A New Environment Parameter Monitoring System Based on ZigBee Protocol

Chaoyi ZHANG[※], Yili ZHENG, Rongqiao CHEN

Abstract—This paper designed a new environment parameter monitoring system which based on Zigbee protocol, the hardware includes Zigbee wireless transmission circuit and control function of peripheral circuits, the software includes coordinator, router and host computer program, and it can realize remote transmission system to achieve environment temperature, humidity and other environment parameters. The system debugging and testing were carried out in the test field, system reliability was verified through a series experiments, such as antenna height test and multi-hop network experiment. The results show that this system achieves the purpose of real-time monitoring environment parameters, reliable network transmission, monitoring area good coverage, combined with different monitoring requirements, this system can be stable and reliable operation under the condition of obstacle shelter and bad weather conditions.

Keywords—Sensor network, Zigbee protocol, environment parameters, monitoring

I. INTRODUCTION

Using wireless sensor networks (WSN) to monitor the environment parameters had been applied in many industries, especially in agriculture and forestry environment, such as greenhouses, farmland, forest and other occasions, to monitor the environment parameters (e.g. temperature and humidity, CO_2 concentration), this can timely guide related staff in decision-making, and conducive to crops growth [1-3]. The sensor module was an important part in monitoring network, the environment parameters direct acquisition was accomplished by sensors, but its deployment, wiring and construction engineering problems were more difficult, and the line of laying, aging will give engineering and construction difficult degree [4-7]. WSN had the advantages of simple networking, no need to lay cables, and its scalability was strong. Wireless communication technology [8] based on ZigBee protocol stack was widely used.

ZigBee system module can be divided into router, coordinator and terminal equipment. Among them, the terminal equipment was equipped with sensors, used to collect environment temperature and humidity parameters, converted them to digital signals, output to terminal module on CC2530

chip [9-11]. After the coordinator and router work together, the data collection was transmitted to the coordinator by sensors [12-14] through wireless multi-hop network. In practical application, the router and terminal node can be added to the existing network to realize the layout of multiple monitoring points[15-16]. Protocol stack was very important, and mainstream Z-Stack was selected in this paper. This protocol used round robin mechanism, when the event occurs, system was waked up, began to enter system interrupt processing event, after finished, system was into sleep state[17-19]. This protocol stack can reduce system power consumption and save energy.

In this paper, a set of ZigBee's technical protocols and standards were analyzed, its unique Z-Stack protocol stack was interpreted and studied from its code structure. Compared with previous wireless network communication technology, ZigBee wireless network technology had the characteristics of low power consumption, low cost, easy to use and other characteristics [20]. A wireless sensor hardware system was designed and implemented which based on ZigBee protocol [21]. The system software was implemented which based on sensor information acquisition and ZigBee protocol stack, an environment temperature and humidity monitoring network was built up [22]. The network monitoring system can remote real-time monitoring environment parameters, which based on ZigBee network protocol requirements, this paper designed a set of hardware and software system, the hardware part included ZigBee protocol module main control board, RF circuit design, power supply module, sensor circuit module and gateway node design. At the same time, the downstream acquisition node application layer's software was programmed.

The main content of this research included two parts: hardware design and software development, hardware included Zigbee wireless transmission circuit, control function peripheral circuit, software mainly included coordinator node and router software, system implemented remote temperature and humidity monitoring function. A test had been established in experiment research base. Through antenna height test, point to point communication experiment, multi-hop network experiment, system barrier free running experiment, weather condition experiment and so on, the system reliability had been verified.

II. SYSTEM MODEL

An important feature of this system was capable real-time monitoring temperature and humidity data in remote

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environment, this system can achieve the following functions: 1) environment temperature and humidity data real-time information, and control software through wireless network to upload to host computer; 2) wireless nodes according to set the time constant, data was transmitted to host computer at regular intervals; 3) The host computer monitoring software can record temperature and humidity data which uploaded by all nodes in real time; 4) the whole system was powered by solar energy, completely removed the damage which caused by cable network construction and maintenance. The function structure of system was shown in Fig. 1:
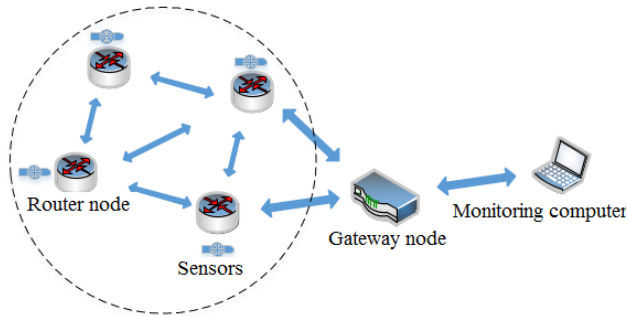

Fig. 1 Structure of wireless multi-hop network

According to the above principles, the system was consisted of wireless nodes and PC host computer, into which wireless nodes were divided sensors and routing nodes, as well as coordinator node directly connected to host computer. Coordinator nodes were used to set up wireless and configuration network's parameters. When network was established, router nodes can join this network. Once the network was formed, coordinator node acted as a router. The router node sent heartbeat packet and environment parameter to host computer at regular time. The heartbeat packet had the function of informing host computer whether it was online or not and the current network quality. The host computer received the data from which uploaded network and recorded them in database. The host computer can also manually configure the designated node parameters, such as frequency of water collection, length of each acquisition time, etc.. The whole system was powered by solar panels and lead acid batteries.

III. ZIGBEE ROUTE NODE HARDWARE DESIGN

Zigbee node design was the focus of system design, the system design process after many failures and discussion, the following focused on the core function module part.
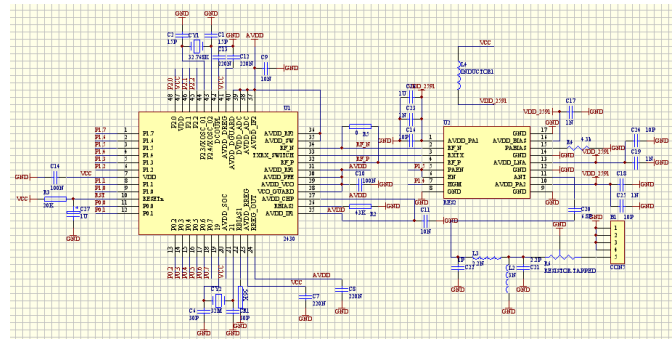
3.1 Wireless node circuit design

Fig.2 Schematic diagram of wireless node

Zigbee node was a RF radio-frequency circuit, so the layout reasonable way had an important role in RF circuit, after repeated debugging and experiments, this paper summarized some RF circuits design experience, this system was designed and it was used in the actual application:

1. Reducing power noise interference. The burr voltage was the main interference of power noise, it was more obvious in analog circuit. Because Zigbee node was a radio frequency circuit, that was analog circuit board, so its power circuit wiring requiremented more stringent. The microprocessor absorbed current in each short period of clock cycle, which was caused by chip processing technology. To solve this problem, the analog part was separated with digital part in power circuit, and the decoupling capacitor was increased to reduce noise interference of power supply to the greatest extent. A large number of decoupling capacitors were deployed to chip pins, and boards overall layout was taken into account. The NPO ceramic capacitor was used as decoupling capacitor.

2. Reasonable layout of electronic components. The RF circuit board usually had the ground layer connected to the ground, so ground layer design was very important. In general, PCB plate line had produced about 1nH inductor per millimeter, when the circuit frequency was 434MHz, PCB line (10mm thickness) inductance was about 27Ω. The design of circuit board was to minimize the impact of external circuit on RF circuit, CC2530 and cc2591 two function modules were both on one circuit board, and then other functions of hardware circuit were on another circuit board, so as to avoid current crosstalk phenomenon.

3. Reliable grounding. On the circuit board, because the RF part, a ground wire layer was designed, and it connected to the power negative pole, we set up a 0V potential point, so that it can effectively decouple the components on the board. The system designed the ground layer on circuit board to cover whole PCB board. In addition, copper was placed on the wiring layer blank in circuit board, so that the ground wire layer and copper coating layer were connected, the components can be further decoupled between each other. It should be noted that the grounding may cause the nature of inductance to change, so the inductor choice was also important.
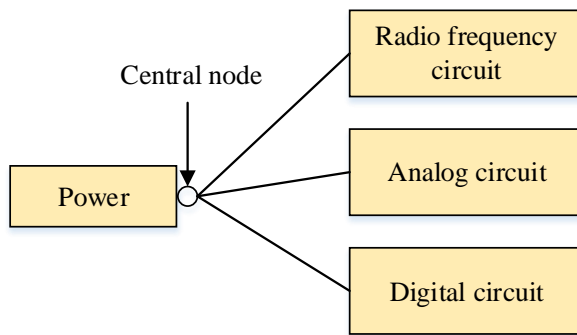
Fig.3 schamatic of star wiring

4. Power star wiring. As shown in Fig. 3, the active components of each module on circuit board had a common power supply point. the node's signal was from RF circuit antenna, this module's power wiring, which circuit's digital and RF part, each had its own independent power line, with the greatest degree of enhancing anti-interference ability, these two parts power was decoupling in close proximity to chip. This power wiring was also an effective way to reduce power noise.

5. Transmission line width. Transmission line circuit board may also cause certain impact, here AppCAD software was used to design system board, according to the calculation of circuit board materials, specifications and other convention parameters, the line width was designed when PCB board was taken back, and then it was verified by special impedance measuring instrument.

3.2 ZigBee gateway node Design

Gateway design had been introduced in a number of articles, it upload data to host computer from other nodes in network, where the repeated design part was not in detail, this section described this system gateway node differences design part.
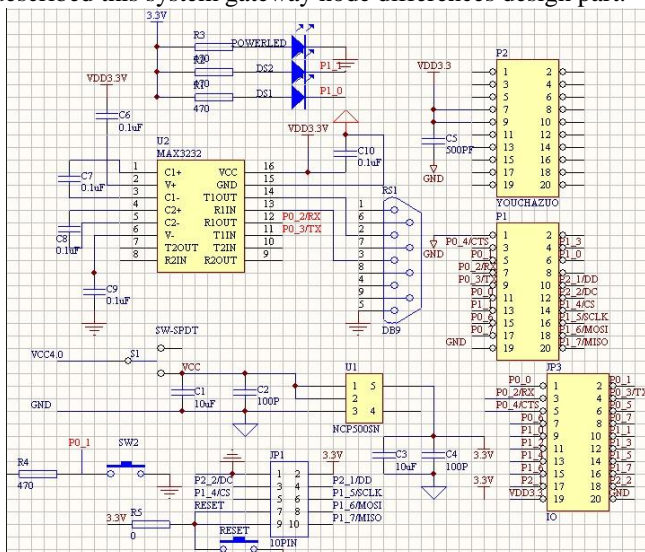

Fig.4 schematic of gateway node

Fig. 4 was the gateway circuit designed. In this map, the first stage switching power supply had LC filter at the back end, but the switch power supply did not directly supply power to each module in system, and the linear power supply had 4V, 3.3V and 1.2V, which were connected to GSM module, controller and chip respectively. This design method was different from tradition unified power supply mode. First, it can prolong the

service life of each electronic component in circuit board, on the other hand, the power supply can improve board efficiency accurately, and make circuit in best working state.
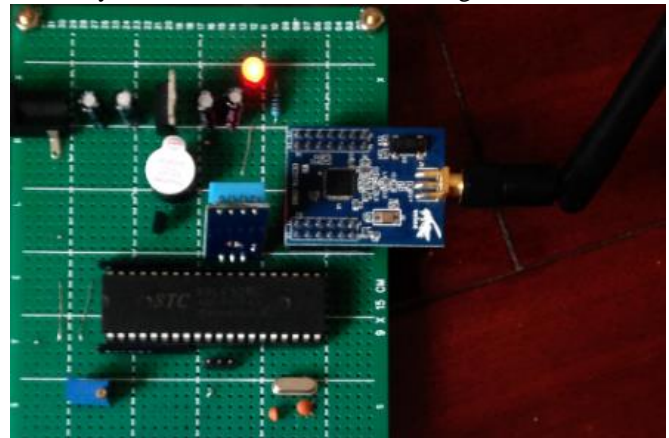

Fig.5 snapshot of gateway node

Fig. 5 was the final fabrication of welding gateway circuit board physical map. In order to make gateway node design better in application, in the first stage of switching power supply, we used a wider voltage input range with 9~50V, the 5V output's load current was designed as 2.2A, the switching power supply used TPS54260 buck chip to do current control.

The gateway was mainly plus a wake-up module which based on original design, this module can not transmit data in network when it entered a dormant state, HTML code was embedded at the same time. In connection with router and coordinator node, these nodes can access into the monitoring page through computer, realize remote wake-up operation of dormant nodes.

3.3 Routing node software design

Firstly, each node was configured in network, after each node was configured, node main function was coded through IO port in system. The main function flow chart on node was shown in Fig. 6:
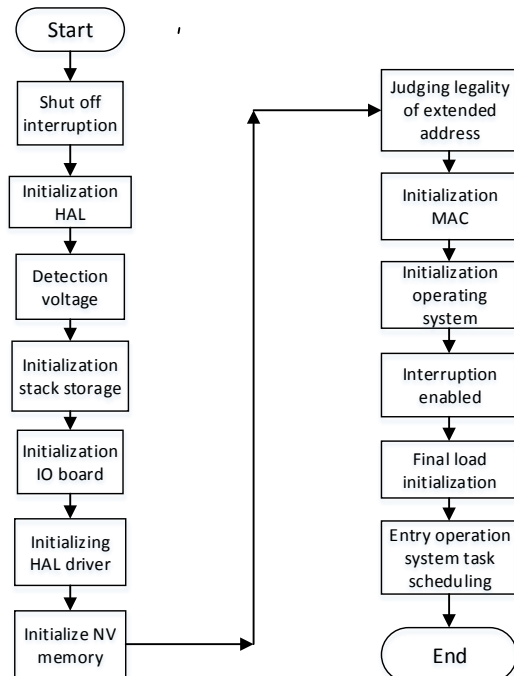

Fig.6 Flow chart of main function

From Fig. 6, it can been seen that this system main core function were concentrated in the node starting to work, the hardware node detection and initialization stage. When the system internal work started, network was connected with detection and a series of initialization operations (including HAL drive, NV memory, etc.), the operation system automatically called a "osal_start_system ()" function, then operation system will proceed the following subsequent operations, system task was scheduled. The protocol stack required the operation system to deal with the events by which generated a message queue. the time library was operation system core, it mainly completed the message command trigger action.

As a duplex mode, if host computer sent the command messages, it needed to operate and control nodes, the nodes will be based on PC command, executed the operation according to the corresponding command function in function library. In view of this process, the specific operation was shown in Fig. 7:
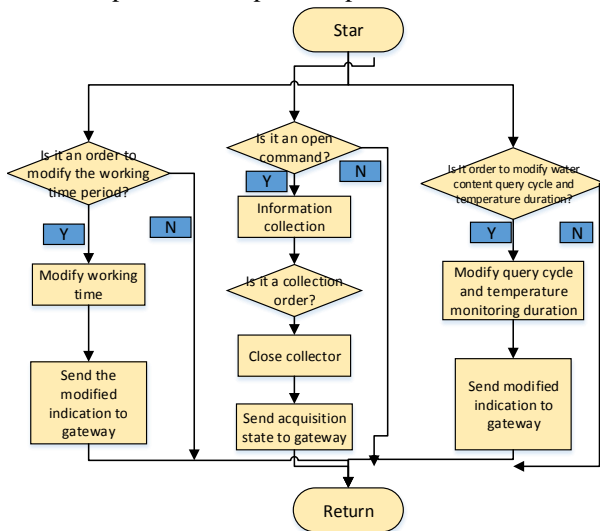

Fig.7 flow chart of command from PC

The routing node was forwarding data, which was the most important node in multi-hop network, its main function was to send and receive data from the downstream node, at the same time, according to the agreement, it forwarded the packet to upstream node, finally through the form of multi-hop, data will be sent to gateway, the gateway node sent data to host computer at the same time. The routing node also had error detection function. Its main functions included:

1) Operation system. Each routing node consisted a protocol stack, which preserved route node's event handling task.

2) Event handling function. The protocol stack core task was event driven mode, a node's rousing, working, sleeping state were event driven, all hardware drivers were also executed here, therefore, in protocol stack of route node, the node's all behavior event driven functions were preserved. There were 6 events in all, these were described in corresponding documentation, which no longer to be described here.

IV. SYSTEM TEST AND RESULT ANALYSIS

The system design was based on Zigbee wireless multi-hop

ad hoc network, the wireless communication part was affected by many factors. System testing phase was to detect system quality, in this paper, network each layer node's data uploading reliability and node's antenna height were tested. The performance parameters such as system sensitivity and anti-interference ability had been analyzed and compared. Among the factors that affected wireless multi-hop network, wireless communication protocol, routing rules and network deployment had an impact on network's QoS. For node's transmission power, reception sensitivity of receiving nodes, these parameters have been determined after chip selection, and they cannot be modified. Field testing and debugging combined with system deployment, this paper mainly evaluated the network in two aspects, the antenna height and the success rate of data link connection, then analyzed the influence of external environment factors on network transmission performance and comparative test.

Before specific analysis, this paper used RSSI (Received Signal Strength Indication) as the criterion of link quality. This value was a signal transmission quality numerical value which solidified in CC2530 chip register. The value was changed with network environment, its value reflected the current network node link quality, and the expression of self-organizing network healing ability. The larger the value, it showed that the better link quality between two nodes in wireless communication, when the test points were put together, RSSI value can be more than 210 (maximum of 255), from the past test results, in a rectangular range of 40m*40m, according to RSSI value calculation, the distance test accuracy of two communication nodes was less than 1m. At the same time, it was found that when RSSI value reached two digits, network can communicate normally, while the network's packet loss rate was larger when RSSI value was a single digit.

4.1 Experimental site introduction

The following map was a field test base, an unsheltered farmland environment. The farmland was normally planted with some crops and covers an area of about 0.1 hectares. In order to monitor environment parameters of farmland in this region, we had arranged 12 wireless sensor nodes in field, with the changing of deployment strategy, the node position had been changed, the deployment of nodes was distributed in all regions of the block, which according to signal's strong and weak relationship. The gateway node was deployed near central computer room of host computer. Fig. 8 showed a position map in the test field of three nodes.

Fig.8 experiment field

3.2 Antenna height experiment

First of all, the node antenna height was tested. One routing node and one coordination node were selected in 12 nodes, these two node's protocol stack parameters were set. When the routing node accessed network, the node sent data to coordinator node per 10s, one test cycle was set as 1 hours, test verified that packet RSSI value was sent within an hour, and determined packet success delivery rate. In antenna setting, it was taken a height value every 20cm, and then measured the height of antenna RSSI value. Making a change every time, the RSSI value was read from node's configuration table, and the data successful delivery rate within measured time period (1 hours), these two indicators were taken as measuring network quality. The results were showned in Fig. 9.
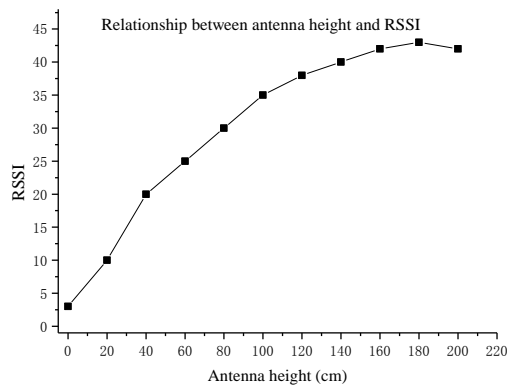

Fig.9 experiment result on antenna length

As can be seen from Fig. 9, when node antenna height was below 60cm in Zigbee network, the network RSSI value was smaller, which less than 25, this value was too novel to say that network can't communicate normally at this time, long circuit breakage occurred in a link, the success rate had been tested at about 30%. At the same time, from field observation and experiment discovery, when antenna height was above the detected environment object 50cm, and there were no obstructions, the communication quality between nodes will be greatly improved at this time. But when the antenna was further elongated, communication quality eventually tended to be stable. Fig. 9 showed after 150cm, the communication quality was basically irrelevant to antenna height, so when deploying the network, it should be based on monitored environment objects and parameters, properly set node's antenna, properly increased aerial suspension height of the antenna, to ensure wireless communication links quality.

3.3 Data uploading reliability test of each layer node

In order to test reliability and stability of Zigbee protocol stack, the wireless multi-hop network was overall tested. In a wireless ad hoc network, when one communication link was failed (such as the occurrence of one node did not work), this may lead the communication link was blocked, and the network all nodes re-sent routing request, to re-build a connection, this required a lot of system resources. In addition, in Zigbee protocol stack's routing part, the event driven node was triggered by a timer of its operation system, so when two nodes

were sending data to their common upstream nodes at the same time, data packet collisions were inevitable, as a result of broadcast storm. When this happened, it was necessary to redesign multiple access protocols in protocol stack to ensure data collisions. In this experiment, these two kinds problems were tested in field.

The field experiment was divided into two groups, the first group selected gateway nodes and 5 routing nodes to constitute a network. In laboratory, these 5 routing nodes were site in lined up, the distance between each two nodes was 10m, in order to make these 5 multi-hop routing nodes in a communication link, the gateway's nearest route node was opened, then according to Zigbee protocol routing rules, downstream nodes were found and sent confirmation packets at the same time, eventually a communication link was built. In this process, each node's RSSI value was recorded, the number of packets successfully delivered to the destination node in 1 hours was also recorded, and the results were showed in Figs. 10~11.
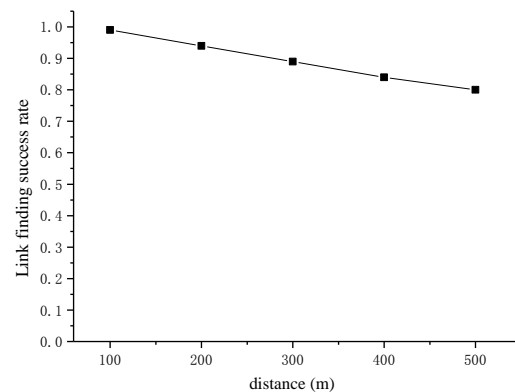

Fig. 10 Link finding success rate and distance relationship in multi-hop network
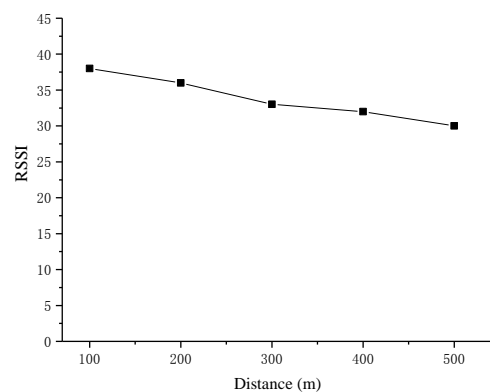

Fig. 11 Communication distance and RSSI relationship in multi-hop network

Experiment group 2: re-deployment this network, all 11 nodes and gateway node were selected, in accordance with the principle of shortest path, these 12 nodes were evenly distributed in whole test site, the physical topology was showed in Fig. 12, then in the deployment strategy, downstream nodes were selected to a link machine was the longest In the whole monitoring period, each node's RSSI values were recorded, the

success rate of packet delivery within 1 hours was recorded at the same time, and we draw the graph, as shown in Fig. 12:
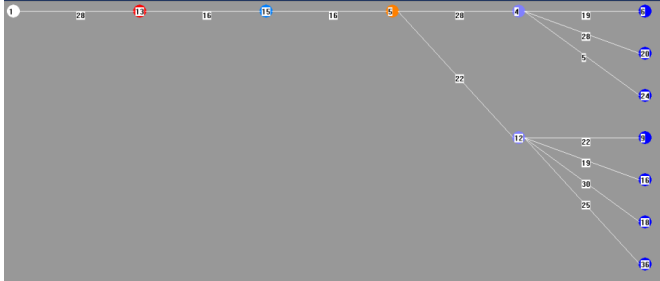

Fig.12 Multi-hop network topology

In Fig. 12, the number on the line represented the delivery success rate of link packets, from the chart, it can been seen that, along with the distance increasing, wireless multi-hop network node's data delivery success rate had been declined in each layer. At the same time, with the number of nodes increasing, network load and capacity were further increased, this needed to consume a large network resources, and sacrificed some link quality, this result was consistent with the theory of wireless ad hoc network capacity.

According to the above two experiments, it can been concluded that, the longer the links, the more network nodes and denser deployment, network Qos must been decreased. And with the diversity of monitoring environment parameters, network load must inevitably increased. But from another point of view, if the nodes were fewer and deployment was simple in network, this network can become more robust, and link connection success rate was higher, but the network coverage area may decreased correspondingly, the monitored area was also decreased. In addition, in node's Zigbee protocol stack, it was observed that during the experiment, the timer event driven task more frequent triggers, the packet loss rate was also higher; in a single packet transmission process, if the transmitted packet length was over longer, the packet loss rate was higher.

V. CONCLUSION

This paper summarized the factors that influence Zigbee wireless sensor network, designed and implemented a set of environment parameter transmission system which based on Zigbee protocol, this system included hardware and software design. At the same time, a field test was done, the environment influence on system quality was verified by antenna height and multi-hop network experiment. The experiment analysis results showed that, the antenna height was less than 50cm when the network quality was poor, antenna height was more than 150cm, network quality had little effect; single point communication distance was slightly shorter than multi-hop network communication, which can guarantee reliable communication quality in the range of 400m; after long period operation of the system, temperature and humidity parameters under monitored environment, which can upload data in real time and steadily, and this achieved the expected goal.

ACKNOWLEDGMENT

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