WIRELESS SENSOR NETWORK USING ZIGBEE

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ABSTRACT

ZigBee is a specification for a suite of high level communication protocols**. Zigbee** is a typical wireless communication technology. ZigBee uses low rate, low-power digital radios based on an IEEE 802 standard for personal area networks. The technology defined by the ZigBee specification is intended to be simpler and less expensive than other WPANs (Wireless personal area network), such as Bluetooth. ZigBee is targeted at radio-frequency (RF) applications that require a low data rate, long battery life, and secure networking. ZigBee has a defined rate of 250 kbps best suited for periodic or intermittent data or a single signal transmission from a sensor or input device. It is Open standard protocol with no or negligible licensing fees, chipsets available from multiple sources, remotely upgraded firmware, fully wireless and low power, mesh networking to operate on batteries, low maintenance and larger network size with standard based high security.

Keywords: Zigbee, WPANs, Home Automation, sensor network, IEEE 802.15.4, wireless.

1. INTRODUCTION

ZigBee is a typical wireless communication technology, which is widely used in wireless sensing networks. ZigBee wireless sensor network is widely used in military security, environment monitoring, and home automation. Various progressive wireless communication standards were developed and implemented into practice during the last decade. GSM, WiFi and Bluetooth are well known amongst people in the modern society. These standards have penetrated into their daily routine with outstanding popularity. "An Internet of people" has become ordinary for everyone who wants to have everybody and everything within reach. Even though it seems that all peoples' wireless requirements have fulfilled, it turns on, that they lack of something like "an internet of things" especially in mainstream Home Automation (HA). As a new technology, in the practical application the advantage of the ZigBee wireless sensor network was not very ideal, especially in a large scale wireless Zigbee sensor network, because the coordinator processing ability is limited. In the large scale ZigBee wireless network the coordinator should deal with too much message, so some shortcomings come out, such as information time delay, data packet loss, and sensor node out of control. There are some algorithms that were proposed to improve the communication efficiency by the researchers, but that only aimed at the software aspects. A distributed processing design is proposed in this paper. The whole task of the network will be divided into two parts; one is about the network building, node joining, and data collecting; the other one is about data processing, network information conservation, and communicate with the host computer. The first part will be finished by the coordinator and the other one by another processor, which is connected with the coordinator by RS-232 interface. By this way the performance of the ZigBee wireless system improves a lot.

2. ZIGBEE OVERVIEW

2.1 ZigBee applications, markets and forecasts

Although ZigBee standard development is still under progress, the ZigBee market is opened for various applications. The most promising of them are:

• *Home Control:* Security, Heating, Ventilation, and Air-Conditioning (HVAC), Lighting control, Access control, Irrigation

• *Personal health care:* Patient monitoring, Fitness monitoring

• *Industrial control:* Asset management, Process control, Energy management, Environmental

• *Building automation:* Automatic Meter Reading (AMR), Security, HVAC, Lighting control, Access control

• *Consumer electronics:* Remote control.

•*PC & peripherals:* Mouse, keyboard, joystick,

• *Environment:* Environment monitoring.

3. ZIGBEE STANDARD ARCHITECTURE

3.1. Network reference model

Network devices, whether wired or wireless, are commonly described by the Open Systems Interconnection (OSI) reference model. This abstraction model was developed by the International Standards Organization (ISO), starting in the 1980 description of communication-related protocols and services. The generic seven-layer model is applied to all network and media types. The adaptation ISO-OSI network reference model for ZigBee purposes is illustrated in the Fig.1. ZigBee network model does not use presentation, session or transport layer and user application is directly tied into Application layer (APL). This figure shows also IEEE, ZigBee Alliance, and ZigBee product end manufacturer particular responsibility for ZigBee certified product as well as hardware and software proportion in ZigBee.

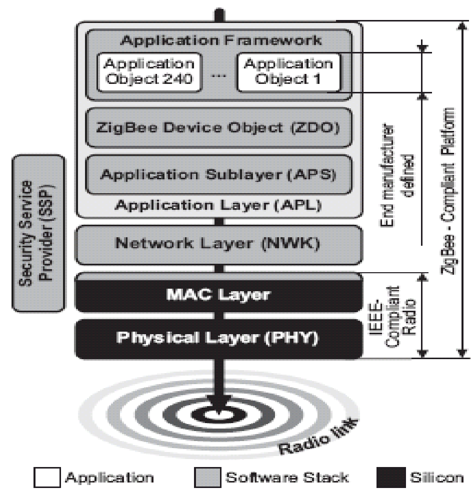


Fig. 1 Adaptation ISO/OSI to ZigBee standard

3.2. IEEE 802.15.4 Standard

The IEEE standard [3] brings the ability to identify uniquely every radio in a network as well as the method and format of communications between these radios, but does not specify beyond a peer-to-peer communications link, a network topology, routing schemes or network growth and repair mechanisms. The ZigBee Alliance selected the IEEE 802.15.4 standard, released in May 2003, as the wheels and chassis upon which ZigBee networking and applications have to be constructed. IEEE 802.15.4 defines three frequency bands to employ a standard over the world. Overview of available bands, modulation method and other properties of each is resumed in the table below (Tab 1).

	868 MHz	915 MHz	2.45 GHz
frequency band	ISM	ISM	ISM
area	Europe	USA Australia	World
bit-rate	20 kbps	40 kbps	250 kbps
number of channels	1	10	16
modulation	BPSK	BPSK	O-QPSK

Tab. 1 Available frequency bands within IEEE 802.15.4 spec with appropriate bit-rate and modulation method

3.3. ZigBee Standard

The ZigBee specification identifies three kinds of devices that incorporate ZigBee radios, with all three found in a typical ZigBee network (Fig.2):

• *Coordinator (ZC):* organizes the network and maintains routing tables

• *Routers (ZR):* can talk to the coordinator, to other routers and to reduced-function end devices

• *End devices (ZED):* can talk to routers and the coordinator, but not to each other.

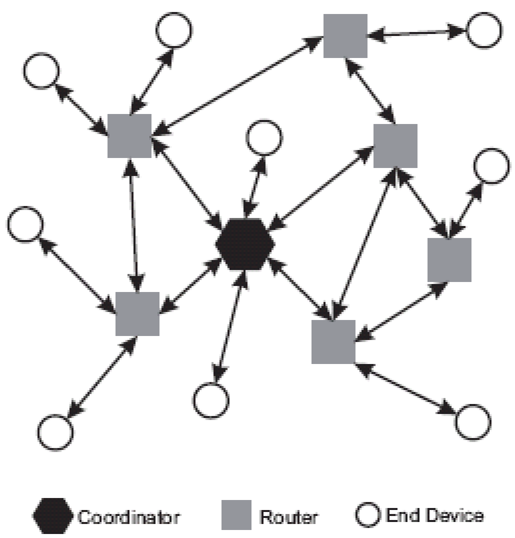


Fig.2. ZigBee network incorporating coordinators, routers, and reduced-function end devices in a variety of topologies (mesh topology shown)

4. EXPERIMENTAL RESULTS

4.1. Experimental hardware platforms

An evaluating hardware was developed with the intention to build a HA network workplace and to test interoperability of various stacks. A Freescale MC13203 chip was chosen for data retransmitting due to its availability in time of consideration and the original RF board with compatible chip was also available. A board (Fig. 5) was designed with onboard F-antenna with the MC13203 chip.

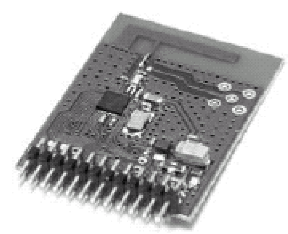


Fig. 5 The experimental RF board with Freescale MC13203 chip developed at DEMC

MC13203 chip developed at DEMC ARM BOARD Phillips LPC2138 and an Analog Devices ADuC836 was chosen as the MCU platform regarding maximal functionality and peripheral connectivity for HA purposes. Evaluation boards were designed for these MCUs. Both ones have adequate options of peripheral connectivity for HA sensors and actuators. These boards are for evaluation purposes only, therefore to test a functionality of the design. The LPC2138 is built on ARM 7TDMI-s based architecture [13] what ensures a very good performance for time-critical tasks.

Fig. 6 The DEMC ARM BOARD with LPC213 microcontroller with inserted Freescale RF boar

Large 512kB flash and 32kB RAM memory is available on this chip what designate ARM based board for network coordinator purpose. The board with this chip could be used also as 1-wire [14] bridge also. The Keil uVision 3 IDE with free GNU Code Sourcery C compiler was chosen for software development. The DEMC ARM BOARD based on LPC2138 (Fig. 6) also contains 10bit ADC and DAC, USB and RS232 UARTs, SD/MMC card slot, 4 general purpose LEDs and buttons, external interrupt button, reset button, JTAG interface, RF card slot and connector for various peripherals connections. The second DEMC ADuC BOARD based on micro-converter Analog Devices ADuC836 is shown in Fig. 7 (micro-converter is a special name for MCU device with high-end sigma-delta analog to digital converter-ADC). This MCU is based on modern single cycle x51 clone with 64kB FLASH and 2.3kB RAM. The most powerful peripheral in this MCU is a 24-bit sigma-delta ADC with programmable input gain amplifier in 1-128 gain range. This converter is very useful for precise low-voltage measurements (e.g. various sensors based on wheatstone bridge, or thermocouple as well). DEMC ADuC BOARD contains similar peripherals as DEMC ARM BOARD, such as SD/MMC card connector, analog input, analog output, LEDs, buttons, RS232, and buzzer. ADuC836 has on-chip thermometer. This board is designed for sensors nodes especially, thanks to rich connectivity of an ADuC836.

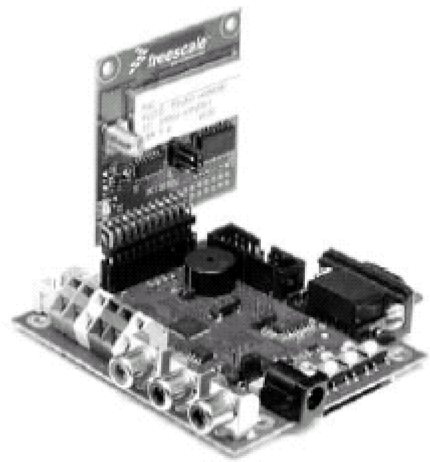


Fig. 7 The DEMC ADuC BOARD with x51 core micro-converter with inserted Freescale RF board

5. SYSTEM OVERVIEW

5.1. System Overview Framework

The improved ZigBee wireless sensor network is composed of various sensors, ZigBee nodes, host computer, and a processor. In the network, the sensor collects the information and uploads it to the ZigBee node. The ZigBee node sends this information to the coordinator. As soon as the coordinator gets the sensor information, it sends the same to the processor by the wired connection. The processor will deal with the information and conserve it. When the host computer queries the ZigBee wireless sensor network, all the information will be provided by the processor. In the improved ZigBee wireless sensor network, the host computer has no direct relationship with the ZigBee wireless sensor network. The typical difference between the improved ZigBee sensor networks and the traditional ZigBee sensor network is the processor, which has two interfaces, one is connected to the coordinator and the other one is connected to the host computer. The interface design is determined by the hardware resource. The USB interface, serial port and parallel port are widely used in the course of the interface designing. In the paper we choose the serial port as the interface between the coordinator and processor. We can choose different communication protocol between the processor and the host computer. In this paper we choose Modbus protocol between the processor and the host computer.

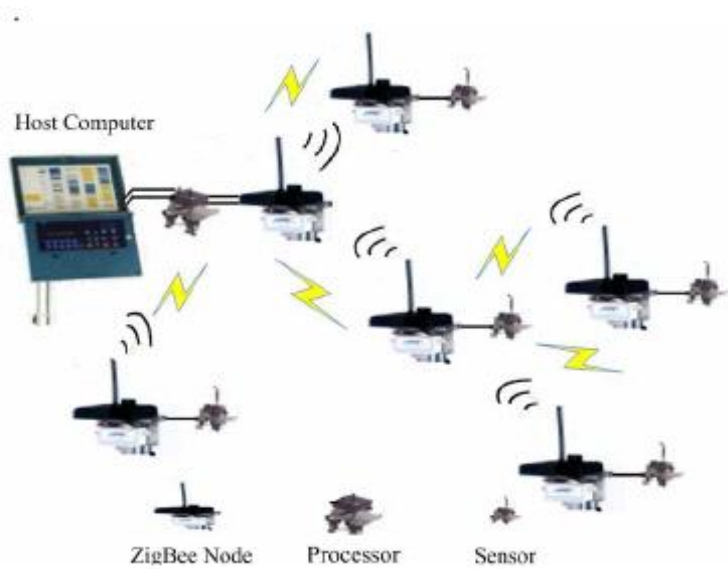


Figure.1 The system overview framework

5.2. Design

The design of the ZigBee wireless sensor network includes four parts: ZigBee sensor node hardware design, interface design, coordinator software design, and processor software design. The ZigBee sensor node hardware designing part presents the structure of the node, and specifies the function each part. The interface designing part presents the interface between the coordinator and the processor, and shows the schematic diagram. The coordinator and processor software designing part describes the working flow of the system.

A. Node Hardware design:-

ZigBee sensor node is the basic unit for information collection. Figure.2 shows the structure of the ZigBee sensor node module. The sensor collects the signal from the environment and the original signal will be processed by the signal processing module. Then the processed signal will be uploaded to the ZigBee module. The ZigBee module sends the information to the coordinator. The power will be provided by two batteries, and the voltage regulator module will assist in providing power. In the course of the designing, we choose CC2430 as the ZigBee protocol chips. The chip CC2430 as the core of the hardware, CC2430 integrated RF transceiver, CPU, and 128K flash memory, and very few external components required in the CC2430 typical application [6]. It also includes A/D converter, some timers, AES128 Coprocessor, Watchdog Timer, 32K crystal Sleep mode Timer, Power On Reset, Brown Out Detection and 21 I/Os. Among the 21 I/0 ports, CC2430 p0 ports can be set to ADC port. 21 I/O ports can be used as the SPI ports, GPIO and so on. These sensor nodes except the coordinator have the same basic structure. These ports are assigned to the sensors and peripheral equipments. The coordinator will not connect with the sensor, which will extend a serial port to connect with the processor.

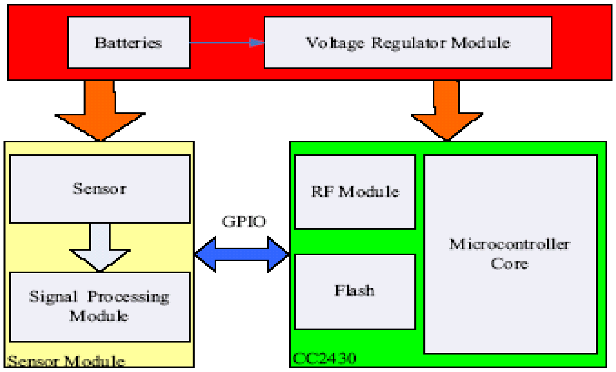


Figure.2 ZigBee Sensor Module

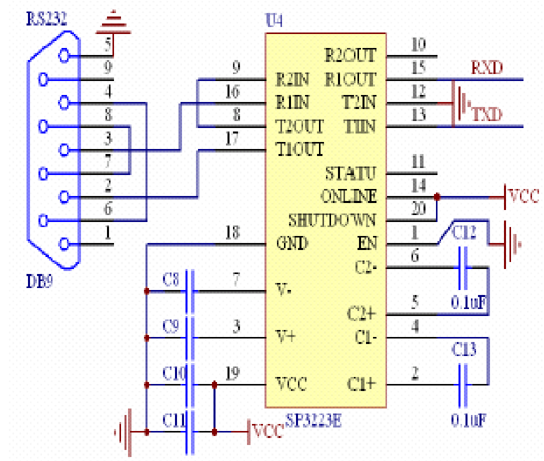


Figure.3 Interface of the processor

B.Iinterface Design

In the traditional ZigBee wireless sensor network, the coordinator connects with the host computer directly, in the improved ZigBee wireless sensor network the coordinator connects with the added processor. The processor can be chosen by the scale of the network. We had better choose a strong functional processor in the large scale network. In our test we choose an 8051 microcontroller as the processor. The interface between the processor and the coordinator can be designed by the hardware resource. In our design we take Modbus protocol as the communication protocol between the host computer and processor. We choose serial port to connect these two parts. Due to the voltage level difference between the host computer and the processor, chip SP3223E[7] is used to convert the level.

Figure 3 is the schematic diagram of the interface signing between the processor and the host computer.

C. Node Software Design

In the improved ZigBee wireless sensor network, the software designing is composed of three parts. Coordinator work flow, sensor node work flow and the processor work flow.The sensor node work flow is the same as the traditional work flow. The sensor node will send the data package to coordinator, which contains node ID, sensor value, and so on. But the coordinator working flow is different. When we turn on the power, the coordinator first initiates hardware board, and then creates PAN identifier, broadcast net ID and so on. The coordinator will keep monitoring the network state, when the coordinator received the information, judge the information whether it is coming from a new sensor node? If it is a new node joining the network, coordinator will allocate the 16-bit short network address the new node. If it is not a new node, the coordinator will send the data package to the processor. The data information contains sensor ID, sensor value, and so on.

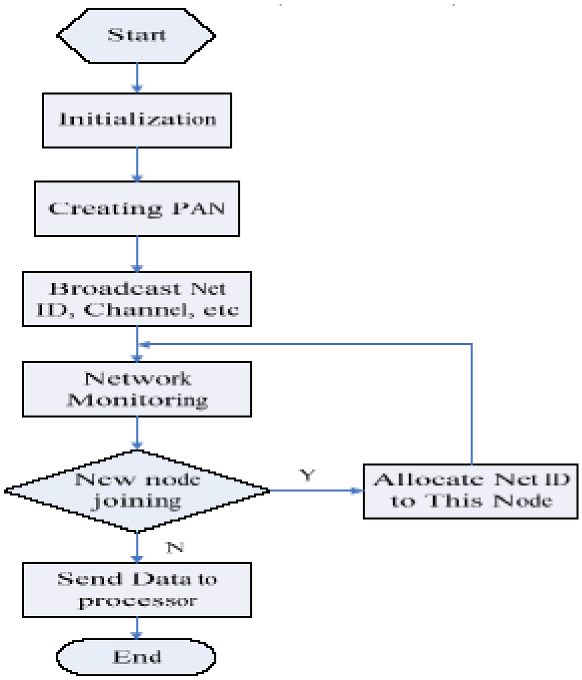


Figure.4 Software Flow of Coordinator

The Figure.4 shows the software work flow of the coordinator. We can see from the work flow, the coordinator will not process and conserve the data package come from the sensor node. When the new data package is coming, the coordinator will send it to the processor directly, and also the coordinator does not need to take the task to communicate with the host computer. By this way the coordinator has enough time to manage the wireless sensor network, so the communication efficiency of the ZigBee wireless sensor network will improve a lot.

D) Processor Monitoring Software Design

From the part C, we can know that the processor's task is to undertake the rest of the work which is abandoned by the coordinator. The processor will initiate the hardware board first, and then open interrupt and keep receiving the data package. When the data package is coming, the processor will analyze the data package and process it. The processed data will be conserved in the relevant register. The processor also communicates with the host computer. In our test, we take Modbus communication protocol between the host computer and the processor[8]. When the host computer sends the query command to the processor, an interrupt will occur in the
coordinator work flow. When the processor receives the interrupt, it would enter the interrupt work flow. First the processor will clean the interrupt flag and then execute the query command.
When the query is finished the processor will send the result to the host computer.

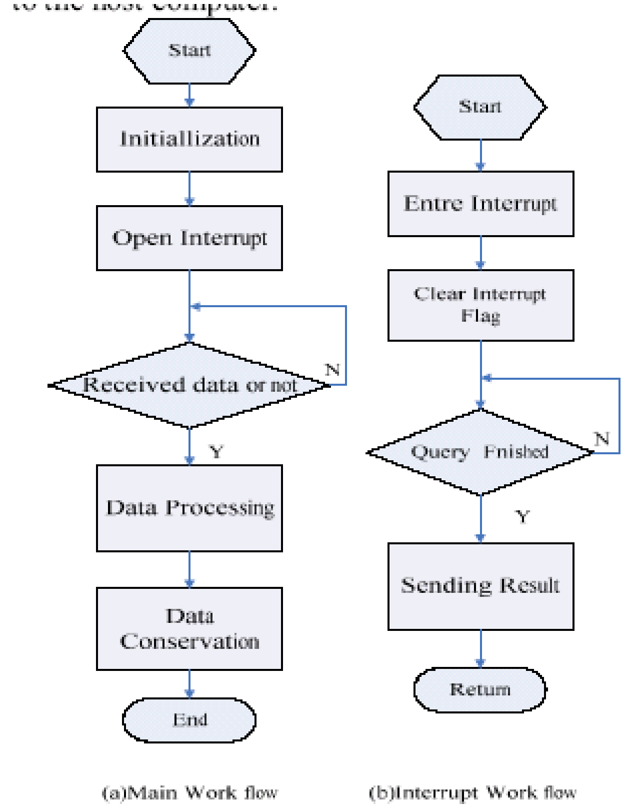
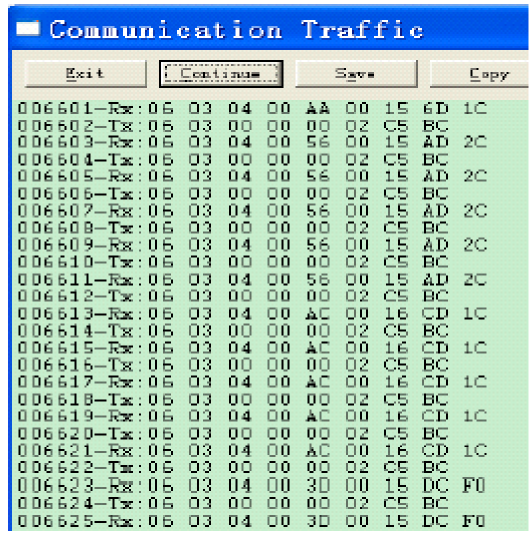


Figure.5 Software Flow of Processor

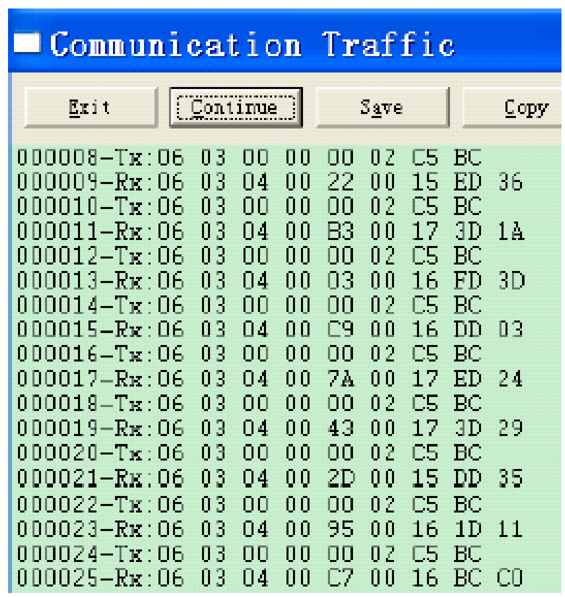
The figure 5 shows the work flow of the processor. In the processor work flow we should know that the received data is coming from the coordinator, and the query command, from the host computer. In the course of the system running, we should make the processor work first, and then power up the coordinator. If the coordinator works first, partial data will be lost, because the processor did not start to work.

6. THE ANALYSIS OF TEST RESULTS

We tested the improved ZigBee wireless sensor network system and compared it with the traditional one. We took Modbus Poll as the test software tool. Modbus Poll is a very convenient software platform for the Modbus transmission test. The processor is connected with the host computer by serial port. When the ZigBee wireless sensor network is running in a stable fashion, we begin to run the Modbus Poll. We can observe the data in the course of the communication by the Modbus Poll. Because the test environment is a little stable, the sensor value changed minutely. So we set an update flag in the sending data package. The update flag is a random data but different from the last update. We choose 8 sensor nodes to build the wireless network. We tested the response speed between the two systems. Figure 6 shows the test result.



(a) Traditional ZigBee System Communication Course



(b) Improved ZigBee System Communication Course

Figure.6 Test Result

We queried the node 6 by Modbus Poll, which is about 100 meters away the host computer. In the traditional system, when the system is running stable, all tasks will be executed by the coordinator, we queried the node 6 by interrupt manner. Figure 6(a) is the traditional ZigBee system test result. "Tx line" is the transmitting data package, "Rx line" is the received data package. Both of the "Rx" and "Tx" data package are typical Modbus frame. We can see from the first "Tx", 06 is the ID of the node, 03 is the command function code, following double 00 is the start address to query, following 00 is the high bit of the number of the register,02 is the low bit, and the last C5BC is the 16 bit CRC. When the Coordinator receives the Modbus package, the Modbus ID, function code, and the number of byte to be queried register will be stored. Then the Coordinator executing the 03 function instruction, and read the information in the registers. The information will be stored in the return Modbus package. As the picture showed, RX is the host computer received Modbus package.06 is the Modbus ID, 03 is the function code, and 04 is the number of bytes to be queried register. Following 4 bytes are the registers value, and the first two bytes are update flags. At last add the 16 bit CRC code into the package. We can see from these two figures, in the traditional ZigBee wireless sensor network, when the host computer sent an interrupt to the processor every 500ms, the return information will be updated one time every 5 times interrupt. In the same condition, we repeat the work in the improved ZigBee wireless sensor network; the return information will be updated one time every one time interrupt. In different work conditions the test result will be different. But it verified the same question that the improved network has a better real-time than the traditional one.

7. CONCLUSION

This article describes features of the ZigBee standard that is great solution for wireless sensor networks. The workplace for wireless sensors networking was prepared and tried out within works at DEMC. This workplace consists of development boards based on perspective ARM and x51 microcontrollers as well as the Freescale's ZigBee development tool chain. Their tool chain includes evaluation hardware, the smart code generator BeeKit and Code Warrior IDE. The HA multi-platform wireless network was based on evaluation hardware, SMAC protocol and proprietary routing algorithm. The interoperability and functionality of used hardware and software were confirmed to achieve sufficient coverage for flat or smaller house. Memory requirement of each MCU platform was also compared. Next step was realization of small ZigBee compliant network using Freescale's tool chain. This tool chain ensures relatively easy network creation and modification. Even though only three nodes was used in the ZigBee, network, works at department continue with ambition to realize larger interoperable HA network based on different manufacturer ZigBee chips.

ACKNOWLEDGEMENT

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