Design of a Gateway Based on Directional Antenna WSN in Paddy Field

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Abstract—This paper designs a WSN gateway for environmental monitoring in paddy field, which includes the hardware structure and the software program. We use the MSP430F149 as the core of the gateway node and the nRF905 as the peripherals equipment for node communication. We choose TDR-3, a soil moisture sensor, and DHT22, a temperature-humidity sensor, to collect and process the environmental information of the paddy field in real time. The MC55 is used as the GPRS module to achieve communication between the gateway and the Internet. We write programs of hardware drivers, communication protocol, abnormal SMS alarm and time synchronization protocol based on the hardware platform. The communication distance, power consumption and data storage rate of the gateway are tested in paddy field. Tests results show that, in open area, the maximum distance of effective communication can reach 331.18m, the longest working hour without charging is 32days, the maximum storage rate is 849.7kbps, the packet loss rate is 0.686% under local network and 0.712% between local network and the internet. The gateway has the characteristics of stable operation, long-time-low-power consumption, long distance transmission and automatic alarm. It can meet the requirement of information acquisition of environmental monitoring in paddy field.

Index Terms—Wireless Sensor Networks; Environmental Monitoring; Paddy Field; Gateway; Network Protocol

I. INTRODUCTION

Rice occupies a very important position in the grain production of China. Improving its comprehensive production capacity is a long-term strategic objective of food security [1]. Precision agriculture is a technology system that we can take different ways of management, which is to obtain the greatest benefit of environment and economy. Based on the demand of precision planting, only if we get the environment system information of paddy field timely and accurately, we can be precise to irrigate, fertilize, and spray them on demand. Therefore, how to acquire and transfer the spatial variables efficiently and effectively that impact the paddy field becomes the premise of precise cultivation [2]. The results show that the monitoring of soil moisture can help the agricultural workers grasp the paddy field’ situation and realize the irrigation of the paddy.

At present, most of the paddy field environmental monitoring use wired-equipment [3], whose quantity and wiring are limited by the conditions, and can’t meet the needs of large-area-real-time monitor [4]. Wireless sensor networks can collect and transfer the data of soil moisture, air temperature and humidity from different type of sensors deployed in monitoring areas. In wireless sensor networks, the gateway is the link between wireless sensor network and other networks, it is responsible for the communication protocol conversion and data transmission [5].

Guo Junzhen [6] designed a water-saving irrigation system of paddy field based on wireless sensor network, which is called Mini 210. The aggregation nodes of this system were responsible for the collection and transmission of the data to the gateway via serial ports. Samsung S3PV210 is used as the major processor of gateway design, working with 5 "HD LCD. Minni 210 is equipped with 512M DDR2 memory and 1GB SLC NAND Flash. It realizes the modules of data collection, irrigation control and information display on android system. However, this design only introduced the functional requirements of the remote monitoring platform, but lacked of further detailed design and functional tests.

Huang Zhaodi etal [7] designed a paddy field monitoring system based on nRF905. In this system, the sensor module was responsible for sending the data from the nodes to the user terminal, and the coordinator acts as a gateway role, which mainly consisted of MCU (STC89C52 SCM) control module, LCD module, SIM300 GPRS module and NRF905 wireless communication module. The writers completed environmental information tests in a small area of paddy field, but the communication distance of the coordinator needed to be improved.

Xiao Deqin etal [8] designed a paddy moisture sensor network system (PMSN). They put forward a low-power transmission control protocol LPTP-PMSN which met the needs of water sampling frequency and data receive. They designed a water information monitoring system that we can take different ways of management, which is to obtain the greatest benefit of environment and economy.
management system and used GSM gateway to realize the communication between base-station and network. Tests proved that though the system is low energy consumption, it was not flexible in terms of real-time acquisition.

Liu Hang [9] adopted JZEE technology to design a visual software platform based on WSN to monitor the environmental information of paddy field. The software platform defined ten major functional modules, which could display the data of temperature, humidity, and illumination collected by sensor nodes. However, the communication between the computer and serial ports is flawed, and it failed to achieve the docking between software and hardware.

Nowadays, though the researches on gateway technology have gained a lot experience at home and abroad, the technology still faces the deficiency of switching among multiple ways of communication and it lacks of early warning mechanism. Most of the network topology modes are in the shape of star or tree, which is not suitable for the environmental monitoring of large-scale paddy field [10]. To solve these problems, we design a WSN monitoring system that can incorporates directional antenna technology, and expands the coverage range of the network communication to realize the communication between gateway nodes and server. It can optimize the network by timely sending warming informaton. The WSN monitoring system of paddy field is shown in Figure 1.

II. GATEWAY NODE STRUCTURE

The processor is the core control module of the gateway, which is responsible for data receiving and dispatching, the conversion of data formats and communication protocols [11], and alarm message producing and sending. The MSP430F149 Microcontroller that produced by Texas Instruments is a 16-bit, RISC-based, mixed-signal processor, which is designed specifically for ultra-low-power. With an 8MHz internal digitally controlled oscillator, whose instruction cycle is 125ns, it is high-speed, and has a strong processing capability and rich on-chip resources. Therefore, it’s capable of dealing with a large number of samples, interrupts and timing, and also has a rich extensibility. It has five kinds of power supply modes from LPM0 to LPM4. The current is only 2.5μA in real-time clock mode, and down to 0.1μA in RAM retention mode.

The GPRS module uses MC55 module of Siemens company that integrates TCP/IP protocols. It’s responsible for sending alarm messages and the communication between the gateway and the remote monitoring center [12]. The RF chip applys nRF905 module that produced by Nordic company, of which working frequency is 433MHz. The serial port module uses UART0 to realize the connection between GPRS module and processor module. The system uses an SD card for data storage. The architecture of the gateway is shown in Figure 2, and the physical architecture of the gateway node is shown in Figure 3.

III. SYSTEM SOFTWARE DESIGN

A. Hardware-driver Design

1) nRF905 Driver

The nRF905 driver includes a data transceiver program. We use an external interrupt of the MSP430F149 to achieve carrier sensing, and the data transmission is also achieve with an interruption [13]. Before transmitting the data, the processor will listen to the channel to make sure whether it is occupied. If the channel is idle, the processor will transmit the receiving data and valid the data to nRF905 through SPI program, then pull up TRX_CE and TX_EN and activate the ShockBurst TX transmit mode.

In transmit mode, data packets are made and sent. If AUTO_RETRAN is high, the nRF905 sends data packets continuously until the TRX_CE is set low by the processor, ends data transmission and enter the mode of standby. The flow of nRF905 sending the data is shown in Figure 4.

By setting TRX_CE high and TX_EN low, the nRF905 switches to ShockBurstRX receive mode. When having monitored the carrier of which the frequency is the same as that of receiving, the carrier detection (CD) is set high, and the nRF905 checks the address. When a valid address is received, the address match (AM) is pulled up, and the nRF905 receives and saves the data packet and then checks the CRC. If it indicates that the packet is valid, the preamble, address, and CRC bits are removed, and Data Ready (DR) is pulled up, which causes the processor
interrupt. Setting TRX_CE low and makes the nRF905 switch to standby mode, and the data read by SPI. After the reading of data, AM and DR are set low to prepare for the subsequent entering of ShockBurst TX, ShockBurst RX or Power down mode. The chart of nRF905 receiving data process is shown in Figure 5.

![Figure 5. The receiving data flow of nRF905](image)

2) **MC55 Driver**

The MC55 can send up to 1500 bytes of data to the Internet in a time. Before sending data, the TCP connection information needs to be initialized. The initialization includes setting APN, target IP address and port number. After the initialization is completed, an connecting application is sent to the target IP. Then a physical point to point link between the MC55 and APN is set. Meanwhile the ISP assign a public IP address to the MC55. The flow of MC55 initialization data is shown in Figure 6. The flow of MC55 sending data is shown in Figure 7.

![Figure 6. The flow of MC55 initialization data](image)

![Figure 7. The flow of MC55 sending data](image)

### IV. SOFTWARE SYSTEM DESIGN

#### B. Communication Protocol Design

1) **Data Reception Protocol**

Although there is a synchronization protocol between the gateway and the node, however, the node sends data that using Flooding algorithm, which makes the information of the same node be repeatedly sent to the gateway. It may cause channel congestion and data redundancy [14]. We should avoid data redundancy especially when the data storage space of the gateway is limited. When the processor receives the first packet, it analyses the packet, saves the data and registers its node number [15]. If the packet’s node number has not been registered before, when the processor receives the next packet, the processor will save its data. Otherwise, the processor will
discard the packet. The received data flow is shown in figure 8.

2) Data Forwarding Protocol
The data forwarding protocol of the gateway consists of two parts, from nodes to the gateway and from gateway to the server [16].
1) From nodes to the gateway
We set a reasonable period of time, which is long enough for the gateway to receive and cache the data packets from all of the nodes [17].

In the hardware driver, we set the length of data packets of nRF905 to 32 bytes, and set the data cache space according to the number of nodes. After receiving the data, the gateway analyses all 32-bytes packets of each nodes and extracts the information of them. Packet format is shown in figure 9.

2) From the gateway to the server
The gateway communicates with the server through TCP connection, which transmits data by characters. The data from the node is hexadecimal, which needs to be converted into the correspondent characters. Format conversion block is written as follows

```c
void xToChar(uint8_t *data,char *s) // 16 Hex conversion
{ char temp[3]=" ";
  for (char i=0;i<DATABUF_LENGTH;i++)
  { sprintf(temp,"%X",data[i]);
    if (data[i]<16) strcat(s,"0");
    strcat(s,temp);
  }
}
```

C. Abnormal Alarm SMS Design
According to the experience of farmers, different upper-lower limits of parameters are set in different paddy field. When any parameter is higher than the upper limit or lower than the lower limit, the gateway will notify the users by SMS, so that they can take timely remedial measures [18]. This system sends SMS with UCS2 coding in the mode of PDU. The SMS warning process is shown in Figure 10.

D. Synchronization Protocol Design
In order to avoid error accumulation caused by long time working, the synchronization protocol uses short work act [19]. After the system starts, the node is in waiting mode, and the gateway sends a synchronization messages before it hibernates. When the node receives the synchronized timers, it adjusts its timing rounds into hibernation. The gateway wakes up and prepares to receive data. It listens to the channel for incoming data. If there is data, the receiving process is interrupted and save the received data [20].
TABLE I. THE COMMUNICATION DISTANCE IN THE DIFFERENT TRANSMIT POWER MODE

<table>
<thead>
<tr>
<th>Emissivity/dB</th>
<th>Communication distance /m</th>
<th>Mean/m</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>94.36</td>
<td>93.72</td>
</tr>
<tr>
<td>2</td>
<td>152.98</td>
<td>153.12</td>
</tr>
<tr>
<td>6</td>
<td>241.95</td>
<td>243.34</td>
</tr>
<tr>
<td>10</td>
<td>330.94</td>
<td>331.67</td>
</tr>
</tbody>
</table>

TABLE II. THE CURRENT OF THE GATEWAY IN EACH WORKING STATE (UNIT / MA)

<table>
<thead>
<tr>
<th>Dormancy</th>
<th>Wireless Module</th>
<th>MC55 module</th>
<th>Serial ports+SD card</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.08</td>
<td>receive</td>
<td>send SMS</td>
<td>idle</td>
</tr>
<tr>
<td></td>
<td>16.50</td>
<td>33.98</td>
<td>149</td>
</tr>
</tbody>
</table>

E. Server Program Design

In this design, the WSN gateway uses GPRS to access the remote server. The server can be located in remote computer terminal. Just set the IP address of the server, then the gateway can connect with the server by searching the IP address [21]. The design of the TCP-UDP service manager, uses the public IP service provided by China Telecom ADSL. The IP address is randomly assigned via China Telecom, and China Telecom will reallocate the IP address once again at fixed intervals, thus the server's IP will be a time-varying public IP [22].

In order to make the gateway and the user can always find the server and access to it, we use dynamic IP to bind domain names. The user can bind domain names access via running the peanut shell in the server, and achieve the resolution from domain name to IP address.

V. GATEWAY PERFORMANCE AND NETWORK TEST

A. Gateway Performance Test

1) The Maximum Communication Distance

Fix transmitting node at different transmit power, and set the antenna 1.5m away from the paddy surface. Send the data every 5 seconds, and the gateway node will be lit when it receives the data.

Move the gateway until the light is instable, and get the maximum communication distance. Use the laser rangefinder Bushnell Legend 1200 ARC to measure the distance from the gateway node to the directional antenna transmitting node.

![Image](image_url)

Figure 12. The test of the maximum communication distance

The measurement ranges from 5 to 1200 yards, and the accuracy is ±1 yard. The test results are shown in Table 1. The test site is in South China Agricultural University Cencun paddy experimental base. From the data of the table, the higher the node transmission power is, the farther the communication distance will be.

2) Gateway Power Consumption

The power consumption is a direct factor that affects the life cycle of a gateway, and the power consumption is closely related to the selection of the hardware [23]. Do the test in every operating state of a working cycle by connecting a multimeter between the battery positive terminal and negative terminal.

The multimeter is set to current detection, reading the output current of the battery in each operating state of the gateway. Also use the same method to test the current of the MC55 module. The results of the measurement are shown in Table 2. Use the data in Table 2 to calculate the life cycle of the main circuit. The method as follows: Lithium battery capacity is measured as \( Q_1 \) (mAh), and \( Q_2 \) (mAh) is the capacity consumed in a cycle. Thus we can calculate the life cycle \( T \). It was shown in equation 1.

\[
T = \frac{Q_1}{Q_2} \times \frac{1}{(3600 \times 24) + t} = \frac{Q_1 \times t}{Q_2 \times 86400} \text{ (d)}
\]

Due to the changes of the paddy environmental parameters are slow, collect the data periodically can reflect the trends of the paddy environmental parameters [24]. The experiment, with the Lithium Battery \( Q_1 \) =1800mAh, set 1h as the duty cycle. After undergoing testes, the time of node communicates with the gateway \( t=15s \). The serial port and SD card working time \( t_{idle-sd} =30s \), and sleeping time \( t_{sleep}=59\text{min} 15s \). Calculated by the formula (2), and the \( Q_2 = 2.295\text{mAh} \).

\[
Q_2 = 2.08 \times t_{sleep} + 16.50 \times t_{rx} + 20.65 \times t_{idle-sd} \text{ (2)}
\]

then calculated by formula (1) to obtain the lifetime of the gateway.

3) Data Storage Rate

The data storage module is used for storing the data [25] when the WSN network is aberrant. When the network is abnormal, all the nodes will still work properly. And the packet will be sent to each node gateway. The gateway packets need to store all the nodes in a certain format. And the storage rate directly affects whether the data can be normally stored [26].

TABLE III. THE TEST OF STORAGE SPEED

<table>
<thead>
<tr>
<th>Parameters</th>
<th>No</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Storage Speed/ kbps</td>
<td>849.7</td>
<td>849.6</td>
<td>849.8</td>
<td>849.5</td>
<td>849.9</td>
<td>849.7</td>
<td></td>
</tr>
</tbody>
</table>
The test inserts a 512MB SD card into the gateway. The system will control the gateway to open a text file in the SD card, and then write the date in to the SD card continuously in 1min. Then take out the SD card and calculate the number of bytes on it, and divide by 1min to get the storage speed. Repeat 5 times and get the average storage speed 849.7 kbps. The test results are shown in Table 3.

### B. Networking Test

1) **Cluster Formation**

According to the directional antenna WSN nodes and the gateway nodes, we use 6 nodes to do the network test in the South China Agricultural University Space Breeding paddy experimental base. The structure of the node cluster is shown in figure 13, node1 to node4 are environmental information collection nodes. Node 5 is the cluster head node, which is responsible for collecting the data from node1 to node4. And node6 is the gateway nodes which is responsible for sending the data to the internet via GPRS.

![Figure 13. The structure of the node cluster](image)

2) **Network Packet Loss Rate**

Packet loss rate refers to the percentage of the lost packets in the sent packets. The network packet loss rate is an important parameter to evaluate the gateway, and it is calculated by using the formula 3.

\[
\rho = \frac{n}{N} \times 100\%
\]

The \( \rho \) is the network packet loss rate and \( n \) is the number of packets lost in the process in per unit of time. \( N \) is the number of packets transmitted of the whole network in per unit time. The Gateway connects two different networks. The rate of wireless sensor network gateway packet loss includes two aspects [27]: the packet loss rate within the network and outside the network. In the experiments, the gateway program automatically records the total number of received information packets of each node in the SD card. The number of packets in the SD card is the number of gateway packets within the network. The system collects the data every 30min, calculates the length of time from the beginning of the test to the end of the test, and gets the number of packets that per node obtained. The network packet loss rate statistics is shown in Table 4.

The outside network packet loss rate largely determines the usefulness of the system, because the user mainly use a remote server for data query and management [29]. The outside network packet loss rate is determined by the strength of the signal of MC55. When the signal is weak, it can’t be connected to the server or lead to the loss of the data. The statistics of outside network packet loss rate is shown as Table 5.

![Figure 14. Three-dimensional model diagram of layout node](image)
The system could monitor different regions and different types of environmental information [31], including TDR-3 soil moisture sensor which measured the soil moisture in the depth of underground 5-8cm, DHT22 digital air temperature and humidity sensor which was used to measure the air temperature and humidity [32] and provide the basis for paddy microclimate regulation. According to the growth of rice seedlings, preliminary data acquisition frequency was 15min/bar, and later stage was 30min/bar. The management of experimental base viewed the real-time environmental data through the gateway, and set the lower threshold on the typical temperature and humidity. It also timely opened or closed the greenhouses when received an alarm message. The system had received a total of more than 7000 monitoring data and up to 45 times of alarm and it had effectively reduced the loss of rice breeding process due to abrupt climate change. The figure 15 was air temperature and humidity data that the gateway received within a cluster.

VI. CONCLUSIONS AND DISCUSSION

Considering with the current problem that exists in paddy environment information collection of the gateway and the environmental characteristics of the environment, this paper has designed a wireless sensor network gateway hardware and software systems, which can monitor the environment of paddy field remotely. Test the performance of the gateway and do the environmental information collection test of the network. The results are as follows:

1) The maximum effective communication distance between the directional antennas WSN nodes and gateway is 331.18m.
2) When the gateway uses 3.6 V/1800 mAh lithium batteries in 1 h sampling period, it can work continuously for 32d without charging.
3) The maximum rate of data storage of the gateway is 849.7kbps.
4) The packet loss rate within the network is 0.686% and the packet loss rate outside the network is 0.712%, so it can meet the requirements of normal transmission of data.
5) The temperature and humidity that measured by the cluster nodes display stably. It indicates that the connectivity of the network is good.

In summary, this paper designs a gateway that has the characteristics of remote communication, long time of stability, fast rate of data storage, automatic alarm, etc. Although this gateway design can meet the requirements of paddy application and the gateway nodes can forward data to the server, it has no downlink data and its operation about the remote node is insufficient. In addition, the hardware is designed to be able to collect data in real time, but it does not take the effects of electromagnetic interference into consideration. These factors will be the focal point to optimize the gateway design.

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A New Construction of Pseudorandom Number Generator

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Abstract—Random number sequences and RNGs play an important role in trusted computing environments and cryptographic applications. For example, we use random numbers in the generation of keys in TPM. In some web protocols, random numbers are applied to resist replay attacks. It is necessary to guarantee the quality of RNGs and their random sequences because deterministic factors are likely to be involved in the generation process. If a random number generator is not designed carefully, then the output number sequences may become predictable and bring high security risks. Thus, the design of random number generators that produce high-quality random number sequences has been a hot research topic in these decades. Recently, with the development of resource constrained environments, the demand of lightweight random number generators dramatically increases. People prefer to use the random number generators with extreme high efficiency in the on-the-fly applications. This will affect the security performance of the generators. In this paper, we design a random number generator which meets the current lightweight requirements in the resource-limited environments. Our design is originally based on a lightweight block cipher, and applies the property of random looking output of block cipher to the random number generators. We combine a traditional encryption mode with a novel structure for the random number generator, so that the trade-off between security and efficiency can be made perfectly. We also take a comprehensive security evaluation for our random number generator.

Index Terms—Random Number Generator; Random Numbers; Lightweight; MIBS; CBC Mode

I. INTRODUCTION

In various modern cryptographic applications, random sequences and random numbers have been used widely. Weak random sequences and random numbers can destroy perfect cryptographic protocols and cryptographic algorithms even they are well designed. In typical cryptographic applications, randomness is produced by generating a sequence of independent uniform variants (usually real-valued between 0 and 1, or integer-valued in some interval) and transformed in an appropriate way.

In general, high-quality random number sequences have various distributions, long cycles, and sequence-independent characteristics. Quality inspection methods have to follow the run-length, uniformity, and the independence of the sequences. These methods include a series of tests, correlation spectral analysis, and ENT (a performance testing program for random numbers) and so on.

Many applications need high-quality random sequences and random numbers. For instance, in hash functions, the initialization vectors are regarded as random. In secure protocols, the fresh nonce is thought to be random according to the different security requirements. In digital signature system, the variables and parameters are assumed to be random. When generating the session keys and the salts, which are hashed based on some rules, the randomness is also required.

The methods for generating random numbers have a range of types. From the mechanism, they can be divided into two kinds: mathematical and physical methods. The random number sequences generated by them are called pseudo-random numbers and true random numbers, respectively. The former one is easily cracked, while the latter one is difficult to crack, because they are taken from the real random sources of the physical world. However, this does not mean that the quality of these random numbers generated based on the true random sources is high, depending on how to use these algorithms to generate true random sources.

On the contrary, many mathematical methods are used to produce random numbers with better quality. Therefore, the combined mathematical and physical methods may produce high-quality true random numbers. From the point of implementation, there are different software-based and hardware-based methods.

Compared to the pseudo-random number generators, the study of true random number generator is still quite preliminary. Designing a true random number generator includes two steps. First, we need to get a true random source. Then, we obtain true random sources and true random numbers according to specific mathematical methods. True random sources exist widely in the real world, such as the arrival time of computer network IP packet, the random noise, the current second-level computer clock, the keyboard response time, the thermal noise, and the processing information of operating system.