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THE INTEGRATION OF WIRELESS SENSOR NETWORKS AND MONITORING TECHNOLOGY FOR ADVANCED METERING INFRASTRUCTURE

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Abstract. *Due to energy shortages, rising prices, and conserve energy problem, it becomes a major government policy to reduce carbon emission. The most important objectives aim to (1) control and use electricity effectively, (2) construct the smart grids, and (3) stabilize electric power systems. This research provides an application of wireless sensor network and Modbus protocol in multi-function power meters to improve the efficiency of energy usage in advanced metering infrastructure system. The communication interface of the traditional meter reading system usually uses the RS-232/RS-485 interface. To enhance the meter system with flexible and stable communication function, the dsPIC33F microcontroller and TI CC2530 ZigBee wireless communication modules are used and combined in multi-function power meters. The wireless sensor network is designed and developed in the two control modes: (1) broadcast mode, and (2) unicast mode, and can acquire the measurement data for variety of digital meters. This monitoring system can offer real time online information about the power consumption of a factory, and provide a considerable competitive advantage in the short-distance communications. Based on the monitoring system, the power consumption can be supervised, measured and analyzed, and the warning message will be shown on the user interface. Experiment results show that our proposed WSN-based monitoring system can be applied to autonomously collecting periodic power measurements and responding to request commands for all indoor or outdoor environments.*

Keywords: Advanced metering infrastructure (AMI), Wireless sensor network (WSN), ZigBee, Monitoring system, Modbus protocol, Microcontroller, Multi-function meter

1. **Introduction.** Smart grid can be considered as the new generation electrical power system that can efficiently deliver reliable, economic, and sustainable electric utility and services to all users in the world. It can integrate with advanced measurement and control technologies. Power industry is facing unprecedented opportunities and challenges. It includes global warming, depletion of fossil energy resources, depleted fossil energy, ecological civilization rising, and increasing distributed power generation resources.

Various AMI pilot projects [1-4] have been implemented to resolve this problem in the world, e.g., in Australia, Japan, the United States, and Europe. Most of these are designed for individual homes and factory automation applications. A multi-interface ZigBee building area network [1,2] (MIZBAN) is proposed for a high-traffic advanced metering infrastructure (AMI) in high-rise buildings. It discussed the practical design of a BAN based on a newly defined tree-based mesh (T-Mesh) ZigBee topology. Based on the typical infrastructure of power grid and high-speed integrated communications network, smart grid applies advanced sensing and measurement technology to providing safe and reliable modern grids.

In building or factory automation systems, it usually uses RS-485 and Modbus [5,6,10] protocol for meter measurement. Modbus RTU architecture is the most popular industrial protocol being used today. It is simple, inexpensive, reliable and easy to use. It is designed for Serial RS-485 protocol derived from the master/slave architecture. Because of the low transmission rate, Modbus is best employed in applications with less numbers of devices and low demands on response time. It tries to design and implement a ZigBee-based smart power meter to recover this deficiency.

The purpose of this paper is to construct a new generation of smart grid that is secure, high efficient and reliable. Wireless sensor network has advantages of low price, low power consumption and elastic use. The wireless sensor network and Microchip dsPIC controller system are developed to establish the AMI architecture. The WSN technology is designed and integrated to communicate with digital meter automatically. Our proposed system is used to measure, collect and analyze the user power consumption information, which can provide the technical support for engineers and power grid system.

The remainder of this paper is organized as follows. In Section 2, system architecture is described. Section 3 proposes the microcontroller and program design. The communication techniques are presented in Section 4. In Section 5, experimental results are demonstrated to verify the proposed methods. Section 6 concludes this paper.

2. System Architecture.

The system architecture of the wireless sensor networks and monitoring technology for multi-function meters system is shown in Figure 1. The system contains a microcontroller, wireless ZigBee modules, PC-based monitoring system, and two types of power meters with Modbus communication protocol. The meter models CTEC 713P and CTEC 2437 are manufactured by Chi-Tai electronic cooperation. The system is classified into monitoring system side and microcontroller side. The monitoring system side can send the command to multi-function meters via Zigbee module. The interface between them uses the TTL signal conversion through the FT232 module. The ZigBee Coordinator node is designed with broadcast or unicast transmission to all Zigbee end-device node. The microcontroller side used Microchip dsPIC33F development platform can communicate with monitor system and each PIC controller and meter have their own device address.

When the end device receives the command, PIC controller will check the data frame and decide that the transmission mode is broadcast mode or unicast mode. If the command is unicast mode, the device will check the address. If the device address is correct,

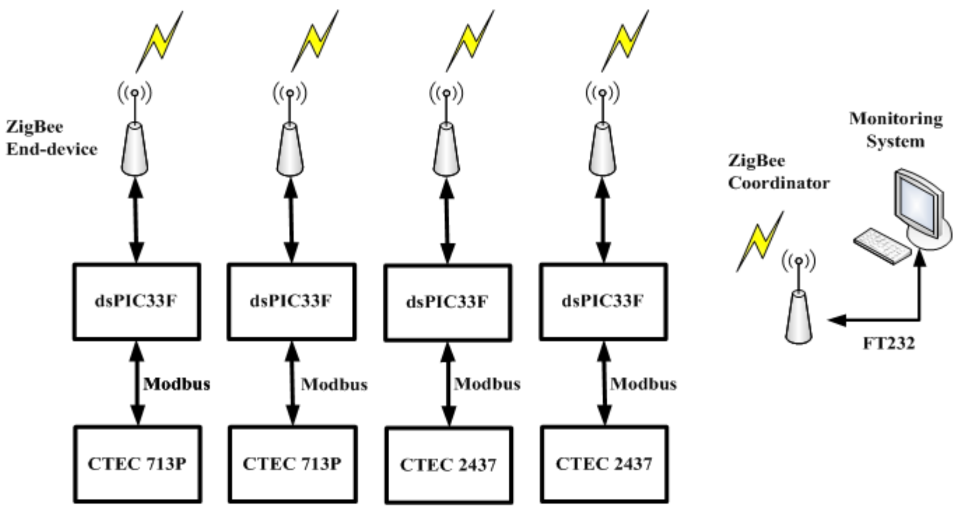


Figure 1. WSN-based monitoring system architecture

the dsPIC33F will calculate the cyclic redundancy check (CRC) code first and then execute the instructions. Once the command of device meter is wrong, the dsPIC33F does not execute. The received data will be placed in the register of microcontroller. It deletes some redundant data frames and send them to computer with ZigBee wireless networks. The Zigbee device objects can perform function like representing node type of the device and also define its role in the network. The basic channel access mode is carrier sense multiple access/collision avoidance (CSMA/CA). The monitoring system will analyze the measurement data, and the collected information will be shown on the monitor.

3. **Microcontroller and Program Design.** The microcontroller used in this system is Microchip dsPIC33F. Its main function is a bridge between the ZigBee wireless networks and the multi-function meters. MODBUS is a "master-slave" system, where the "master" communicates with one or multiple "slaves". The master typically is a PLC (Programmable Logic Controller), PC, DCS (Distributed Control System) or RTU (Remote Terminal Unit). MODBUS RTU slaves are often field devices, all of which are connected to the network in a multidrop configuration. The MODBUS RS-485 interface is the communication between the power meter and microcontroller. This interface does not support broadcast mode (0x00 command), and each meter's Modbus format is different, too. So microcontroller can receive the message and determines whether to execute. The program flow chart of microcontroller is shown in Figure 2. At program beginning, two groups of UART are initialized. The UART1 interface is connected with digital meter and UART2 interface is connected with ZigBee module. The functions of each program are as follows.

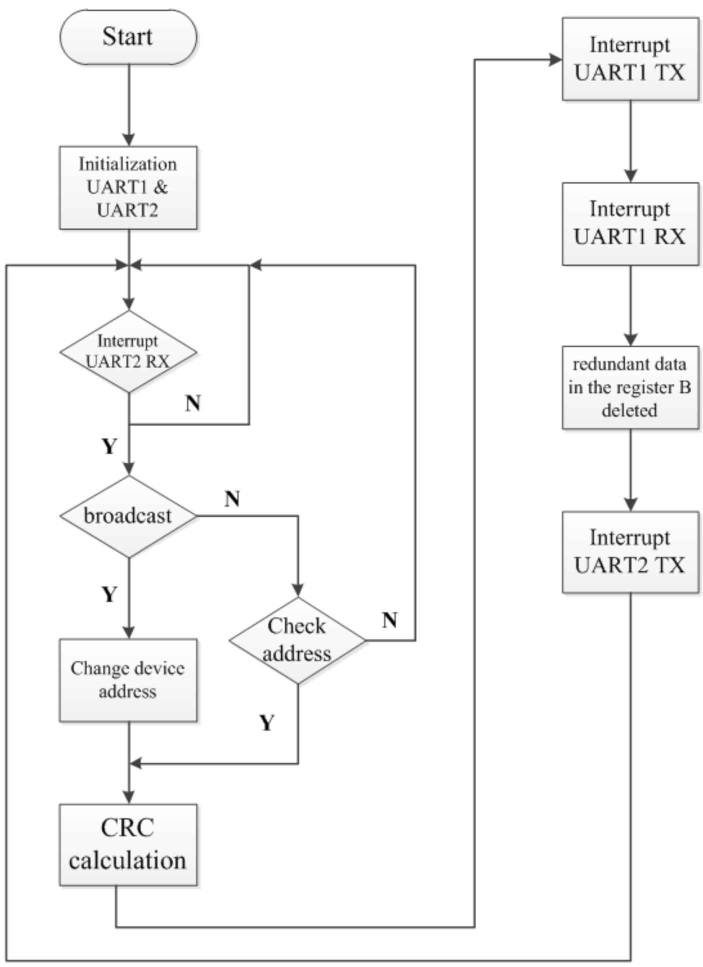


FIGURE 2. Program flow chart developed in dsPIC33F

a. Main program: It is designed to communicate with digital meter and Zigbee module. It is an infinite while loop waiting for command from computer and WSN interrupt. When the ISR occurs from UART2 RX pin, it will check the broadcast or unicast mode. If it is broadcast mode, it only needs to calculate CRC code. If it is unicast mode, the slave has to check both device address and CRC code. If the CRC check fails, it will wait for another interrupt of UART2 RX again. The serial port connected to digital meter can receive and transmit the measurement data with digital meter. The ISR function is also developed to transmission via the Modbus protocol stack.

b. UART1 TX: This is the interrupt service routine (ISR) to send data to digital meter.

c. UART1 RX: This is the interrupt service routine (ISR) to receive data from digital meter.

d. UART2 TX: This is the interrupt service routine (ISR) to send data to monitoring computer.

e. UART2 RX: This is the interrupt service routine (ISR) to receive data from monitoring computer.

4. **Communication Techniques.** ZigBee wireless networks use TI CC2530 chip. ZigBee mainly aims for low data rate applications and helps in energy conservation. The ZigBee protocol stack is built on top of the IEEE 802.15.4 and uses universal 2.4GHz ISM bandwidth. This standard operates at three bands, 2.4GHz, 868 and 912 MHz by having data rate from 250kbps, 20kbps and 40kbps, respectively. It includes 16 channels and is divided into three functions: coordinator, end device and router. Application architecture is shown in Figure 3. The meter measures data through ZigBee End Device node and sends it to coordinator node. This system uses the architecture star networking topology that is the simplest network topology in ZigBee network. The Star topology is the simplest and most limited one of the possible ZigBee topologies. A Star network consists of a coordinator node and a set of end device nodes. Each end device node can communicate only with the coordinator node. The star topology is shown in Figure 4. The benefit of this network topology is simple architecture, and all nodes only set to the same PAN ID, without regard to whether it will be affected by the other networks.

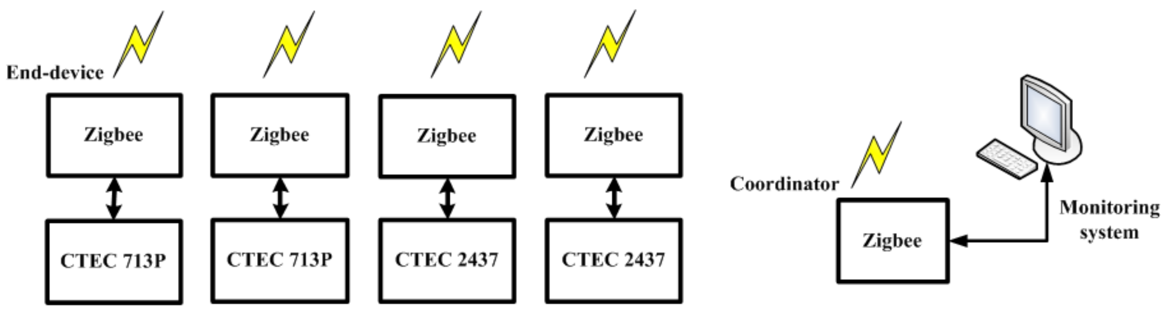


Figure 3. System architecture of wireless sensor networks

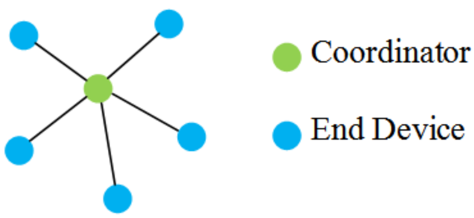


Figure 4. System architecture of ZigBee star networking topology

This system uses Modbus protocol to communicate between digital meter and PIC controller. MODBUS is the most popular industrial protocol being used today, for good reasons. It is simple, inexpensive, universal and easy to use. Also, Modbus can link multiple devices on the same network and master and slave architecture. To communicate with a slave device, the master sends a message containing (a) device address, (b) function code, (c) data, and (d) error check. The function code defines the command that the slave device is to execute, such as read data, accept data, and report status. In MODBUS RTU, data is coded in binary, and requires only one communication byte per data byte. If the master sends the query message, the slave will give a response and the corresponding architecture. The Modbus protocol format includes query and response message. There are 8 bytes in query signal and each byte has two HEXs format shown. The response bytes are based on the number of point from query. The definition of each byte is described as follows.

a. Device address: Each device has its own address. It has 256 devices from 0x01 to 0xFF. The code 0x00 is designed as broadcast command.

b. Function code: Modbus protocol can command to device and it is determined from this function code byte. For example, the command "0x03" can read holding register function. It is the command that this system usually uses to read the measurement from the instruments.

c. Starting address: Each device's address represents different Modbus slave addresses. The address range is from 0x0000 to 0xFFFF. It is the command that needs to tell device from which address is starting.

d. Number of point: From starting address, it determines the bytes that need to be operated.

e. CRC code: It does the error check function.

f. Byte count: It maps the number of data based on query message.

5. **Experimental Results.** According to the above research methods, the prototype of the WSN-based power monitoring system is designed and developed. It consists of (a) microcontroller, (b) ZigBee wireless networks system, (3) PC-based monitoring system, and (d) two model types of digital multi-function power meters. The architecture is shown in Figure 5. The multi-function meter can measure AC voltage, AC electric current, real power, reactive power, kilowatt-hour (KWH), power factor, and frequency. It also

Figure 5. The proposed prototype of monitoring system

supports the electricity measurement of three-phase four-wire system and three-phase three-wire system. As the computer uses FT232 chip module and receives the experiment data, all the power utility condition can be monitored and analyzed in an on-line fashion.

The developed board contains dsPIC33F chip, ZigBee module, MAX232 chip, and RS-232 connector. The 5V-3.3V voltage step-down circuit is also applied because the different voltage level is needed for IC module. All the circuits are designed and developed by PCB prototype machine.

The system uses Microsoft Visual Studio C# language to develop monitoring system. Its main functions are as follows.

a. Login system: After user account and password are entered, we can log in the system.

(a)

(b)

FIGURE 6. (a) User login interface, (b) graphical user interface of monitoring system

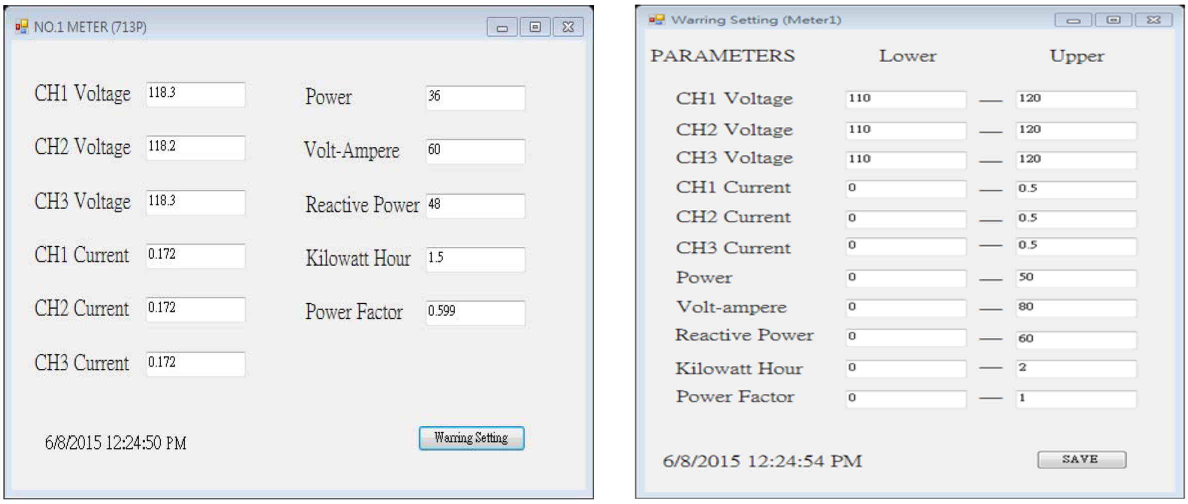
b. Real-time monitoring: The user can know the system's status immediately, and it includes (1) voltage, (2) current, (3) power, (4) real power, (5) reactive power, (6) kilowatt-hour, and (7) power factor.

c. Warning signal: If warning happens, the light will change from green light to red light.

d. System parameters setting: The user and engineer can set the upper and lower range of warning and communication setting.

It is shown in Figure 6(a) that the user needs to enter account and password when you use this application program. The parameters of COM Port number and baud rate need to be selected before the communication channel is established. After this initialization, the monitoring system starts to acquire the measure data from the digital power meters shown in Figure 6(b). The warning function is developed to indicate the status of digital meter. The warning light on the right side of digital meter indicates the status of measurement value. When the warning light is green, it means that all the measured values are in the range of normal condition. Otherwise, the red light is turned on.

If the meter picture button is clicked, it will display all of the meter parameters shown in Figure 7(a). On the bottom right corner, it has a button where we can set the upper warning level and lower warning level. Because the requirements of each meter device are different, it is necessary to set the upper warning level and lower warning level shown in Figure 7(b). The error message will display if the setting value is out of limit range.



(a) (b)

Figure 7. (a) The measurements of digital meter, (b) upper warning level and lower warning level setting

6. **Conclusions.** This system has presented a wireless network and monitoring technology using ZigBee star topology and microcontroller to achieve wireless transmission. The traditional RS-485/Modbus architecture uses polling method to support the broadcast architecture. In this paper, the WSN structure integrated with broadcast and unicast schemes is proposed to receive all digital devices measurement at the same time. With the development of computer monitoring system, the engineer can monitor and analyze all the experiment data. It can be developed and implemented to be a useful wireless monitoring system for industry applications in the future.

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