Design and Implementation of Smart Irrigation System Based on LoRa

Wenju Zhao*, Shengwei Lin*, Jiwen Han*, Rongtao Xu†, Lu Hou*
*Intelligent Computing and Communication Lab,
Key Lab of Universal Wireless Communications, Ministry of Education,
Beijing University of Posts and Telecommunications, Beijing, China, 100876.
†State Key Laboratory of Rail Traffic Control and Safety, Beijing Jiaotong University, Beijing 100044, China.
Email: wenjuzhao@bupt.edu.cn

***Abstract*—Water resource: one of the most important natural resource problem to be paid more attention in the world in 21st Century. Irrigation method in traditional agriculture has low utilization of water resource. With the development of Internet of Things(IoT), smart irrigation system has became a new trend in the field of agricultural irrigation. This paper proposes a LoRa-based smart irrigation system. In this system, the irrigation node is mainly composed of LoRa communication module, solenoid valve and hydroelectric generator. The irrigation node sends data to cloud through LoRa gateways via wireless transmission. The system can be controlled remotely by mobile applications. Experimental results show that both transmission distance and energy consumption in the proposed system are reliable the proposed system are reliable.**

I. Introduction

IoT technology provides the interconnection of objects which have built-in computing, communication and sensing capabilities [1]. The advancement of the Internet of Things has highly facilitated its implementation in various industries such as smart agriculture, smart city, smart factory, smart healthcare, etc. As one of the important communication technologies of IoT applications, LoRa is a designed specifically for long-range, low-power communications [2]. It is a proprietary radio modulation technology licensed by Semtech Corporation. It provides long-range connectivity by using the chirp spread spectrum technique and can be operated at the ISM frequency band of 433 MHz, 868 MHz, and 915 MHz [3].

With the emergence of IoT, agriculture has advanced in the direction of automation and intellectualization [4]. Smart irrigation system can utilize water efficiently, in the precision place, at the appropriate time and in the right amount [5]. It can also optimize the electricity consumption and labor costs. However, the smart irrigation system equiped with GPRS has the problems of high power consumption and high cost of maintenance and deployment [6] [7]. On the other hand, the systems use ZigBee or Wi-Fi have the problem of low coverage [8].

In general, a LoRa Wide Area Network (LoRaWAN) can cover 20 km in rural area and around 8 km in urban area, which can ensure the high coverage of the irrigation system. Because of low power consumption, the LoRa device can operate up to ten years on battery. In the long term, it brings great benefits, such as water-saving, lower costs of maintenance and deployment. Therefore, a smart irrigation system based on LoRa technology is proposed in this paper. It is a great solution to these problems mentioned above. The proposed system is capable of communication between irrigation devices and applications through LoRaWAN. The main intention of the work is to enable applications to control the irrigation system via cloud. Irrigation node will send its status information to the gateway, and these information will be forwarded to cloud to process and store. By using cloud Application Programming Interfaces(APIs), applications can send command to control the irrigation system. Furthermore, solenoid valve in irrigation node can be charged by a hydroelectric generator. In this way, full utilization of energy can be realized.

The paper explains the design and implementation of the LoRa-based smart irrigation system in detail. The system architecture is given in Section II. Particulars on the design and implementation are discussed in Section III and Section IV. Experimental results are presented and discussed in Section V. Finally, the conclusions are presented in the Section VI

II. System Architecture

The proposed system architecture is depicted in Fig. 1. It consists of three parts, i.e., Device, Cloud and Application.

A. Device

There are two kinds of devices, i.e., irrigation node and gateway. Irrigation node is responsible for controlling and reporting status information of solenoid valve which can be the core component of this irrigation system. It sends data through LoRa to gateway, and these information are transmitted to LoRa cloud server via Long Term Evolution(LTE) network or ethernet. As a relay node, gateway is responsible for the data forwarding between nodes and server. The details of irrigation node and gateway are provided in the next section.

B. Cloud

The cloud is mainly responsible for data processing, storage and providing APIs to the applications. In order to ensure the scalability of the system, the cloud is divided into two parts, i.e., LoRa server and service server. The gateway communicates with the LoRa server directly. The communication protocol between gateway and LoRa server is User Datagram

978-1-5386-3920-7/17/$31.00 ©2017 IEEE

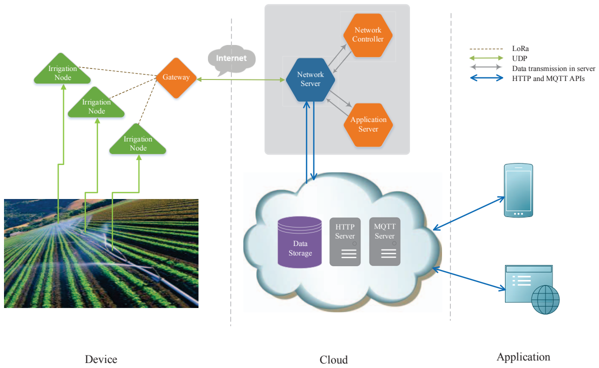


Fig. 1. Illustration for System Architecture

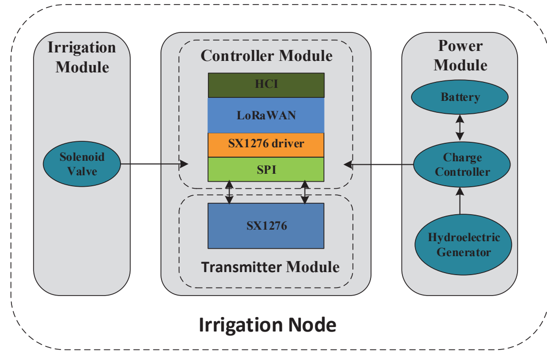
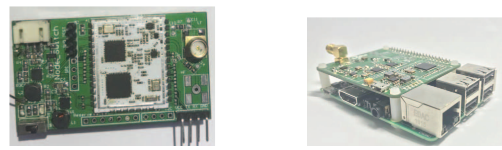


Fig. 2. Structure of Irrigation Node



(a) Irrigation Node (b) Gateway

Fig. 3. Prototypes of LoRa node and gateway

Protocol (UDP). LoRa server is responsible for validation, decryption, and analysis of data received from gateways. Cloud server is mainly responsible for data storage and implementation of HTTP and MQTT interfaces for both LoRa server and applications. LoRa server and cloud server interact with each other through MQTT and HTTP protocol. The specific implementations of server will be given in Section IV.

C. Application

By using the APIs provided by Cloud server, diverse applications can be offered in application part, i.e., web applications, mobile applications developed in Android or iOS platforms. Users can obtain the status of irrigation nodes in the field via application, and can also control the irrigation system by sending control commands through applications.

III. System Implementation

A. Device

The smart irrigation device mainly contains two parts, i.e., Irrigation Node and Gateway. Irrigation Node is used to control solenoid valve and interact with gateway. Gateway is used to transfer signals between server and irrigation node. Details on node and gateway is described as follow.

1) Irrigation Node: As shown in Fig. 2, irrigation node contains four modules, i.e., transmitter module, controller module, irrigation module and power module. The irrigation module is the switch of the solenoid valve which could be control by controller module. The control module can execute switch control instruction, track solenoid valve's state and interacte with transmitter module through LoRaWan stack and SX1276 driver. The transmitter module can interact with gateway via radio-front (RF) signal. The power module is responsible for power supplement.

a) Transmitter Module: Using Semtech's patented LoRa modulation technique, the SX1276 transceiver provides ultra long range while maintaining low current consumption. The SX1276 can achieve sensitivity of over -140 dBm using a low cost crystal and bill of materials. The high sensitivity combined with integrated +20 dBm power amplifier creates the highest link budget making it optimal any application requiring range.

b) Controller Module: The STM32L151CB Microcontroller Unit (MCU) is chosen to realize all control functions in the control module. This MCU offer two basic timers, as well as standard and advanced communication interfaces, i.e., Seral Peripheral Interfaces(SPIs) and three Universal Synchronous/Asynchronous Receiver/Transmitters(USARTs). Thus, the controller module could communicate with transmitter module via SPI interface. All these features make STM32L151CB suitable for our proposed system.

c) Irrigation Module: Hengda's solenoid valve (DN15 CR03) is made of all metal gear structure, and switching times reach over $100,000$ times. MCU can turn solenoid valve on/off by controlling its power supply. This solenoid valve's simplicity and stability make it suitable for our irrigation system.

d) Power Module: The irrigation node is powered by lithium battery, which can be charged by the hydroelectric generator (GOSO F40). When Solenoid Valve turning on, hydroelectric generator can provide about 100 mA current to charge lithium battery. The charge controller is designed to protect battery from over-charging or over-discharging. BQ24072, the main chip of charge controller, features dynamic power path managemen that powers the system while simultaneously and independently charging the battery.

2) Gateway: As shown in Fig. 4, the gateway consists of three functional modules, i.e., the host, the LoRa RF transceiver and Global Positioning System (GPS)module. The host is the bridge between LoRa RF transceiverused and LoRa server, mainly used to forward RF packets received by LoRa

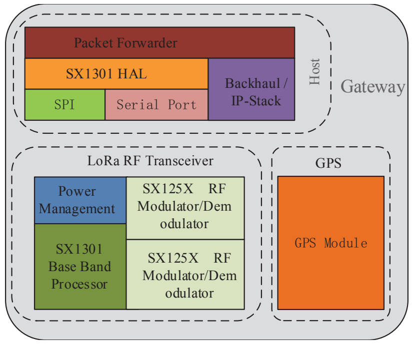


Fig. 4. Illustration of gateway structure

RF transceivers to LoRa server through UDP link and send message to LoRa RF. The LoRa RF transceiver is used to receive and demodulate RF packets, meanwhile, emit and modulate RF packets. The GPS module is used to provide location information.

a) Host: Usually, the gateway runs on an operating system, in our proposed system, we choose the Raspberry PI3 as the host. The Raspberry PI has rich interfaces, i.e., SPI, USART, I2C, etc. The host communicates with LoRa RF Receiver through SPI, and exchanges data with GPS module via USARTs.

b) LoRa RF Transceiver: RF packets are mainly processed by the LoRa RF Transceiver. It consists of three parts, .i.e, power management, SX1301 base band processor and two SX1255 RF modulators/demodulators.

- Power management is used to transfer USB-5 V to multiple voltage output.
- The SX1255 is a highly integrated RF front-end to digital I and Q modulator/demodulator, which is used to preliminarily process of RF signals.In this system,the gateway has two SX155s, they can receive RF signals at the same time, however, only one can be used to emit RF signals.
- The SX1301 digital baseband chip is a massive digital signal processing engine, designed to offer breakthrough gateway capabilities in the Industrial Scieneific Medical(ISM) band worldwide. It has 10 programmable parallel demodulation paths to ensure massive node intervention. It is responsible for packet handling and exchanging data with the host via SPI principally.

c) GPS module: The GPS module is used to provide timestamps to the host, meanwhile supply the latitude, longitude and altitude infrmation of the gateway.

B. Cloud

In our system, LoRa server is divided into three parts as shown in Fig. 1.

1) LoRa Network Server: Network Server (NS) is responsible for the gateway protocol translation as a component that interacts directly with gateway. NS is considered as the process control center in LoRa server. NS is responsible for sending data which received from the gateway to Application Server(AS). Then, it will publish the processed data to the service server by the Message Queuing Telemetry Transport (MQTT) protocol. At the same time, NS acts as a subscriber of control commands sent by applications and forwards user's control commands to the gateway.

2) LoRa Application Server: AS is the data processing module in LoRa server, which is responsible for data deduplication, MIC verification, decryption, encryption and extraction. After a series of data processing operations, AS will return the core data to NS. Besides, AS is responsible for device activation and registration. Especially, when using Over-The-Air-Activation (OTAA) mode, a node sends join request to server before sending normal data.

3) LoRa Network Controller: The LoRa server provides a packet type named MAC command which can be used to config nodes and gateways in LoRaWAN. Besides, data, the status information of the gateway and node will be sent to NC by NS. NC is responsible for RX and TX packet settings. When received MAC command, NC can make Adaptive Data Rate (ADR) configuration to specific nodes, and can also do dynamic routing configuration for the gateway which guarantees the flexibility of this system structure. In addition, data storage and APIs are implemented by cloud server.

4) Data Storage: Cloud server uses Redis and MySQL to store data. By Storing all key-value data in the memory, Redis can highly increase I/O speed. MySQL database can store the relation among devices and applications. Storage in cloud server provides data persistence and querythe services of data persistence and querying.

5) HTTP and MQTT APIs: HTTP and MQTT APIs are used for both LoRa server and applications to send or get data. The data of mobile applications is fetched by a HTTP request and returned in JSON format. For LoRa Network Server, the data is sent by a publish operation in MQTT and fetched from MQTT broker when NS has subscribed related topics.

C. Application

As mentioned above, a mobile Application can be used to control the smart irrigation system. We provide both Android and iOS application to interact with the cloud platform. A mobile application mainly provides three functions, i.e., view device status, send on/off command in schedule, control devices in group. An Android Application is provided by Fig. 5.

IV. Design of Smart Irrigation System

Smart irrigation system contains four parts, i.e., App, Server, LoRa Gateway and Irrigation Node. Our design is shown in Fig. 6, user can use App to send command to irrigation node. The App can control the time on/off of the irrigation node. Meanwhile, user can set the time for the irrigation node to open or turn on/off irrigation nodes regularly through App. Besides, user can pull multiple irrigation nodes into a packet, if that, a control command is issued to a plurality of devices

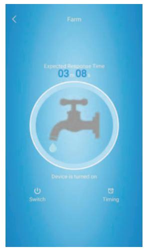


Fig. 5. A sample of App display

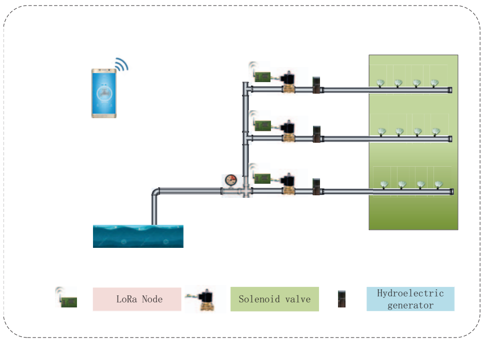


Fig. 6. Illustration of the proposed irrigation system

within the packet at the same time. When the solenoid valve is open, the hydroelectric generator is driven by hydrostatic pressure which can charge the battery in LoRa node.

The detail of work flow is shown in Fig. 7.

1) Check the irrigation node state and the time of the irrigation node send up-link packet. If the command is same with the current state of irrigation nodes, the server will not send down-link command to gateway.
2) Server processes the packets from cloud, and distinguish group command messages. Group command messages will send to multiple irrigation nodes by gateway. If not, command message will send to specific irrigation node.
3) Gateway send command to specified nodes after irrigation node report the latest state.
4) Irrigation node will change the sleep time cycle into 2 minutes if the irrigation node receive open command, meanwhile storage the time into backup register. Besides, the irrigation node will change the sleep time cycle into 10 minutes if the irrigation node receive the off command.
5) The irrigation node will report the latest state after all the operations has been performed.

As shown in Fig. 8, we assemble a smart irrigation display platform based on smart irrigation system design scheme. It works well in the last few months.

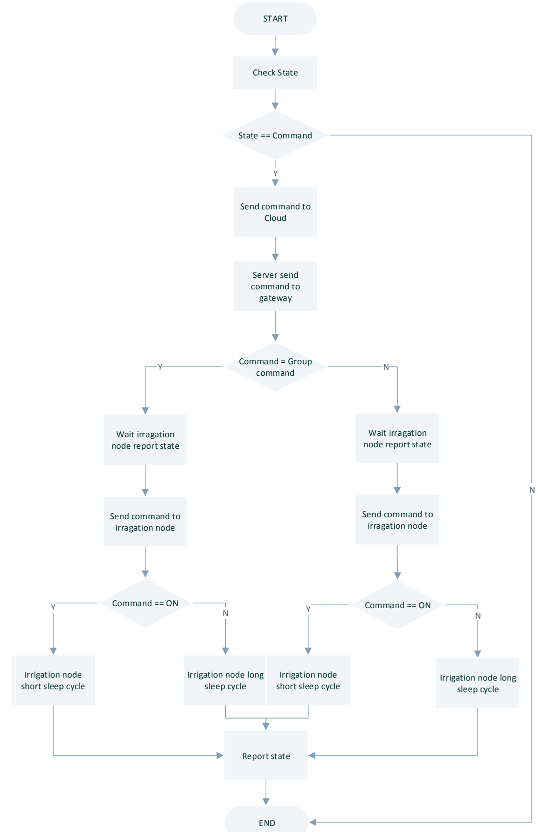


Fig. 7. Work flow of the proposed system

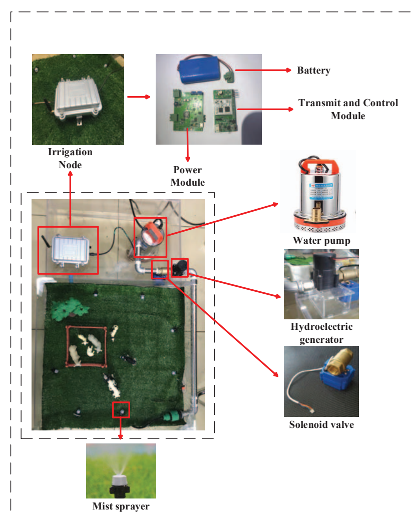


Fig. 8. Smart Irrigation System Display

V. Experimental Results and Analysis

A. Transmission performance

The transmission distance experiment is carried out in Beijing typical urban environment. The antenna of Gateway is installed on the roof of central building in an university. Gateway operates at frequency band of 433 MHz, the Irrigation node main parameters setted in field tests are listed in Table I. As shown in Fig. 9, the uplink RF signal quality including RSSI and SNR are measured every 0.5 km.

The experimental results are shown in Fig. 10(a) and 10(b). The RSSI decreases sharply within 0.5 km, while it tends to be stable in range of remaining 7.5 km. The SNR decreases

TABLE I
NODE PARAMETERS SETTING

Parameters	Value
Modulation scheme	LoRa
Carrier frequency	433 MHz
Preamble	8 $bytes$
Transmit power	20 dBm
Coding Rate	4/5
Spreading factor	12

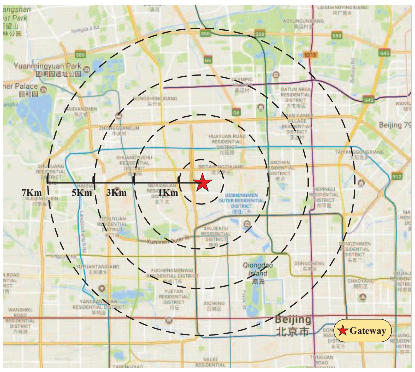
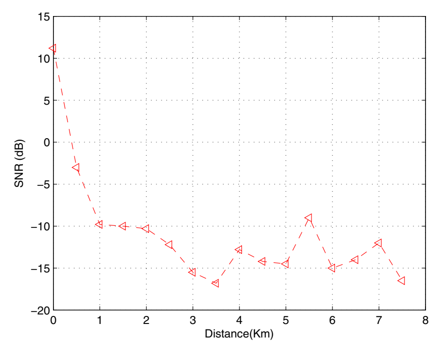
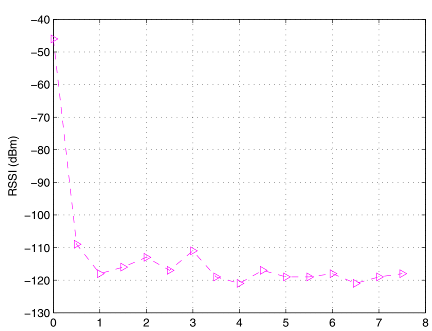


Fig. 9. Map of field tests



(a) Transmission Distance - SNR



(b) Transmission Distance - RSSI

Fig. 10. Performance on SNR and RSSI under different transmission distances

20 dBm in the first 1 km, while it decreases slowly in the last 7 km. After the uplink RF signal's RSSI decreasing to -118 dBm and SNR decreasing to -16.5 dBm, the node's uplink RF signal can't be received by gateway any more.

B. Energy Consumption Performance

This test consists of two parts, i.e., water turbo charging and power consumption in different operative mode. Meanwhile, whether our system is self-sufficient can be verified by this test.

1) Power consumption in different operative modes: The measurements of the nodes in our smart irrigation system include the operating current and duration in different operative modes. According to the different power consumption the irrigation node can be divided into three modes: on/off mode, maintain original state mode and timing off mode.

a) On-Off mode
According to LoRa protocol, after the node send uplink data to gateway which will open receive window to receive down-link packets. In this system, when the node wakes up, the node will report current state immediately. Then, it will implement down-link control message and go into long or short sleeping duration.

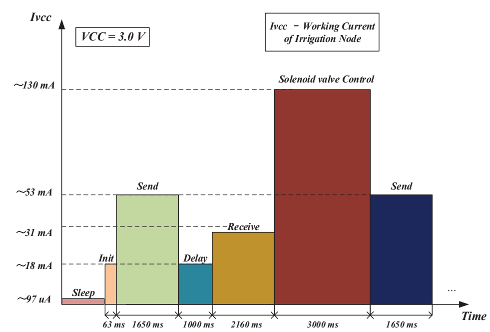


Fig. 11. On-Off Mode Consumption

b) Maintain original state mode
In this mode ,the solenoidvalve maintain original state. Only data reporting or don't receive down-link message or receive the command that does not change current status.

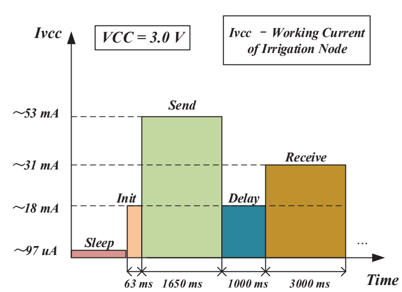


Fig. 12. Maintain Previous State Mode Consumption

c) Timing off mode
The original state of solenoid valve is open, when it opens to specified time, the node wakes up and changes the state to close, meanwhile, reports states. Then, the node goes into long sleep cycle.

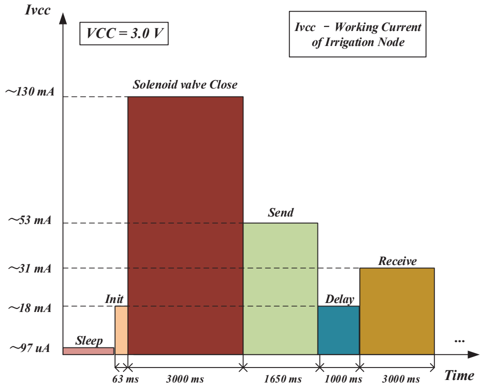


Fig. 13. Timing Off Mode Consumption

TABLE II
WATER TURBO CHARGE

Resistance value ()	Voltage (mV)	Current (mA)
2	92	46
2	96.5	48.25
2	92.6	46.3
2	98.1	49.05

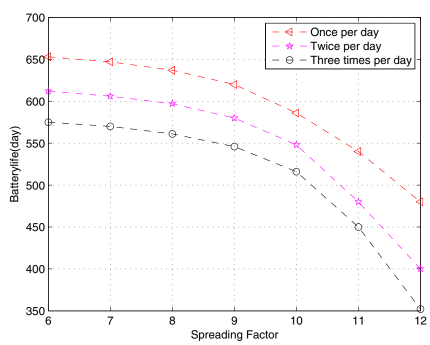


Fig. 14. Battery Life in Different Situations

2) Water turbo charging: When the solenoid valve is open, the charging device of the turbo can charge lithium battery of the node. In this test, hydraulic pressure is $0.2\ Mpa$. Series a minimum resistance in the road input, the voltage can be measured when it runs via the resistor. The charging current can be calculated by voltage. The charging voltage with load is $6.7\ V$, and the voltage of lithium battery is $3.6\ V$. Test results as shown in Table. II.

3) System without water turbo charge: This system is powered by lithium battery with $4,800\ mAh$. According to the numbers of the solenoid valve is turned on per day, battery life can be calculated as shown in Fig. 14.

4) System with water turbo charge: As shown in the table above, the minimum battery life can be chosen to verify whether this system can self sufficient. If the solenoid valve turns on 30 minutes per operation, the charge can be calculated. The charge is about $45\ mAh$ per operation.

According to the calculations, the energy consumption is lower than the charge, thus, this system can realize self-sufficient.

VI. Conclusion

The communication technologies of IoT play a very important role in smart agriculture system. This paper proposes a smart irrigation system based on LoRa technology. In order to validate the excellent performance of the proposed irrigation system, experiments have been carried out. Experimental results validate the applicability of the proposed system. At the same time, the advantages of LoRa technology adopted in smart irrigation system have been shown by experiments. The system proposed by us facilitates more efficient, also minimizes the cost of deployment and maintenances. According to the experimental results, the irrigation node equipped with hydroelectric generator can operate up to for decades. The communication distance between the irrigation node and gateway is up to $8\ km$, thus the irrigation system can cover up to 200 hectares. By mobile App, users can control the irrigation system remotely and check the status of system in time. It is believed that adopting LoRa technology to smart irrigation system will significantly simulate development of smart agriculture.Of course, we have a lot of follow-up work to do to make the system more intelligent and precise controlling.

VII. Acknowledgment

This work supported by China Unicom Project and the National Natural Science Fundation of China (61671089).

References

[1] L. Atzori, A. Iera and G. Morabito, "The Internet of Things: a survey," *Computer Networks: The International Journal of Computer and Telecommunications Networking*, vol. 54, no. 15, pp. 2787-2805, Oct. 2010.

[2] K. Zheng, S. Zhao and Z. Yang, "Design and Implementation of LPWA-Based Air Quality Monitoring System," *IEEE Access*, vol. 4, pp. 3238-3245, June 2016.

[3] K. Nolan, W. Guibene and M. Kelly, "An evaluation of low power wide area network technologies for the Internet of Things," *International Wireless Communications and Mobile Computing Conference*, Sept. 2016.

[4] M. Roopaei, P. Rad and K. Choo, "Cloud of things in smart agriculture: intelligent irrigation monitoring by thermal imaging," *IEEE Cloud Computing*, vol. 4, no. 1, pp. 10-15, Mar. 2017.

[5] K. Raju and G. Varma, "Knowledge based real time monitoring system for aquaculture using IoT," *IEEE 7th International Advance Computing Conference*, July 2017.

[6] N. Sales, O. Remedios and A. Arsenio, "Wireless sensor and actuator system for smart irrigation on the cloud," *IEEE 2nd World Forum on Internet of Things*, Dec. 2015.

[7] K. Zheng, F. Liu and L. Lei, "Stochastic Performance Analysis of a Wireless Finite-State Markov Channel," *IEEE Transactions on Wireless Communications*, vol. 12, no. 2, pp. 782-793, Feb. 2013.

[8] K. Zheng, H. Meng and P. Chatzimisions, "An SMDP-Based Resource Allocation in Vehicular Cloud Computing Systems," *IEEE Transactions on Industrial Electronics*, vol. 62, no. 12, pp. 1557-7928, Sep. 2015.