# IOT Gateway: Bridging Wireless Sensor Networks into Internet of Things

Qian Zhu*†, Ruicong Wang*†, Qi Chen*†, Yan Liu* and Weijun Qin†
*School of Software and Microelectronics, Peking University, Beijing 102600, China
†Wireless Ad-hoc Sensor Networks Lab, Institute of Software, Chinese Academy of Sciences, Beijing 100190, China
Email: zhuqian@is.iscas.ac.cn, wangruicong@is.iscas.ac.cn, chenqi@is.iscas.ac.cn, ly@ss.pku.edu.cn, qinweijun@is.iscas.ac.cn

***Abstract*—With the development of sensor, wireless mobile communication, embedded system and cloud computing, the technologies of Internet of Things have been widely used in logistics, SmartMeter, public security, intelligent building and so on. Because of its huge market prospects, Internet of Things has been paid close attention by several governments all over the world, which is regarded as the third wave of information technology after Internet and mobile communication network. Bridging between wireless sensor networks with traditional communication networks or Internet, IOT Gateway plays an important role in IOT applications, which facilitates the seamless integration of wireless sensor networks and mobile communication networks or Internet, and the management and control with wireless sensor networks. In this paper, we proposed an IOT Gateway system based on Zigbee and GPRS protocols according to the typical IOT application scenarios and requirements from telecom operators, presented the data transmission between wireless sensor networks and mobile communication networks, protocol conversion of different sensor network protocols, and control functionalities for sensor networks, and finally gave an implementation of prototyping system and system validation.**

***Keywords*-gateway; IOT; WSN; Zigbee; GPRS**

## I. Introduction

The Internet of Things is regarded as the third wave of information technology after Internet and mobile communication network, which is characterized by more thorough sense and measure, more comprehensive interoperability and intelligence. The technologies of the Internet of Things can effectively facilitate the integration of material production and service management, the integration of the physical world and the digital world. With development of IOT technologies, the most important IOT application areas cover infrastructure construction, public security, environment protection, modern agriculture, intelligent industry, urban management, business service and other fields[1].

In 1999, MIT Auto-ID Labs first proposed the concept of the Internet of Things, which investigates to realize object localization and state recognition using wireless sensor networks and radio frequency identification technologies[2]. In 2005, International Telecommunication Union (ITU) released 'ITU Internet Report 2005: Internet of Things', formally proposed the concept of the Internet of Things, which noted that ubiquitous Internet of Things communication era dawned, in which all objects in the world can exchange information via the networks actively[3]. In 2009, IBM presented the "Smart-Planet" concept which aims to embed sensors in several physical objects such as power grid, railway, buildings, and make them smart by intelligent processing technologies[4]. From the perspective of information technology, Internet of Things is a huge global information system composed of hundreds of millions of objects that can be identified, sensed and processed based on standardized and interoperable communication protocols. With the support of broadband mobile communication, next generation networking and cloud computing technologies, the IOT system can intelligently process the objects' state, provide management and control for decision-making, and even make them cooperate with each other autonomously without human's intervention.

Nowadays, the traditional mobile communication network and Internet are mainly used in the transmission of information among people, while the WSN can realize the short-distance communication among the objects by constructing wireless networks in ad-hoc manners. However, it's difficult to connect the WSN and mobile communication networks or the Internet with each other because it lacks of uniform standardization in communication protocols and sensing technologies and the data from WSN cannot be transmitted in long distance with the limitation of WSN's transmission protocols. Therefore, with the development of the Internet of Things, a new type of network equipment called the Internet of Things Gateway is invented, whose goal is to settle with the heterogeneity between various sensor networks and mobile communication networks or Internet, strengthen the management of the WSN and terminal nodes, and bridge traditional communication networks with sensor networks to make network communication easier and manage the devices of sensor networks. Therefore, the key issues of implementing IOT Gateway system is to address the heterogeneity of different sensor networks and diversity of protocols in the WSN and traditional telecommunication networks. Besides, it's necessary to build a suite of uniform identified instructions and standards for all the IOT Gateways in order to realize the functionality of IOT management and control.

The rest of the paper is organized as follows: Session II starts with related works of IOT Gateway system and standards. Session III introduces a use scenario of IOT appli-

978-0-7695-4322-2/10 $26.00 © 2010 IEEE
DOI 10.1109/EUC.2010.58

cation in smart home, presents the typical WSN-based IOT application architecture and characteristics of IOT Gateway. The system requirements and software architecture of IOT Gateway system are given in Session IV. Session V gives the initial implementation issues and finally some concluding remarks are made in Session VI.

## II. RELATED WORKS

There are already some academic and industrial works on standardization and design of IOT Gateway system. Domestic and international telecom operators have launched related business in applications combining WSN and telecommunications networks, conducted active exploration according to the demands of industrial users. Among the foreign standardization organizations, ETSI M2M TC[5] and 3GPP all established related standards. ETSI M2M TC's main goal is to do some research on M2M(Machine-To-Machine) standardization, who have already further their works on the existing achievements of 3GPP and ETSI. ETSI M2M TC now focuses on M2M's definition and application examples, with this basis, proceeds business requirements and standardization, but didn't address any specific technology yet. 3GPP launched research team on M2M in 2005. Its main work is to discuss the demands, feasibility and framework. Meanwhile, domestic enterprises also carried out equipment specification work in accordance with the standardization work abroad. China Telecom also announced the MDMP protocol for WSN terminal management, and carried out demonstrating applications in agriculture and smart home.

As for design and implementation, Shanghai Research Institute of China Telecom proposed a home system of IOT, which indicated that gateway was the core unit of information gathering and control, Shanghai Research Institute of China Telecom summarized that the key features of gateway system were protocols conversion, state control, information gathering, terminal addressing and authentication[6]. Web of Things architecture was proposed in [7], through the intelligent gateway, the real objects can be transformed into RESTful resources to be integrated into the existing systems, in order to be directly accessed by external HTTP hosts. Intelligent gateway interacts with sensor nodes via Bluetooth, which allocates URL for sensor nodes, forwards the collected perception data to Web server through HTTP packets including JSON data segment, thus, linking the sensor network and traditional telecommunications network[7]. In a word, in the existing systems related to IOT, gateway plays a leading role, basically, implementing the functions of data transmission and forwarding. However, the management and control issues are less considered.

## III. IOT GATEWAY

### A. Use Scenario

The application of Internet of Things covers logistics, SmartMeter, intelligent building and so on, we illustrate IOT

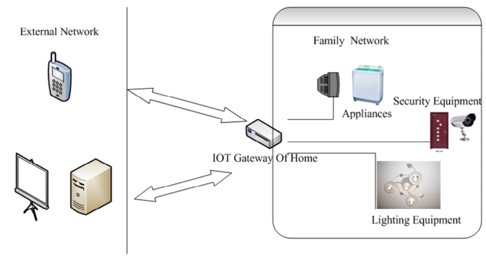


Figure 1. Use scenario in smart home

Gateway with smart home, which is a typical IOT application. Smart home is a new type house which is embedded with sensors, information home appliances, network communications and automation equipment, etc. in order to provide a comfortable, safe, green, convenient living environment. With the development of sensors, micro-motor system, wireless communication, the intercommunication among the embedded equipments in smart home becomes easier. On one side, the in-home IOT Gateway plays a very important role in interconnecting multiple smart devices together to form in-home network and share resources and information among various home appliances. On the other side, in-home IOT Gateway also plays another role to connect the external networks to the in-home network, and provides the access interface to the external networks as the Fig. 1 shown. In this scenario, several common home appliances, such as TV set, washer, lights, camera, which are embedded with sensor and wireless communication modules, can construct several ad-hoc in-home wireless networks. The in-home IOT Gateway integrates several common ad-hoc network protocols and supports the intercommunication among the equipments with different network protocols. The users can control the in-home smart equipments through the IOT Gateway. Besides, the in-home IOT Gateway also integrates 2G/3G mobile communication network modules and Internet to facilitate the connectivity with external networks. In this way, the users can access and control any equipment anywhere, any time through the in-home IOT Gateway.

### B. WSN-based IOT Application Architecture

The typical IOT application architecture can be divided into three layers shown in Fig. 2 as follows:

*1) Perception Layer:* In the perception layer, the system aims to acquire, collect and process the data from the physical world, which consists of two parts: the sensor device and wireless sensor networks. The former one includes RFID label, sensor nodes, and camera and so on. The latter one is a self-organizing wireless network which consists of many sensor nodes distributed in a large area. These devices coordinately monitor the state of physical environment. In details, the perception layer collects the data through data acquisition device at first, and then the data is transferred to the next layer using RFID, Bluetooth or other technologies.

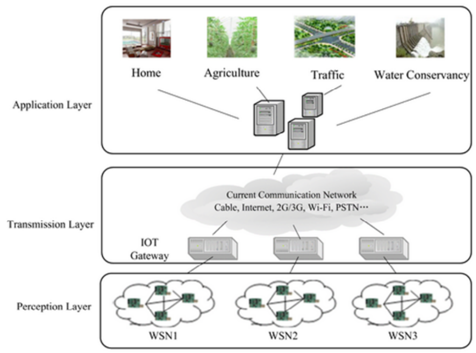


Figure 2. Typical IOT application architecture

Above all, this layer is the basis of IOT system with critical technologies including signal detection, short-range radio technology and so on.

*2) Transmission Layer:* In the transmission layer, the system aims to transfer data in a large area or long distance, which is constructed based on the traditional mobile broadband communication network, Wi-Fi and other communication technologies to realize the integration of the perception and communication network. Thus the data collected from perception layer can be transferred successfully to remote destination. Long-range wired and wireless communication technologies, network techniques are important in this layer.

*3) Application Layer:* Data processing and services providing are two major purposes of the application layer. The data from transmission layer is handled by corresponding management systems and then various services will be provided to all kinds of users.

### C. Characteristics of IOT Gateway

As the bridge to connect sensor networks with traditional communication networks, IOT Gateway can provide the functionalities of protocol conversion and device management. Referred to the general gateway, IOT Gateway has the following characteristics:

*1) A wide range of access capability:* Currently short-range communication technology standards are diverse including Zigbee, Z-Wave, Rubee, WirelessHART, etc. However, it lacks of protocol compatibility.

*2) Manageability:* The IOT application takes terminal sensor nodes as antennae, programs running in large server as the brain, to perceive and control the physical world. Therefore, it's necessary to manage millions of terminal sensor nodes. In the meanwhile, the management of IOT Gateway not only means sensor node management in the subnet, but also means the gateway device management. The former one aims to acquire the node's identification, status and properties, and realize remote startup, shutdown, control and analysis. The latter one aims to realize the gateway device's control, diagnosis, configuration, upgrade and maintenance.

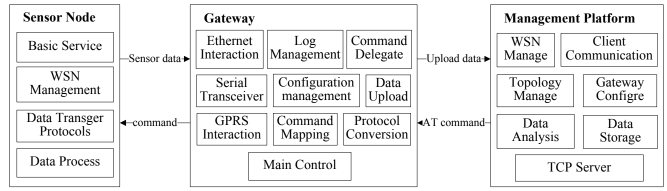


Figure 3. The software architecture of IOT Gateway system

*3) Protocol interworking:* Traditional network and sensor network need to exchange information in the IOT scenarios. The IOT Gateway should support protocol interworking between traditional network and WSN seamlessly.

## IV. Design of IOT Gateway System

### A. System Requirements

Based on the in-home use scenario, IOT Gateway should support internal data collaboration and aggregation in WSN, and data transmission among Internet, 2G/3G networks, DSL networks, and other network interfaces. The system requirements of IOT Gateway system is listed as follows:

*1) Data Forwarding:* The basic function of IOT Gateway system is to receive data from sensor network terminals or Internet terminals, and then transfer data to the other networks transparently and correctly .

*2) Protocol Conversion:* IEEE 802.15.4/Zigbee network communication protocols are proposed in WSN, while the Internet network is based on TCP/IP protocol. It means that IOT Gateway system should use short-distance wireless communication protocol (e.g. Zigbee) to acquire the packet from the sensor nodes, and use the 2G/3G, DSL and other network interfaces to send the packets to telecommunication networks or Internet. Therefore, IOT Gateway should analyze and re-package the sensor data based on WSN protocols after receiving it, and then capsulate and send the re-packaged data based on telecommunication protocols.

*3) Management and Control:* Besides receiving or uploading data, IOT Gateway should also support managing and controlling the sensor nodes. For example, when the gateway receives the commands from the remote server, it should process the commands and then dispatch them to the sensor nodes so that the remote server can manage and control the sensor network through IOT Gateway.

### B. Software Architecture

IOT Gateway system is composed of three subsystems: sensor node, gateway and application platform as Fig.3 shown.

Sensor node is in the perception layer of the system, its main function is not only to collect sensor data and transfer information to gateway, but also to receive commands addressed from the gateway. To achieve these goals, sensor node is deployed with Data Processing module to parse the commands and send the data, Data Transfer protocols and

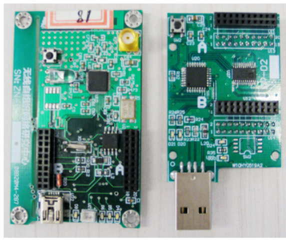

Figure 4. The hardware structure of sensor node

Basic Service modules to dispatch data packets, and Time Synchronization module.

IOT Gateway is in the middle layer between sensor node and application platform, it not only receives sensed data from sensor node and commands from application platform, but also transmits data to application platform. GPRS Interaction module and Ethernet Interaction module are deployed in gateway to exchange data with application platform. Serial Transceiver module is deployed to exchange data with sink node. Command Mapping module parses the commands from application platform, implementing sensor network management or gateway management. Protocol Conversion module packages the sensed data with defined format. Log Management and Configuration Management modules implement the management functions of gateway, recording the important events and configuration information in gateway, providing the upload functionality. Data Uploading and Command Agent module in sink node are responsible for gathering data, sending data to serial port, and dispatching network commands.

Application platform is in the management layer of the system, whose purpose is to manage gateway and sensor network through the gateway, store the data in the database and provide user control interface. TCP Server and Client Communication module implement data transmission, Sensor Network Configuration and Gateway Configuration realize the gateway and sensor network management, Data Analysis and Statistical supports for control management.

## V. Implementation Issues

This section presents some initial implementation issues about the IOT Gateway system.

### A. Wireless Sensor Nodes

The hardware architecture of the sensor node is shown in Fig.4. The sensor node in the prototyping system is TelosB node, which uses MSP430 as the CPU and CC2420 as the wireless communication module, integrated with temperature and light data collection module. In the TelosB node, we use TinyOS operating system and implement the modules in nesC. Here we just present the packet format we defined. The packet format on the nodes is divided into two types: Data Reporting and Command Agent.

Table I
THE PACKET FORMAT OF DATA ON THE NODES

| Field | Description |
|---|---|
| X1X2 | Destination Address |
| 0000 | Source Address |
| X3 | The Length of Payload |
| 00 | Group ID |
| X4 | AM Type |
| Payload | Effective data |
| F1F2 | CRC Code |

Table II
PAYLOAD FIELD DEFINITION OF LIGHT/TEMPERATURE/HUMIDITY DATA

| Field | 1 | 2 | 3 | 4-5 | 6-7 | 8-9 |
|---|---|---|---|---|---|---|
| Name | SeqNum | NodeID | Value | Seconds | Node2 | Ticks |

Table III
PAYLOAD FIELD DEFINITION OF ROUTE REPORT

| Field | 1-2 | 3-4 | 5-6 |
|---|---|---|---|
| Name | NodeID | ParentID | ETX |

Table IV
COMMAND OF OPEN OR CLOSE ONE MORE NODES

| Field | 1 | 2 | 3 | 4-5 | 6-7 | 8-9 |
|---|---|---|---|---|---|---|
| Name | Type | SubType | SeqNum | Node1 | Node2 | Interval |

*1) Data Reporting:* The data collected by the sensor nodes is sent to the sink by built-in wireless chip. Sink is linked to the gateway through serial port. So the data is reported to the gateway by the serial port finally. The data we report starts with '\x7E\x45' and ends with '\x7E'. The specific format is defined as "7E 45 00 X1 X2 00 00 X3 00 X4 Payload(AM) F1 F2 7E". Table I presents the form of the reporting data. The length value of the Payload field is varied according to the payload types. There are mainly two typical data types: light/temperature/humidity data, shown in Table II; route report data, shown in Table III

*2) Command Agent:* This module not only receives and disseminates the command from the gateway, but also executes the command to control the mote's working state or configure the mote's parameter. It is critical to guarantee that the format is valid, so that the mote can interpret and execute it. The dissemination command starts with '\x7E\x44' and end with '\x7E'Specifically it is defined as a string like "7E 44 00 00 X1 X2 00 00 X3 00 X4 Payload(AM) F1 F2 7E".

Table I is the instruction for each field of dissemination command, in which Payload(AM) field's style varied according to user's application, for example, the classical style listed as bellow: open or close several motes, shown in Table IV; open or close all motes, shown in Table V.

Table V
COMMAND OF OPEN OR CLOSE ALL THE NODES

| Field | 1 | 2 | 3 | 4-5 |
|---|---|---|---|---|
| Name | Type | SubType | SeqNum | Interval |

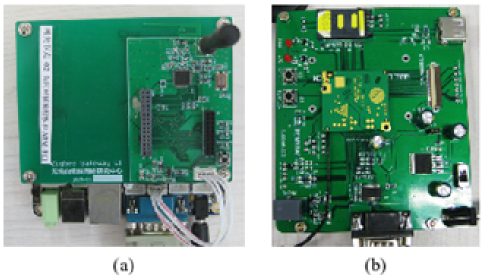


Figure 5. The hardware structure of gateway. (a) Mainboard; (b) GPRS module

## B. IOT Gateway

The hardware structure of WSN Gateway is shown in Fig.5. IOT Gateway's mainboard in Fig.5(a) uses ARM9 Samsung S3C2440 400MHz CPU, 64M Flash and 64M SDRAM as the processor, storage and memory respectively, in which ARM Linux and Python work as operating systems and programming environment. The Sink node module embedded in Fig.5(a) uses MSP430 and CC2420 as the processor and wireless communication module, TinyOS and nesC as the operating system and programming language. GPRS module in Fig.5(b) uses Huawei EM310 module as the wireless communication module.

In detail, the main functions of the gateway are to read data from serial port, write data to the serial port and forward sensed data. After transplanting Linux operating system into the ARM9 mainboard, we need to implement the data transmission, protocol conversion and command agent functions to meet the requirements mentioned above. In Fig.6, we illustrate the process of main program of IOT Gateway. After the system is turned on, the Linux operating system boots first, and then the main program will initialize the applications. Our design provides two modes of interaction with the remote server: GPRS Interaction and Ethernet Interaction. The former one starts GPRS module by sending AT commands, which also sets the serial communication speed to establish socket connection for data transmission. The latter one establishes the socket connection by setting the remote server's IP address and listening port. Both of them provide a unified interface, so the main program selects one of them to start easily.

After all the modules initialized, IOT Gateway starts with port listening and waiting for external events interruption. Once the interruption events are detected, the main program determines the appropriate response by checking the type of data. If the data is received from remote server which means

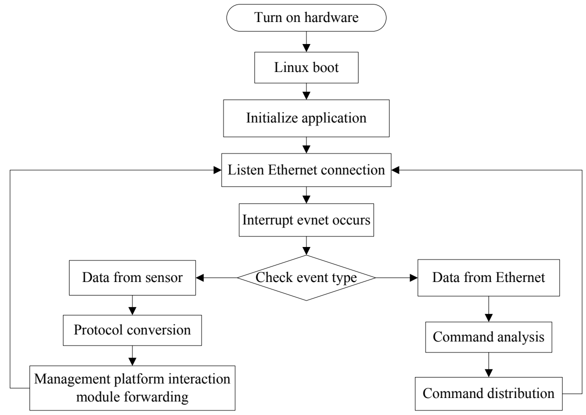


Figure 6. The workflow of gateway's main program

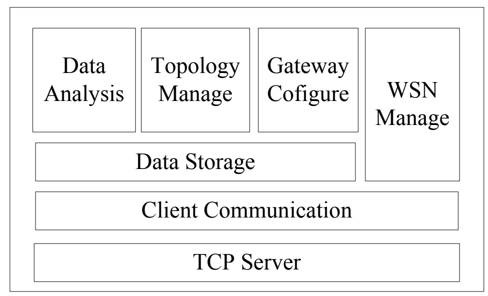


Figure 7. The structure of application platform

that the data is a command, the main program analyzes the command and sends it to the WSN. If the command asks for reporting the gateway information or gateway log to server, the main program calls the remote server interaction module's interface to send logging and configuration data to the remote server. If the command is target with the sensor nodes, the main program analyzes the command by calling the protocol analysis module's interface, and then calls serial data transceiver's interface to send information to the sink sensor. If the data is received from WSN, the main program analyzes the data by calling protocol analysis module, and then calls the remote server interaction module to send sensed data to the remote server.

## C. Application Server

The application server uses Python as the runtime environment. Fig.7 shows the main modules deployed in the application server.

In TCP Server, we implement data reporting and command sending functions which supports GPRS and Ethernet communication channels. Socket communication technology is adopted in TCP Server. We open three threads in the main process. The first one is to listen on the client's connections and accept multiple socket connections. The second one is to read the commands via Client Communication module and send it to IOT Gateway by GPRS or Ethernet, or to read

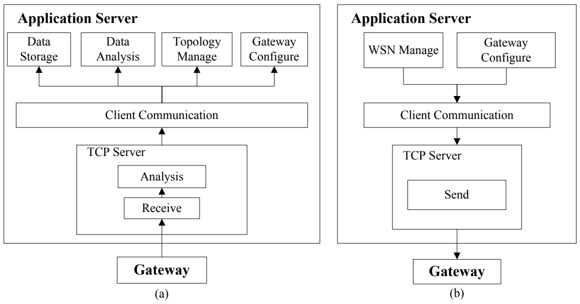


Figure 8. Workflow of command and data between gateway and server. (a)Data reporting; (b)Command sending

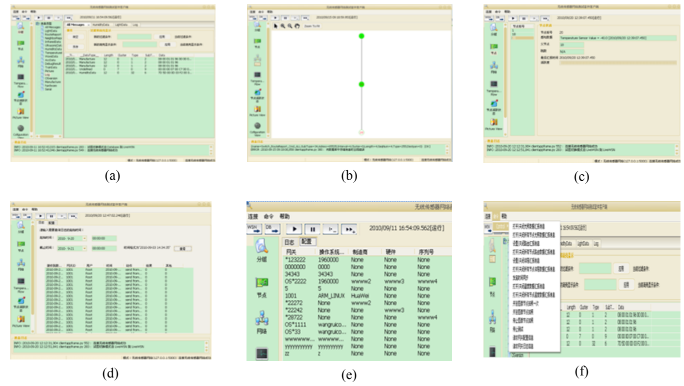

Figure 9. Prototyping of application functions. (a)Sensed data; (b)WSN topology; (c)Node's status analysis; (d)Gateway log; (e)Gateway configuration; (f)AT command sending

data from the IOT Gateway and parse the data, then send it to the Client Communication module. The third thread is to connect TCP Server and the gateway via Ethernet.

In Fig.8, we show the workflow for data reporting and command sending. Fig.8(a) shows the process of data reporting, in which the data is transmitted from IOT Gateway to the TCP Server, after received and parsed by reading the XML file about data formats, the data can be fitted into a specific data structure, then it is sent to the Client Communication module. Client Communication module sends the received data to the relevant application modules including Data Storage module, Data Analysis module, Topology Management module and Gateway Configure module. Fig.8(b) shows the process of command sending, in which WSN Management module can generate WSN's instructions (such as ON/OFF instruction), and Gateway Configure module can generate Gateway management instructions (such as request for the gateway log information). After parsed, the command is converted into AT command, sent to the Client Communication module, transferred through socket communication to the TCP Server module.

The application platform provides the functions including data display, topology management, node's status analysis, gateway configuration, WSN management. As shown in Fig.9(a), the application server displays the classified sensed data from the gateway after parsing the data in real time mode and database mode. Fig.9(b) shows WSN node's topology management, which can draw network topology after collecting and analyzing the routing and neighbor information from the IOT Gateway. Fig.9(c) shows the node's status analysis, and Fig.9(d) shows the log information of the IOT Gateway. Fig.9(e) shows the gateway configuration information stored in the database. Fig.9(f) shows WSN configuration module which can send AT commands to IOT Gateway including the commands for opening or closing the target node, and time synchronization.

## VI. Conclusions and Future Work

The IOT Gateway is a key component in IOT application systems, which is working as a bridge between telecommunication network or Internet and the WSN. This paper presents a prototyping implementation of IOT Gateway based on Zigbee-GPRS protocols, which realizes data forwarding, protocol transformation, WSN management and control. Therefore, it can be widely used in smart home, industrial monitoring, smart grid, environment monitoring etc. In future works, we will consider advanced functions of IOT Gateway including fault handling and security management.

## Acknowledgment

This work has been funded by National Natural Science Foundation Project No.61073014, National Major Special Science and Technology Projects No.2009ZX03006-004_1 and 2010ZX03006-007.

## References

[1] L. Atzori, A. Iera and G. Morabito, "The Internet of Things: A Survey", *Computer Networks*, Vol. 54, No. 15, pp. 2787-2805, Oct. 2010

[2] I. Bose and R. Pal, "Auto-ID: managing anything, anywhere, anytime in the supply chain", *Communications of the ACM*, Vol. 48, No. 8, pp. 100-106, Aug. 2005.

[3] ITU, "ITU Internet Reports 2005: The Internet of Things", *The Internet of Things*, Nov. 2005.

[4] Q. Liu, L. Cui, HM. Chen, "Key technologies and applications of Internet of Things", *Computer Science*, Vol. 37, No. 6, 2010.

[5] ETSI M2M Standardization, *http://www.etsi.org/Website/Technologies/M2M.aspx*

[6] H. Jin, WC. Liu, JT. Han and YL Ding, "Application Study of Internet of Things in Home", *Telecommunications Science*, Vol. 26, No. 2, 2010.

[7] D. Guinard and V. Trifa, "Towards the Web of Things: Web Mashups for Embedded Devices", in *2nd Workshop on Mashups, Enterprise Mashups and Lightweight Composition on the Web (MEM 2009)*, Madrid, Spain, April 2009.