OPAIMS: Open Architecture Precision Agriculture Information Monitoring System *

Yuexuan Wang
Institute for Theoretical Computer Science
Tsinghua University,Beijing, China, 100084
wangyuexuan@tsinghua.edu.cn

Yongcai Wang
Institute for Theoretical Computer Science
Tsinghua University,Beijing, China, 100084
wangyongcai@gmail.com

Xiao Qi
Institute for Theoretical Computer Science
Tsinghua University,Beijing, China, 100084
qix08@gmail.com

Liwen Xu
Institute for Theoretical Computer Science
Tsinghua University,Beijing, China, 100084
kyoi.cn@gmail.com

ABSTRACT

In order to realize precision agriculture information monitoring over long periods of time and over large areas of space, we propose OPAIMS, an open-architecture precision agriculture information monitoring system. OPAIMS consists of a two-tiered sensor network and an information service platform. The sensor network contains a large amount of energy-limited low tier nodes (LNs) to capture and report information of their designated vicinity, and some powerful GPRS gateways in the high tier to organize the LNs to form clusters and to report the aggregated information to the Internet. The information service platform logs information from the sensor network and provide value-created services to the users. In this paper, we focus on the design methodologies of OPAIMS, including the system architecture, the standard interfaces and the multi-hop joint scheduling of LNs. Such designs make OPAIMS not only scalable and longevous, but also universal for various kinds of sensors and hardware. Users can easily establish a precision agriculture monitoring system based on the proposed OPAIMS.

Categories and Subject Descriptors

C.2.1 [**Computer Communication Networks**]: Network Architecture and Design - distributed networks, wireless communication

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General Terms

Design, Experimentation, Measurement

Keywords

Wireless sensor networks, Agriculture, Information monitoring

1. INTRODUCTION

Precision agriculture which is defined as the art and science of utilizing advanced technologies for enhancing crop production while minimizing potential environmental pollution[2] has attracted great research interests in recent years. A major technology that drives the fast development of such precision agriculture is the wireless sensor networks[1][3]. The wireless sensors are commonly battery or solar energy powered, which can be easily deployed into the farmland to form self-organized network by wireless communication. Various kinds of sensors can be integrated into the sensor node, therefore, the conditions of the crops and the soil, including temperature, humidity, illumination, crop disease, and insect pest etc can be monitored remotely and in realtime.

Some preliminary experimental systems have been reported in the literature. Jenna Burrell,et.al., investigated different sensor network configurations in vineyard application[4], and summarized some design guidelines for agricultural monitoring system. Murat Demirbas, et.al.[5] deployed a small scale sensor monitoring system in a green house and drew suggestions that single-hop cluster should be a better solution for easy-to-use and network longevity. A mobile field data acquisition system was developed by Gomide et al. [6] to collect data for crop management and spatial-variability studies. Mahan and Wanjura [7] cooperated with a private company to develop a wireless, infrared thermometer system for in-field data collection. Crossbow developed eKo system[8], which involves solar-powered "eKo node" with zigbee radio and "eKo view" for real-time data rendering. It uses Xmesh protocol to make the eKo system easily setup.

These studies concluded some similar requirements of precision agriculture applications.

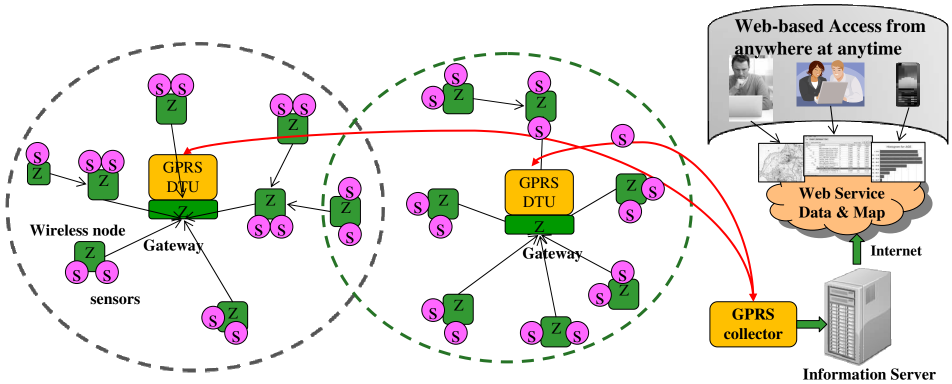

Figure 1: The architecture of proposed OPAIMS system

- Large scale. The farm field is often in scale of thousands hectares. To cover the broad land using the communication range-limited tiny sensors, tiered-structure sensor network was widely adopted [5][8].
- Longevity. The growth circle of the crops is a year or half a year. Solar energy[8] and node scheduling schemes[5][2][4] are proposed to achieve network longevity.
- Easy-to-Use. Farmers are commonly not skillful in network technologies. The sensor system must be easily deployed and easy-to-use. Single hop cluster [5] or autonomous data aggregation protocols [8] are proposed.

However these studies are mainly case-by-case. Systems are developed with some specified protocols, without the consideration of system universality. When a farmer sets up a system, he must handle all the hardware, software and network issues, which is common challenging work. For example, since the Xmesh protocol of eKo[8] is closed, if a farmer want to change his INSIGHT system to eKo system, he has to totally change the hardware, the software and the network settings. But the fact is that he shouldn't care about the infrastructure and the setting issues at all.

Therefore, two important requirements of agriculture information monitoring systems should be emphasized, which are seldom addressed:

- Standard. Since sensor types and requirements of agriculture monitoring are similar, standard interfaces and platforms should be designed, so that users can use any kinds of hardware to collect data, and use any kinds of monitoring system to log and render the results.
- Open Information Service Platform. The information service platform refers to the high level platform which logs, processes, renders and utilizes the agriculture information. This platform should be open that any users can access their agriculture monitoring network to the platform and utilize the information service.

Seeing of these, we proposed OPAIMS, an Open-architecture Precision Agriculture Information Monitoring System. We designed OPAIMS to be open in architecture and tries to standardize its interfaces for universality. Particularly,OPAIMS is composed by two parts: 1) a two-tiered sensor network, 2) a service platform. The two-tiered sensor network is further composed by many low-tier energy-limited nodes (LNs), and some high-tier gateways. The LNs in low-tier capture environmental data and report the raw data to the gateway. The gateways organize the neighboring LNs into clusters and work as the cluster head. It collects information in its cluster, aggregates the information, and reports the results to the Internet. The service platform contains data logging daemon, database, and web server. It processes and provides agricultural information service to users.

Particularly, we propose two standard interfaces in OPAIMS: "Sensor-Wireless Interface" which transform raw sensory data to meaningful sensor reading, and "WSN-Internet Interface" which forwards information from sensor network to Internet. Futhure, we propose multi-hop joint scheduling for the low-tier sensors to provide network longevity. With above design methodologies, OPAIMS satisfies not only the **large scale, longevity** and **easy-to-use** requirement, but also provides **standard interfaces** and **open service platform**. By using OPAIMS, users can easily import different agricultural sensors, and easily monitor agricultural information.

The rest of this paper is organized as follows. In section II, we describe the system architecture of OPAIMS. In section III, we describe the standard sensor-to-wireless node interface and the WSN-to-Internet interface. Section IV presents the design of multi-hop joint scheduling method, and Section V summarizes our preliminary experimental results. The paper is concluded in section VI, with remarks and future work discussions.

2. SYSTEM ARCHITECTURE

We present the system architecture of OPAIMS system in this section. As shown in Fig.1, the architecture of OPAIMS basically contains a two-tiered sensor network and an information service platform. The two-tiered sensor network is further composed by many energy-limited low-tier sensors and some high-tier gateways.

2.1 The Low-tier Node

In the lower tier of the sensor network, a large amount of energy-limited sensor nodes (LNs) are deployed to capture environmental data in designated vicinity and report the data to the gateway. Each LN is an integration of a wireless node running Zigbee radio stack and several environmental sensors, such as temperature sensor, humidity sensor etc. The composition of a LN node is shown in Fig.2. One LN may integrate different kinds of environment sensors. Each

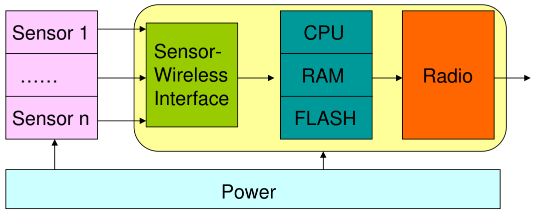

Figure 2: The composition of LN node

sensor capture raw data in its vicinity. The formats of raw data are commonly voltage or electric current values. The raw data is converted to meaningful sensor readings in the "sensor-wireless interface", and after that, the meaningful data is processed or stored by embedded processor. At last the results will be broadcasted via the radio module to the gateway.

2.2 The High-tier Gateways

In the higher tier of the sensor network, some powerful gateways organize the LNs to form clusters and report the aggregated information to the Internet. The composition of a gateway node is shown in Fig.3.

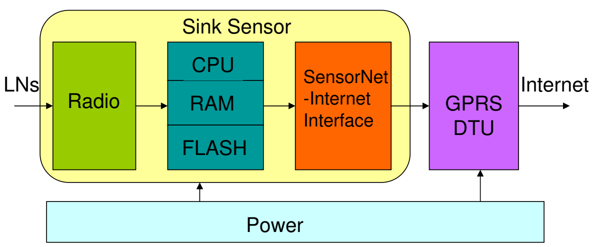

Figure 3: The composition of gateway node

Each gateway is an integration of a sink sensor and a GPRS DTU (Data Transmission Unit) [9]. The sink sensor is responsible of collecting and aggregating data from local cluster. It can receive LNs' message via radio and process the message via the embedded processor and flash. The GPRS DTU works as a transparent relay unit, which only forwards the data of sink sensor to the information service platform via Internet without any modification to the data. Therefore, the GPRS DTU can be seen as a part of the Internet. An interface called "WSN-Internet interface" is designed between the sink sensor and the GPRS DTU. It is responsible for packaging the various sensor data and routing information from the sink sensor into standard packets that can be recognized by the service platform. We will discuss the details of the interface in later section.

2.3 The Information Service Platform

An information service platform is designed to remotely log the agriculture information to provide value-created services via web service. It is composed by an Information logging daemon, a Database and a Web server. The information logging daemon continuously receives the TCP/IP packets from the GPRS DTUs. It extracts the sensor data from the packets and stores the data into the database. The database includes tables of sensors and tables of gateways. It stores the historical sensor readings and stores the topology information of the sensor network. The Webserver retrieves data from database and uses Google Earth API to render the sensor network topology and render the readings of each LN in a 3D map. The web server support various kinds of queries, for example, time-based, gateway-based etc. So that users can conveniently access precision agriculture information from anywhere and at anytime.

3. INTERFACE STANDARDIZATION

Based on above system architecture, the dataflow in the OPAIMS system is shown in Fig.4. From the figure, we can more clearly understand the functions of the two interfaces in the system.

1. In the low-tier of the sensor network, the "Sensor-Wireless Interface" converts the raw data of sensor readings to meaningful values.
2. In the high-tier of the sensor network, the "WSN-Internet Interface" packages the various sensor readings for transparent data relay via GPRS DTU.

Our aim is to make the platform open to various users. We hope that

1. The sensor network should be transparent to users. Users of OPAIMS need not care about the configuration and the communication parts of the sensor network. They only set their environmental sensors via the "Sensor-Wireless Interface", and the setting will be very easy. After such setting, the sensor network will work for the user to collect and transport the sensor data.
2. The information service platform should be open to user. What the user need to do is to package the sensor readings following the standards of "WSN-Internet" interface, and then they can use the service platform to render and process their agriculture information. So that the cost and efforts of service platform development can be saved.

3.1 Sensor-Wireless Interface

In each LN, standard interface is defined for transforming raw sensor data to meaningful sensor reading. The raw data is commonly voltage or electronic current values, while the meaningful readings are commonly temperature, humidity, illumination, etc. The raw data is transformed to the meaningful values by some functions. Therefore, the standard interface is defined as a set of functions for different kinds of sensors. For a sensor type S_i, which provide raw data X, the interface is:

$$S_i(X) = \{Y = f(X), (Y_{min}, Y_{max}), Y_{precision}\} \quad (1)$$

where $f(X)$ is a function transforming the raw data to meaningful value. (Y_{min}, Y_{max}) characterize the measuring range of the sensor S_i, and $Y_{precision}$ is the measurement accuracy.

The user only need to specify $\{Y = f(X), (Y_{min}, Y_{max}), Y_{precision}\}$ to register the sensor. The sensor network will be transparent to the user to capture environment data and transport the meaningful results to the Internet.

3.2 WSN-Internet Interface

In each gateway, a standard interface is defined to transport data from the sink sensor through the transparent GPRS

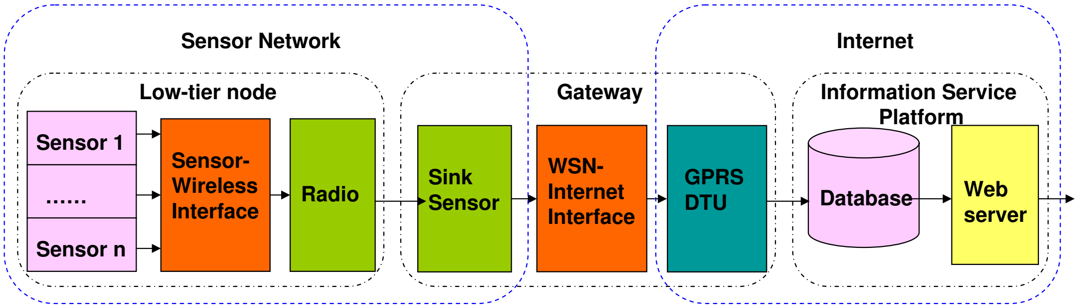

Figure 4: Dataflow in the proposed OPAIMS system

DTU to the Internet. Since every gateway works as the head node of its cluster. It is responsible for data aggregation and transportation for all the LNs in its cluster. To render the topology of sensor network and the real-time agriculture information, there are two kinds of information which should be sent from the sink sensor to the Internet. 1). The topology information of LNs in the cluster. 2) The realtime sensor readings collected by the LNs. The "WSN-Internet Interface" is defined to transport these information in following packet formats.

Topology Packet

The sink node maintains the topology information of its cluster. This topology information is obtained via hop information extraction during data collection or by special topology message broadcasting[10]. The service platform queries the cluster topology information periodically. The sink node answer the request in the message type as shown in Fig.5.

Type	Length	Sink ID	Group ID	Route List	CRC	End
4 Bytes	2 Bytes	1 Byte	1 Byte	Various in length	2 Bytes	1 Byte

Figure 5: Format of the topology packet

where

1. *Type* defines the type of topology packet;
2. *Length* is the length of the packet;
3. *Sink ID* is the id of the sink node, always be 0.
4. *Group ID* is the id of the cluster;
5. *Route List* is the payload. Because all routes end at the sink with ID 0, every route can be presented by a string of node indices, for example $2 \rightarrow 1 \rightarrow 0$. The Route List is a set of such strings.
6. *CRC* is the Cyclic Redundancy Check;
7. *End* is a byte indicating the end of the packet.

By formatting topology information into this packet format, users can easily send the topology of their sensor network to the service platform for rendering in Google Maps.

Real-time Senser Data Packet

Another important information that the sink sensor will send to the service platform is the real-time sensor data. The data is the aggregation results of the cluster during one sampling period. The packet format for real-time sensor data report is defined as shown in Fig.6. where

Type	Length	Sink	Group	Node 1	Data
4 Bytes	2 Bytes	1 Byte	1 Byte	1 Byte	16 Bytes

Node2	Data	…	…	Node n	Data	CRC	End
1 Byte	16 Bytes			1 Byte	16 Bytes	2 bytes	1 byte

Figure 6: Format of the real-time sensor data

1. *Type* defines the type of the packet;
2. *Length* is the length of the whole packet;
3. *Sink ID* is the id of the sink node, always be 0.
4. *Group ID* is the id of the cluster;
5. *Node ID + Data* is real-time sensing data of one sensor node.
6. *CRC* is the Cyclic Redundancy Check;
7. *End* is a byte indicating the end of the packet.

By formatting real-time sensing data into this packet format, users can easily send the environment information to the service platform for rendering and querying.

4. DESIGNS IN SENSOR NETWORK

The interface standardization aims at providing transparent sensor network and service platform to users. However the system performances are still determined by the sensor network itself. Precision agriculture system requires the sensor network to cover large area; desires the system to be low cost and can work long time. To meet these requirements, we designed Multi-hop Joint Scheduling method for energy saving and multi-hop communication in the two-tiered sensor network[11]. When the sensor network is deployed, MJS can be established automatically. This help the user to utilize the sensor network as a transparent data sensing and transportation tool.

The basic idea of MJS is to make the LNs in the same cluster sleep cooperatively for most of time and wake up in assigned sequence for multi-hop communication. Recall that the two-tiered network is composed by a set of clusters and each cluster is centered at the gateway and contains many

LNs. After definition of the "sensor-wireless interface", the LNs sense local information with designed sensors and report the results to the gateway using desired sampling frequency. Since the sampling frequency is very low, LNs can put most of time to sleep for energy saving. However, for supporting multi-hop communication, LNs cannot sleep independently because if a LN turns to sleep, the route it serves will shut down. Therefore, we proposed multi-hop joint scheduling (MJS) method. MJS is established based on Level-based

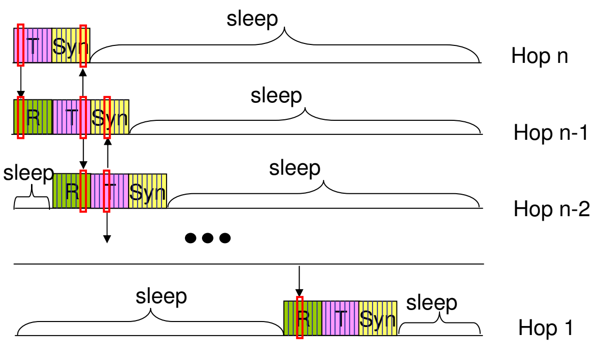

Figure 7: Multi-hop Joint Scheduling for LNs in different Levels

Energy-Balance (LEB) routing[12]. The LEB tree is constructed in the cluster initialization phase. The gateway broadcasts topology messages. The LNs receives the messages to estimate its distance from the gateway. Then each cluster is divided into n levels based on the average hop progress[13]. At the same time, the Level-based Energy-Balanced (LEB) tree is constructed during the broadcasting process. It establishes the multi-hop data transmission routes in the cluster. After these, the gateway will run a multi-hop joint scheduling (MJS) algorithm to assign task slots to LNs in different levels. The assignments help the LNs sleep cooperatively for most time and wake up in assigned sequence for multi-hop communication. Once the MJS is initialized, the LNs can maintain the slot sequence in fully distributed manner.

The MJS scheme is illustrated in Fig.7. If the largest level is n, and the sample period of each LN is divided into M task slots, the MJS works as follows.

For a ith level LN, it will sleep from its 1st to $(n-i-1)$th slots, and will activate at the $(n-i)$th slot. The active status will last three slots, and then the LN turns to sleep, till the end of the sample period. Among the three active slots,

- The first slot is used to receive messages from the child LNs in the $(i+1)$th level. We call it "R-Slot"
- The second slot is used to sense local area and forward message to a parent node in the $(i-1)$th level . We call it "T-Slot".
- The third active slot is used to synchronize time between the parent node and this node. Since the link is symmetry, when the parent node relays the message towards CH, the broadcasting will be over-heard by this child. The over-heard message is processed to synchronize time between the parent and this node. We call this slot "Syn-Slot"
- For communication collision avoidance, each slot is designed to contain m slices. In "T-Slot", the LN randomly select one slice for data transmission. Carrier sense and retransmission scheme is not used in MJS.

Once the initial active slots are assigned to LNs, LNs maintain MJS in fully distributed manner. Time synchronization is done hop-by-hop to avoid clock drifting. In "T-slot", LN broadcasts sensing data together with its local time. This broadcasting will be heard by its child nodes due to the symmetry link. These child nodes user the MAC-layer time-stamping [14] to record the processing delay and adjust their clock to the clock of their parent. With this hop-by-hop scheme, children synchronize clock with their parent, and the process repeats until the CH is reached as the last parent. Hence the clocks of the whole cluster can be continuously synchronized. And based on this, all LNs can maintain the MJS scheduling" in a fully distributed manner. For details of MJS, please refer to [11].

5. PRELIMINARY SYSTEM IMPLEMENTATION

We present preliminary system implementation results in this section. To verify the proposed methodologies, we developed LNs, GPRS gateways, and the information service platform. Our first version LN is composed by a temper-

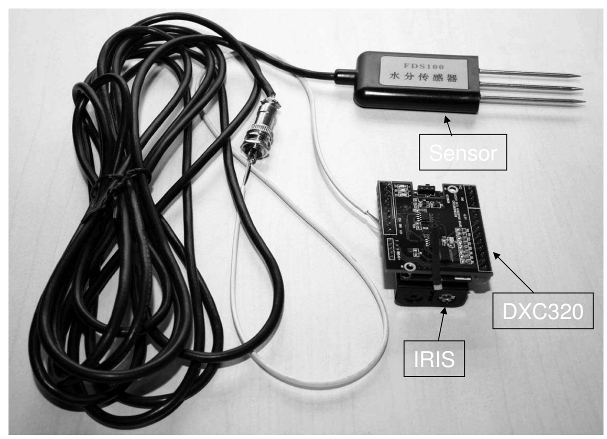

Figure 8: Composition of the LN node

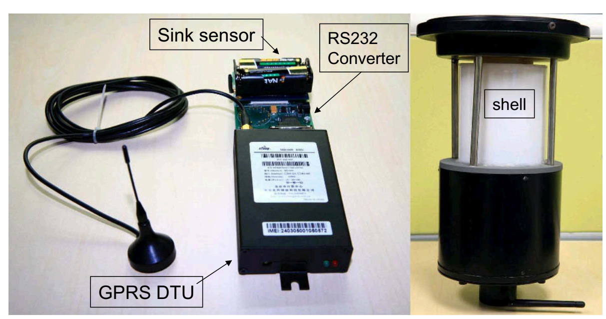

Figure 9: Composition of the gateway nod and the shell

ature sensor, a humidity sensor[15], an IRIS node[16] and a DXC320[17] data collection board. The photo of the LN node is shown in Fig.8. The device with long line is sensor. The bigger board is DXC320, and the smaller board is IRIS. The temperature and the humidity sensor provide voltage-type sensor readings to the DXC320 board. The DXC320 board provides eight ADC channels, which convert the analog voltage data from sensors to digital values. Then the digital value will be processed by the sensor-wireless interface. The sensor-wireless interface is implemented in the IRIS node. It converts the voltage values from sensors to meaningful temperature and humidity data. For example, the scope of voltage reading of the humidity sensor is $0-1500mv$; the measurement accuracy is 3%, and its transformation function is $y = f(v) = 0.05071(V - 106.9)$, therefore the interface of the humidity sensor is:

$$S(v) = \{0.05071 * (V - 106.9), \{0, 1500\}, 3\%\} \qquad (2)$$

The iris node has $128K$ flash and $8k$ RAM and has 802.15.4 radio stack. It can process and store the sensor readings and send the results via wireless communication. The communication range is about 100 meters. In our preliminary experiments, we use the XMesh [18] radio stack for multi-hop data collection.

The gateway is composed by a sink sensor, a serial converter and a GPRS DTU[19]. The composition of the gateway is shown in Fig.9. The node which looks like a black box is the GPRS DTU. It connects with a sink sensor by the serial port. The sink sensor is also an IRIS node. Because the IRIS node does't have on-board serial port, we use an serial converter to connect the sink sensor and the GPRS DTU. The GPRS DTU provides transparent data forwarding from the sink sensor to the Internet. It supports standard TCP/IP protocol, and can be always online by heartbeat signal. An WSN-Internet interface is defined in the sink sensor, as explained in Section 3.2. In the right part of Fig.9, it is the shell of the gateway node. The shell basically looks like a lawn lamp. On the top of the shell, it is the solar panel, which can provide $5V$ power to the GPRS gateway node. There is an antenna of GPRS DTU at the lower part of the shell. The shell is designed to resist rain and dirt.

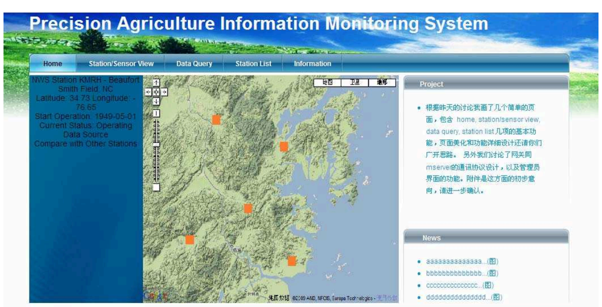

Figure 10: Homepage of agricultures monitoring

We developed the information service platform. The platform consists of a data collection daemon, a data base and a web server. The daemon processes data reception from the GPRS DTUs, and stores the received data into the database. We build the database using mySQL[20]. It maintains the sheets of LNs and gateways, which stores the historical and the real-time data. The web server is implemented by JavaScript and Tomcat. It uses the Google Earth API to render the topology information of the sensor network, and supports graphical rendering of the real-time and

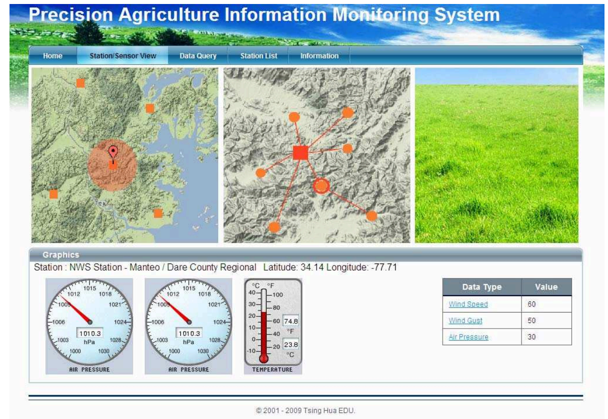

Figure 11: Real-time information of a cluster

historical data of the LNs and the gateways. The web server also supports various query forms for spatial and historical data analysis. The snapshots of the web pages are shown in Fig.10 and Fig.11. Fig.10 shows the homepage. The figure in the center part of the homepage shows the topology of the gateways in the system. When user moves the cursor onto one of the gateways, the realtime agricultrue information of the gateway will appear on the left column. The right two columns provide project information. When a gateway is clicked, the web turns to page shown in Fig.11.

Fig.11 shows the real-time information of a cluster. The gateway is the cluster head. The topology of the cluster is shown in the middle figure. The scene of the cluster area is shown in the right figure. The overview of the system is shown in the left figure. When one LN in the cluster is clicked, its realtime information will be displayed in the below part of the page. The realtime data is displayed both graphically and numerically.

The information service platform also provide functions of gateway and LN management, sensor type management, user account management. It allows user to add their gateways and LNs. If users send data of their sensor network with the standard "WSN-Internet" interface, they can easily view their agriculture information in this information service platform.

6. CONCLUSION

In this paper, we have presented an open-architecture precision agriculture information monitoring system. It is composed by two-tiered sensor network and an information service platform. In the low tier of the sensor network, a large amount of energy-limited sensor nodes (LNs) are deployed to capture and report information of their designated vicinity. In the high tier of the sensor network, some powerful GPRS gateways organize the LNs to form clusters and report the aggregated information to the Internet. The information service platform is designed to log, render and analyze the temporal and spatial agriculture information to provide value-created services. We have presented the design methodologies of OPAIMS. We proposed two standard interfaces in OPAIMS to make the system open to various users. In addition, we presented the design of multi-hop joint scheduling for LNs. Such designs make OPAIMS scalable, longevous, and also universal for various kinds of sensors.

Users can easily define their sensor and sensor network outputs using proposed interface and they can easily establish a precision agriculture monitoring system using the proposed OPAIMS.

In future work, we will focus on implementation of OPAIMS in the large scale field experiments, and to further verify the proposed methodologies in real environment. System improvement will also be pursued, including the hardware and the information service platform refinement.

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