# Testbed implementation of cloud based energy management system with ZigBee sensor networks

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***Abstract*— Energy management systems are focused to achieve efficient electricity control in smart grid systems. In order to achieve the effective systems, various functions such as sensing mechanisms, control mechanisms, management mechanisms and user interface mechanisms are required. In this paper, we employ Arduino micro-computer as basic field devices and use virtual private server services for cloud server in order to construct a testbed system. Our testbed can provide an environment measurement function, a JEM-A equipments control function, an online monitoring function and an online control function. As the results, we show that it is a good fundamental platform to consider effective energy control mechanisms in real fields.**

***Keywords*— Energy management systems, Wireless sensor networks, Online control, JEM-A**

## I. Introduction

EMS (Energy management systems) are an important function to achieve efficient control of electricity in smart grid systems. Therefore, BEMS (Building Energy Management System) for buildings and HEMS (Home Energy Management System) for homes have drawn attention as application technologies [1], [2]. Generally, they consist of various functions such as sensing mechanisms, control mechanisms, management mechanisms and user interface mechanisms. As the results, collaboration of these technologies are key issues to achieve useful systems [3], [4].

In EMS, sensing mechanisms measure environment information such as consumed energy, air temperature, air humidity etc. For these purposes, sensor network systems are a good candidate technique [5]. Especially, wireless sensor networks are well suited to these purposes because it's easy to install sensor devices in real fields [6]. Control mechanisms monitor a status of each equipment such lighting, HVAC (heating, ventilation and air conditioning), and other systems, to provide improved convenience, comfort, energy efficiency and security. etc. , and control their operation status [7], [8]. In Japan, commercial equipments usually implement JEM-A terminals [9] for monitoring and controlling. Additionally, ECHONET Lite [10] is decided as a new standard for these purposes due to the shortage of electrical power. However, equipments with ECHONET Lite functions are quite few in the present circumstances. Therefore, JEM-A is a good candidate standard for control mechanisms at this time. Management mechanisms gather the sensing information and make a decision for equipment control. User interface mechanisms provide a control method for users. Especially, remote control mechanisms are useful function to provide improved convenience according to the installation of EMS. In each mechanism, various studies have been considered recently. However, implementations including whole mechanisms are quite few.

In this paper, we develop a cloud based energy management system with wireless sensor networks and JEM-A equipments. The system consists of wireless sensor devices, a management gateway, a cloud management server and user interface terminals. Each wireless sensor device can measure environment information by using equipped sensors and transmits the measured information to the management gateway. The management gateway can make a decision for operations of each equipment by using JEM-A terminals, and forwards the measured information to the cloud management server. Therefore, the cloud management server also controls each equipment through Internet. Additionally, it provides web services for user interface terminals. Therefore, users can monitor the measured information and operation status of each equipment, and control them online.

## II. Cloud based energy management system

### A. System Model

Fig. 1 shows the overview of the proposed cloud based energy management system. We employ Arduino [11], which is a micro computer device, as wireless sensor network devices and a management gateway device because power consumption of Arduino is quite low and hardware cost is also inexpensive. As wireless communication devices, Xbee, which supports ZigBee protocol, is used for these devices. The cloud management server is constructed on virtual private server services. Therefore, the user interface terminal can access to the cloud management server through Internet. The explanation about each device is described as the followings.

- Wireless sensor device
  The wireless sensor device consists of an Arduino Fio, a Li-ion battery, an Xbee Pro and some sensors for air

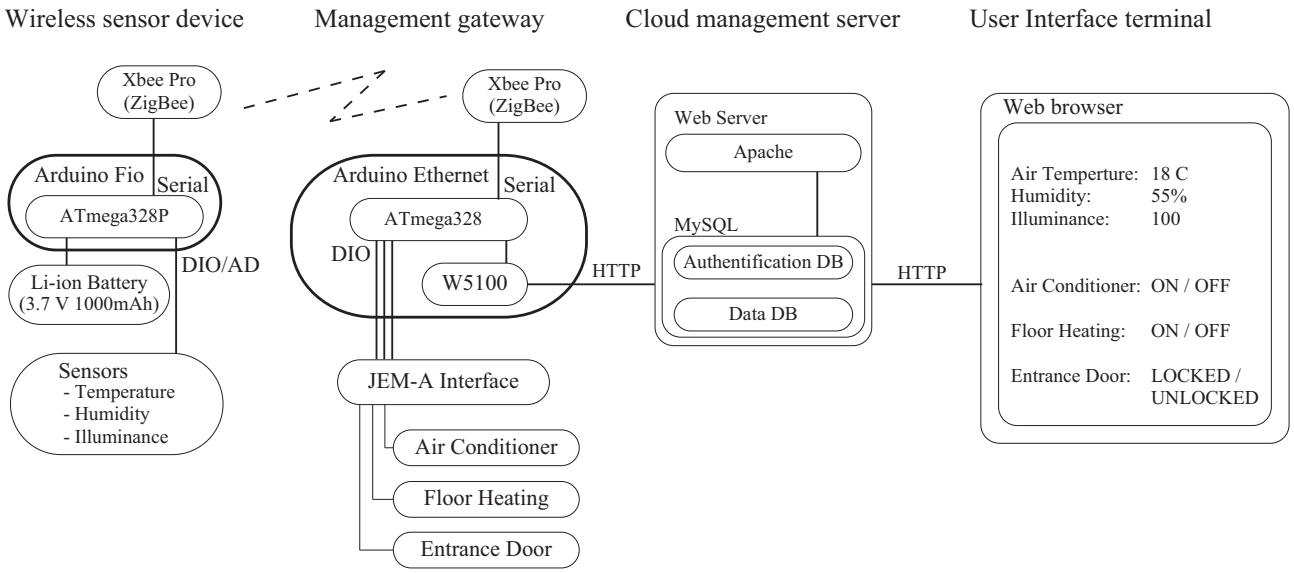


Fig. 1. System model.

temperature, humidity and illuminance. By employing deep sleep operations, it operates for more than one month even if it transmits the measured information with one minute interval. Since frequent measurement is not required in the practical usage, the wireless sensor device can operate for a few months by one time charge. Additionally, Arduino Fio supports solar panel charging. Therefore, it is possible to extend the operation period by using a solar panel.

- Management gateway
  The management gateway consists of an Arduino Ethernet, an Xbee Pro and the original JEM-A interface. The Arduino Ethernet has an ethernet interface, and suports the TCP/IP protocol stack. The management gateway also has a Hypertext Transfer Protocol (HTTP) client function and a HTTP server function. The HTTP client function is used to forward measured information to the cloud management server. The HTTP server function is used to response requests from the cloud management server. In the testbed, air conditioner, floor heating system, and electronic key system are connected via JEM-A interfaces. Therefore, the Arduino Ethernet has the original interface board between JEM-A and Digital Input/Output ports.
- Cloud management server
  The cloud management server consists of a web server function and a database server function. The web server receives the forwarded measured information from the management gateway and registers the IP address of the management gateway. It also provides a web service for user interface terminal to monitor the measured information and control the equipments under the management gateway.
- User interface terminal
  Users can access to the cloud management server by using web browser. So, almost all terminal can support these functions because the user interface is provided based on HTML5.

### B. Flowchart

Fig. 2 shows the flow charts of the wireless sensor device and the management gateway. The following is the process of each device.

*Wireless sensor device:* The wireless sensor device performs the following operations.

- Initialization of device
  The wireless sensor device initializes I/O ports of Arduino and Xbee device after bootup. Finally, it starts the watchdog timer of Arduino to monitor the operation status of own device. The watchdog timer is refreshed when each wakeup process occurs. Therefore, the device will restart when the watchdog timer is not refreshed due to software issues.
- Periodic monitoring
  The wireless sensor device measures values such as temperature, humidity, illuminance etc. by using some sensors. The measurement is performed periodically according to predefined parameters.
- Periodic reporting
  The wireless sensor devices calculates the average value of measured value, and report the averaged value to the management gateway. The interval of reporting is set according to the predefined parameters.

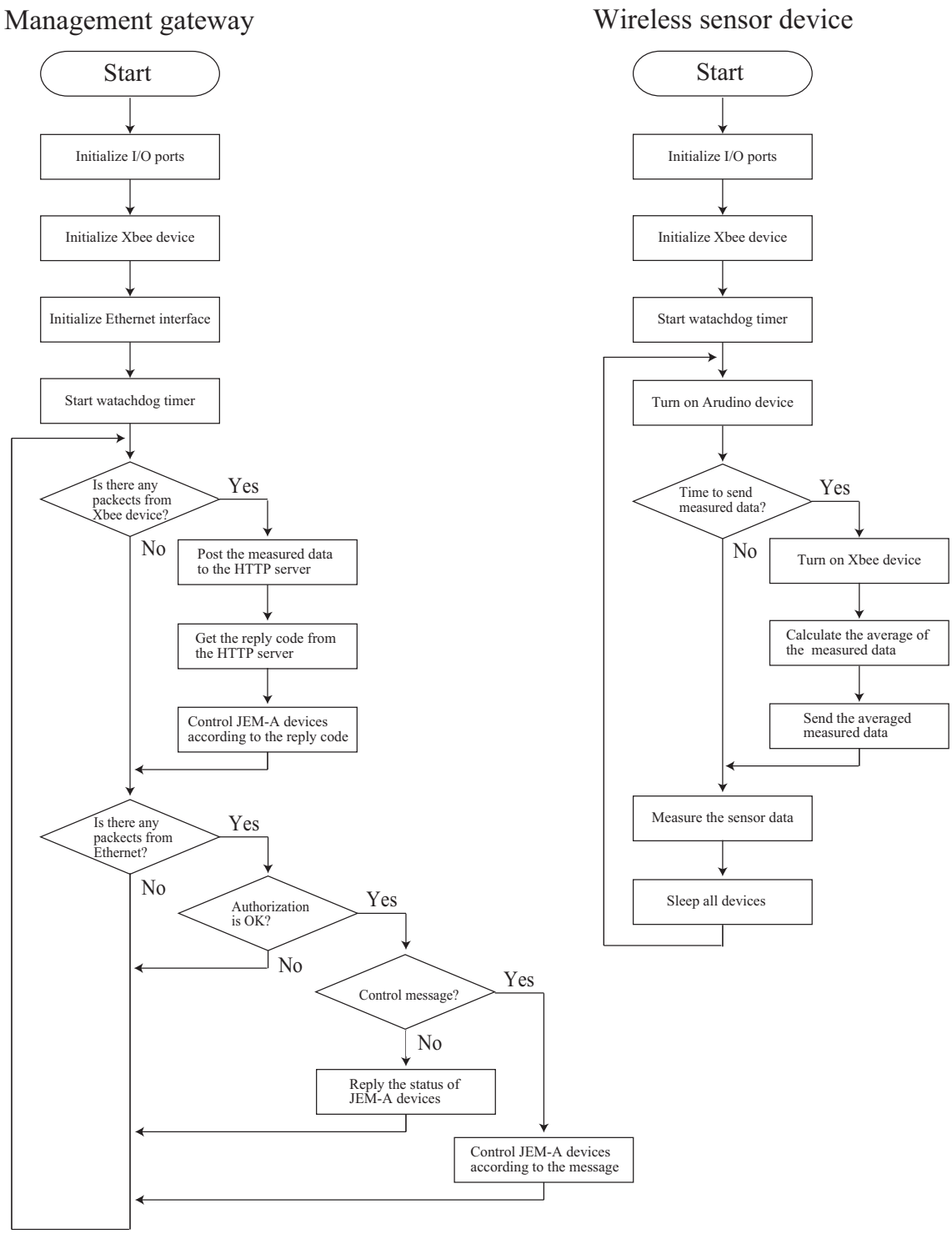


Fig. 2. Flow charts of wireless sensor device and management gateway.

- Sleep operation
  The wireless sensor device turn off all devices to change the device status to sleep status after monitoring or reporting operations.

*Management gateway:* The management gateway performs the following operations.

- Initialization of device
  The wireless sensor device initializes I/O ports of Arduino, Xbee device and Ethernet interface after bootup.

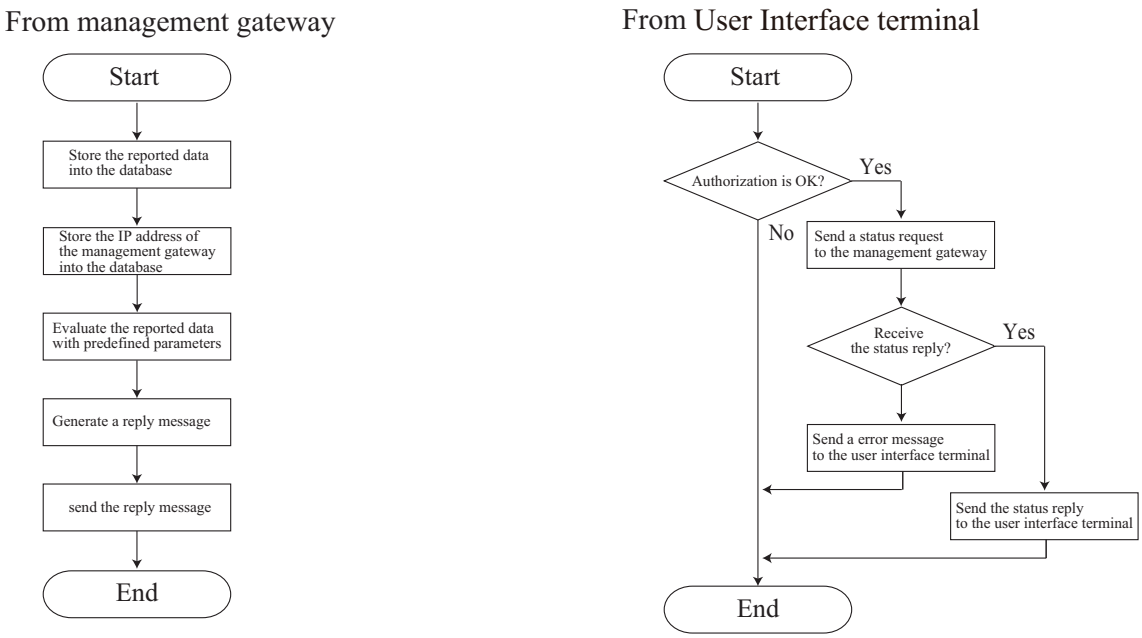


Fig. 3. Flow charts of cloud management server.

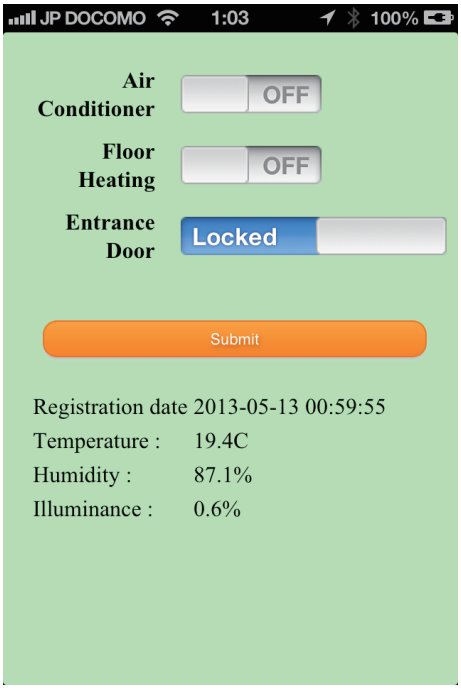


Fig. 4. User interface.

Finally, it starts the watchdog timer of Arduino to monitor the operation status of own device.

- Packet reception from the wireless sensor device
  The management gateway checks the buffer of Xbee. It receives packets from Xbee when Xbee has some data packets from the wireless sensor device. Then, it generates HTTP message including the average measured data according to the received packets, and sends to the cloud management server. The cloud management server replies the reply message including control direction for JEM-A devices. The management gateway controls JEM-A devices according to the reply message. As the results, the cloud management server can control some JEM-A devices according to the monitored data.
- Packet reception from the cloud management server
  The management gateway authorizes the message when it receives packets from the cloud management server. It replies the status of JEM-A devices when the message requests the status. It controls the JEM-A devices when the message requests to control the devices.

*Cloud management server:* Fig. 3 shows the flow charts of the cloud management server.

- Packet reception from the management gateway
  The cloud management server stored the reported data into the database when it receives the packets from the management gateway. Then, it stores the IP address of the management gateway into the database according to the source address in the packets. The IP address is required to communicate with the management gateway when it receives packets from the user interface terminal. It also evaluates the reported data with the predefined parameters such as threshold and operations. For examples, users can set that the air conditioner should be turned on when the temperature is more than 28 degrees Celsius. It generates the reply message according to the predefined parameters,

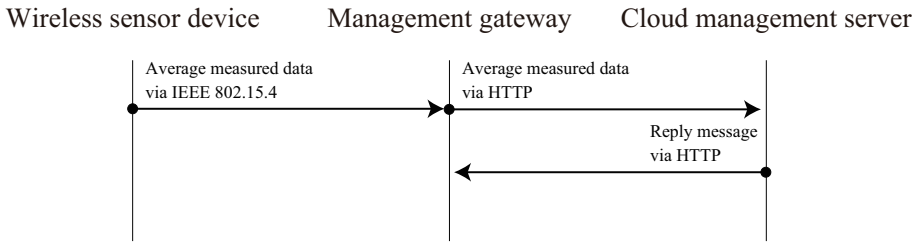


Fig. 5. Signaling for reporting measured data.

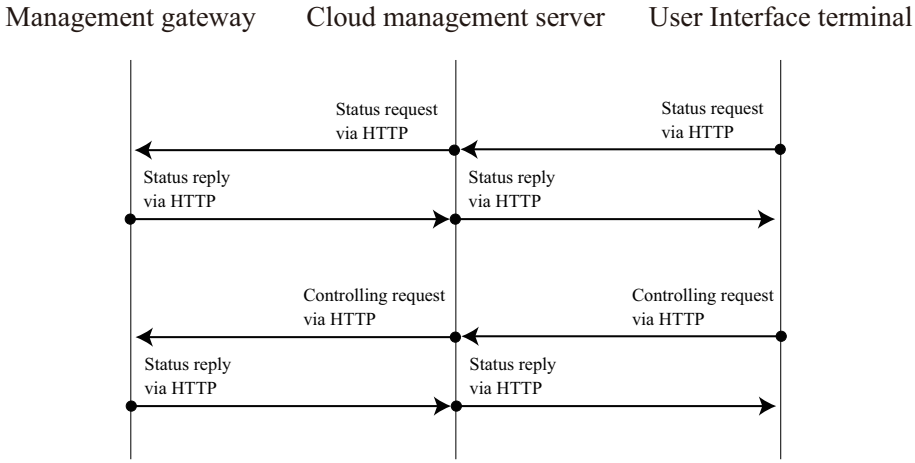


Fig. 6. Signaling for controlling devices.

and replies to the management gateway.

- Packet reception from the user Interface terminal
  The cloud management server requests the authorization to the user interface terminal when it receives the packets from the user Interface terminal. It requests the management gateway to report the status when it confirms the authorization. Then, it replies the message including the status of each JEM-A devices such as Fig. 4. It also sends the message including the control request of JEM-A devices when the user interface terminal submits the request to change the status of JEM-A devices.

### C. Communication process

*Periodic reporting:* Fig. 5 shows the signaling for reporting measured data. The wireless sensor devices report the measured data periodically. Each signaling for reporting the data is performed individually. Therefore, it sends the measured data via Xbee devices. The unicast mode in Xbee devices supports an acknowledgement operation. Hence, it recognizes the transmission errors between the management gateway and own device. The management gateway converts the measured data from IEEE 802.15.4 protocol to HTTP. The cloud management sever replies the message when it receives the HTTP message from the management gateway. Finally, the management gateway can receive the reply message including

controlling request for JEM-A devices.

*Controlling devices:* Fig. 6 shows the signaling for controlling devices. The user interface terminal accesses the cloud management server via HTTP. The cloud management server requests the authorization of users. The user interface terminal posts the authorization data to the server. The server accesses the management gateway to check the status of JEM-A devices when the user is authorized. Then, it replies the status of JEM-A device to the user interface terminal. The user interface terminal also sends the controlling request when the user requests to control JEM-A devices. The server also sends the controlling request to the management gateway to control the JEM-A devices. The management gateway replies the status of JEM-A devices when it has controlled them according to the controlling request.

## III. EXPERIMENTAL EVALUATION

In order to evaluate the proposed mechanisms, we have developed the testbed implementation.

### *Wireless sensor device*

We employ Arduino Fio which is a small energy consumption microboard. It operates by Li-ion battery, and supports sleep operation to reduce consumed power. It also employs a Grove Temperature and Humidity Sensor Pro which are a 1-wired digital sensor, and Grove Light Sensor which is a analog sensor. Therefore, it can monitor temperature, humidity and illuminance periodically. As the wireless communication device, we employ Xbee Pro Series 2 which is ZigBee based long-range communication device. The Xbee operates as end device mode of ZigBee to achieve sleep operation. The sleep operation of Xbee is controlled through the digital input pin for sleep operation by Arduino Fio.

### *Management gateway*

We employ Arduino ethernet with the wireless shield connecting to Xbee Pro Series 2. It operates by AC adapter because it waits for an access from the cloud management server and Xbee operates as coordinator mode. The IP address of ethernet interface is fixed according to the predefined address. Therefore, a global IP address or a port forwarding mechanism is required to access the management gateway from the cloud management server. In the experiment, we set a private IP address and port forwarding setting at a gateway router.

### *Cloud management server*

We employ Cent OS on a virtual private server service. The apache web server and postgreSQL database server are used to create web applications. The application is written in PHP.

### *User interface terminal*

Our user interface is provided as the web application using HTML5. Therefore, almost all browsers can use the web application on the Cent OS. In the experiment, we use iPhone 4s as the client device to access the could management server.

## IV. CONCLUSION

In this paper, we have implemented the cloud based energy management system based on Arduino which is an open-source electronics prototyping platform and virtual private server services. The system supports measurement of environment information, data collection, operation control based on the measured information, remote monitoring and remote control. From the testbed, our developed system can achieve remote monitoring and remote controlling of JEM-A devices from various kind of browsers. As the results, we can confirm that the proposed system can work well as EMS and can be the fundamental platform for the intelligence energy management.

## ACKNOWLEDGMENT

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