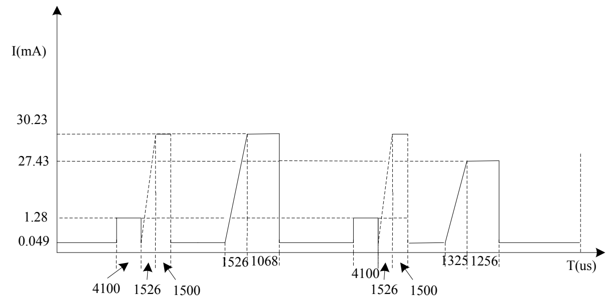


Figure 11. Specific current change in one period

Since the system is powered by batteries, the average current determines the system's life cycle. According to the formula of average current, I_{avg} equals to the quotient of total current and time. The former one refers to the sum of the product of working current and working time in active state and product of sleep current and sleep time in sleep state. Suppose that the working cycle of one node is 2s, we can calculate the average working current of temperature & humidity sensor node:

$$i = 0.049 + \frac{1.28 \times 4100 \times 2 + \frac{(1068 + 1068 + 1526) \times 30.23}{2}}{2.0 \times 10^6}$$
$$+ \frac{\frac{(1256 + 1256 + 1325) \times 27.43}{2} + (1526 + 1500 + 1500) \times 30.23}{2.0 \times 10^6}$$
$$\approx 0.113 mA$$

The light intensity sensor node needs far less time than temperature & humidity sensor node to collect data, so the average current is 0.1118mA. The working cutoff voltage of nodes is 2.7V. Assume the node is powered by two common lithium batteries with 1.5V voltage and 2700mAh capacity. According to the discharge characteristics of lithium battery, when battery discharges to 2.7V, the loss of battery capacity is about 2000mAh. Node's life can be roughly estimated as 2000/0.118=17889h=745.4 days, which means that a sensor node can last for more than one year.

C. Communication Distance Test

Experiment is tested in the place without buildings. This test wants to know the communication distances between sensor nodes, and between sensor node and sink node.

1) Two sensor nodes: The max distance is 50 meters. And within 35 meters, the communicational quality is well.

2) One sensor node with sink node: The sink node Exchanges data with its neighbor sensor node, And within 35 meters, the communicational quality is well.

This communication distance is not very well because of the design of PCB, antenna and climate. But still can meet the requirements of greenhouse agriculture.

D. System Reliability Test

To test the correctness and reliability of point to point, we established two groups: sensor node to sensor node, and sensor node to sink node. Each time, node sent 2000 data. The results are shown in table 2 and table 3.

TABLE II.
RELIABILITY TEST BETWEEN SENSOR NODES

No	Sending data packets	Correct receiving data packets	Accuracy
1	2000	1993	99.65%
2	2000	1997	99.85%
3	2000	1991	99.55%
4	2000	1996	99.80%

TABLE III.
RELIABILITY TEST BETWEEN SENSOR NODE AND SINK NODE

No	Sending data packets	Correct receiving data packets	Accuracy
1	2000	1998	99.90%
2	2000	1994	99.70%
3	2000	1995	99.75%
4	2000	1996	99.80%

To test the correctness and reliability of multi-point communication, we have carried out three groups of experiments, each of which measured 2000 completed cycles. The testing results are shown in table 4, we can see that data accuracy is substantially maintained.

TABLE IV.
RELIABILITY TEST OF MULTI-COMMUNICATION

NO	Correct data received	Accuracy
1	1988	99.4%
2	1985	99.2%
3	1990	99.5%

From the three tables, the accuracy of multi-point communication is a little lower than the one of point to point communication. But they are all above 99%. Compared with other wireless MSGA, this accuracy is quite well.

On the premise of excluding interference, there should not be packet loss in theory. The main reason is: nodes synchronize time by the time synchronization information in beacon frames and the own clock information, which can cause synchronization error when small differences and drift of clock are existed.

V. CONCLUSION

Differ from other networks adopted wired and wireless communication, we designed and implemented one novel C-WSN applied in greenhouse, which proposes CMAC-T protocol according to the application environment. Results verify the C-WSN can satisfy the specific application requirements in agriculture, including high reliability, Low-Power, low cost and etc.

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