

Design of Wireless Smart Metering System Based on MSP430 MCU and ZigBee for Residential Application

Murat Kuzlu¹, Mehedi Hasan¹, Saifur Rahman¹ and Hasan Dincer²

¹Advanced Research Institute, Virginia Tech, Arlington, VA, U.S.A
mkuzlu@vt.edu, mehedi45@vt.edu, srahman@vt.edu

²Electronics and Telecommunications Eng. Dept., Kocaeli University, Kocaeli, Turkey
hdincer@kocaeli.edu.tr

Abstract

Wireless smart metering is an integral part of smart grid to realize kilowatt-hour metering, real-time data acquisition, meter reading analysis, real time monitoring and decision making etc. In this paper a low-power wireless communication system based on 16 bit MSP430FE4272 MCU and ZigBee is designed. The system architecture and the design of hardware and software are introduced in details. The designed system realizes the functions of real-time data acquisition, wireless transmission and communication between the smart meter and the central computer with the help of standard ZigBee modules.

1. Introduction

Wireless smart metering system is essential to fully realize the potential of smart grid. Real time monitoring of the electricity parameters like voltage, current, real and reactive power of the significant devices in a home is important for the control and optimization of the energy usage of those devices. In power system, the time of power demand is equally important as the amount of power demand. For example, at the time of peak load it is sometime a burden to supply the demand. However by optimizing the time of usage of heavy load devices, it is possible to make the electricity generation, transmission and distribution more stable and economically profitable. Granular control over the user devices is required to obtain this optimization goal. Wireless metering can enable the user as well as the utility to obtain that necessary control by providing real time data reading and by facilitating command and control. Smart power meter based on ZigBee communication has been proposed in [1] for the Advanced Metering Infrastructure (AMI) of smart grid. They proposed a dsPIC30F based power meter with the capability of outage recording. However, that system is not intended for the residential application as a part of Home Management System (HMS). In this paper we propose a MSP430 based smart meter which is suitable for integration with the home appliances of single phase power such as found in the ordinary home power setup. Another related design based on double MSP430 is proposed in [2] without accounting the energy monitoring system essential for HMS. Therefore, we propose a smart metering system capable of sending data to the computer to be displayed in a user interface. Software design and required serial communication schemes between the computer and the ZigBee module are also discussed at length. In addition the proposed system is capable of sending command from the computer to the remote meters, which is an essential feature for the DR (Demand Response) application.

There are several shortcomings of traditional meter readings such as biased reading, vulnerability to reading manipulation etc. So those meters are unsuitable for the modern power system applications. Detailed data, such as the time of usage, power quality, power factor, individual power phases, etc. are required to realize the smart grid applications. The remote meter reading of domestic users and industrial users is very important for ensuring safe and optimal operation of the devices. This paper designed a wireless communication system based on 16 bit MSP430FE4272 from TI (Texas Instruments) and 2.4 GHz XBee (ZigBee) module from Digi International (www.digi.com). These devices are especially suitable for low-cost and low-power wireless communication system.

The proposed wireless smart metering system design focused mainly on the collection of electric data such as Voltage (V), Current (A), Peak Voltage (V), Peak Current (A), Frequency (Hz), Power (kW), Energy (kWh), and sending these information via ZigBee wireless communication to the monitoring unit. It can capture and communicate these information on a real-time basis to enable constant monitoring of the system status and decision making at the central computer. Control command from the central computer can also reach to the remote end via the identical ZigBee based wireless communication interface which enables the use of smart plugs in addition to the smart meter to control the operation of the load in connect/ disconnect basis.

The paper is organized with the discussion of the wireless smart meter hardware in section 2. The design of monitoring module is also included in that section. Required software design is followed in section 3. Block diagram of the overall system is shown in Fig. 1.

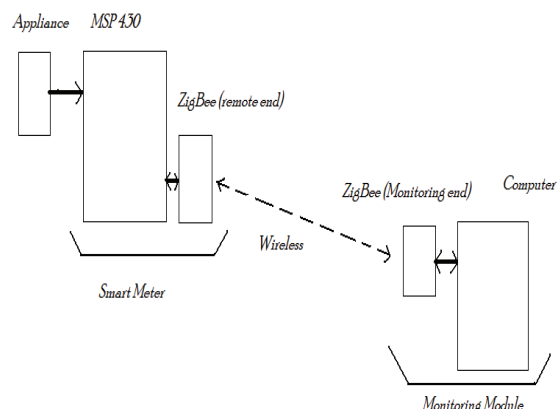


Fig. 1. Block diagram of the smart metering system.

2. Hardware Design of Wireless Smart Metering System

Two parts of the wireless smart metering system are the smart metering module and the monitoring module. The smart metering module consists of a MSP430 core and a ZigBee module. The MSP430 core collects data from the electrical appliance with the help of suitable integrated sensors. Then it uses the ZigBee module to send the collected data to the monitoring module. There is a ZigBee module connected to the computer via a serial communication port in the monitoring module. ZigBee module uses chip antenna to send and/or receive data. On the other hand, RS-232 serial communication interface is established between the ZigBee module and the computer. It is also possible to use the USB port with the help of a serial port to USB converter. A similar wireless communication system design concept is proposed in [3]. However, this design is specialized for the smart metering for the residential environment.

2.1. Wireless Smart Meter Based on MSP430FE4272

The hardware diagram of wireless smart meter is shown in Fig. 2. The Micro Controller Unit (MCU) consists of MSP430FE4272 and ESP430CE1. The MSP430FE42x2 devices are microcontroller configurations with two independent 16-bit sigma-delta analog-to-digital (A/D) converters and embedded signal processor core. Those are used to measure and calculate single-phase energy in both 2-wire and 3-wire configurations. A built-in 16-bit timer, 128 LCD segment drive capability, and 14 I/O pins are also included [4].

The MSP430FE42x(A) and MSP430FE42x2 with the ESP430CE1(A) and ESP430CE1B respectively have been specifically developed for energy metering applications. The Embedded Signal Processor (ESP) with an integrated analog front end and temperature sensor is designed for single phase energy metering. The ESP430CE does not require the computational support of the CPU because it does most of the work for the energy measurement automatically. This removes the burden from the CPU so that it can realize other tasks such as communication. The ESP430CE offers wide flexibility for current sensors, so that it is possible to use shunts or current transformers without additional hardware. All the parameters are adjustable by using the software, and the calibration parameters can be stored in the MSP430 flash memory and passed to the ESP430CE during the system initialization [5]. MSP430FE4272 is suitable for the smart meter application. This system has some advantages in power consumption, performance and integration. This wireless smart meter hardware design is done in a highly modularized way. It is divided into some modules such as saving module with UART interface, LCD, clock, serial communication module, signal conditioning circuits, impulse counting input circuits, power module, remote control module.

V+/V- and I+/I- in Fig. 2 are used for the current inputs analog front-end and voltage inputs analog front end. The voltage input from the main is usually between 110V and 230V and needs to be brought down to a range of 500mV. The analog front end for voltage consists of spike protection varistors followed by a simple voltage divider and a RC low-pass filter that acts like an anti-alias filter. The analog front-end for current inputs is a little different from the analog front end for the voltage inputs. Fig. 2 shows the analog front end used for current channel-I following the shunt resistor used. The value of the shunt resistor for this design is 250 Micro-Ohm. The anti-

aliasing circuitry follows the shunt resistor. Detailed information can be found in [5] about analog front end circuits.

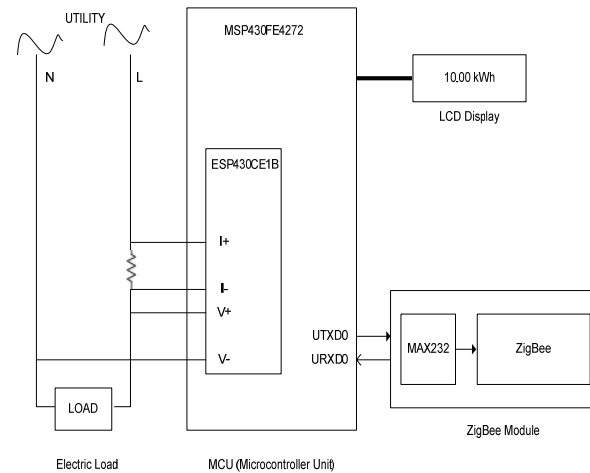


Fig. 2. The hardware diagram of wireless smart meter

2.2. 2.4 GHz ZigBee Module

In wireless smart meter and monitoring module, the used ZigBee module is a 2.4 GHz XBee module from Digi International. This module is highly optimized for the low cost ZigBee applications. IEEE 802.15.4 standard stack is the basis for ZigBee. So, this module is composed of a simple to use serial command set. It allows a very reliable and simple communication between microcontrollers, computers, embedded systems etc., virtually with any system with a serial port. 2.4 GHz XBee module supports both point to point and point to multipoint communication [6]. Therefore, it is possible to communicate with several remote units associated with different appliances from a single monitoring unit. Different ZigBee modules' configurations can be used to meet different design requirements such as: distance, budget, network topology etc.

XBee Explorer Serial from Digi International is used to connect ZigBee Module to PC via RS232 serial communication. It is a simple to use RS232 serial communication base unit for the XBee line. This unit works with all XBee modules including the Series 1 and Series 2.5, standard and Pro version. Serial and programming pins on the XBee unit can be direct accessed by plugging the unit into the XBee Explorer, attaching a RS232 cable. The board also supports DTR communication to reprogram and reconfigure the ZigBee unit [7].

2.3. Monitoring Module

The hardware diagram of monitoring module is shown by Fig. 3. ZigBee device in monitoring module is responsible for receiving the energy data from wireless smart meters and transmitting the request command from control center to wireless smart meter. Communication is performed between ZigBee module and control center by RS232 serial communication. In monitoring module, ZigBee wireless transmission module is 2.4GHz XBee module from Digi International. Also the collected energy data can be sent to the utility companies via internet by a network gateway in monitoring module.

3. Software Design of Wireless Smart Metering System

There are two software requirements for this smart metering system. One is energy monitoring software for the monitoring and control of the multiple forms of energy information by users. The other is the embedded software. This software uses C program as the development tool. It also uses IAR Embedded Workbench for MSP430 as the development environment for MSP430 MCU.

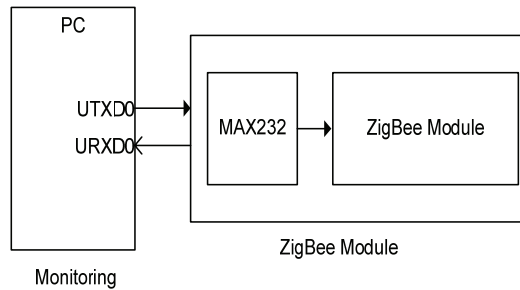


Fig. 3. The hardware diagram of monitoring module

3.1. Energy Monitoring Software

GUI (Graphic User Interface) based software provides the users to monitor and control the energy data in the computer. Its functions include real-time data exchange with MSP430, data storing, data processing and analysis. GUI based Energy monitoring software sends the request commands to MSP430 MCU for collecting the energy data such as Voltage (V), Current (A), Peak Voltage (V), Peak Current (A), Frequency (Hz), Power (kW), Energy (kWh) each 15 minutes or any different time period stated (e.g., 1, 5, 10, 15, 30 minutes etc) by users via ZigBee module. Thus, users can see all energy data on the computer screen. RS232 serial communication is used for communication interface between ZigBee module and computer. Fig. 4 shows the GUI based energy monitoring software's operational flow chart.

3.2. System Embedded Software

As stated before, MSP430FE4272 uses C program as development tool and IAR Embedded Workbench for MSP430 as the development environment. The initialization of the ESP430CE, the data output on the display, and the LED usage are included in the embedded software. It also includes UART communication and some auto-calibration routines that store the parameters back into the flash memory. After power up, the system performs the control of system initialization and call of the functions for the display update. Init FLL and system clock, init basic timer and real time clock, init LCD, init analog front end, init ESP430CE parameters, start measurement through main function, once requested in the interrupt service routines. So embedded software initializes the ESP430CE for energy measurement and outputs the data on the LCD display. Additional information about smart meter software for MSP430FE4272 is available at [5].

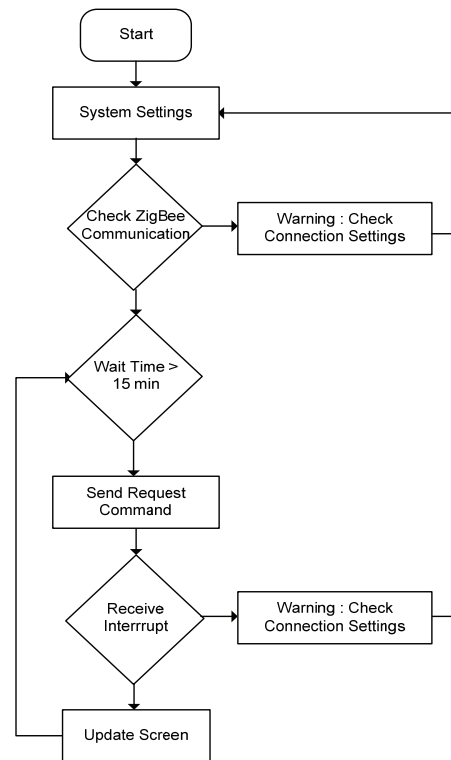


Fig. 4. Energy Monitoring Software flow chart

The software program includes two parts: background and foreground. Fig. 5 shows the background software flow chart of data acquisition and transmitter module. First of all, the module should be initialized, for example, I/O port initialization, chip configuration, opening timer and exterior interruption. Fig. 6 shows the foreground software flow chart. When the system receives the interrupt, it goes into interrupt servicing subroutine, performing data acquisition and wireless transmit.

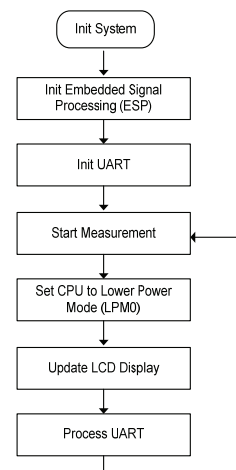


Fig. 5. Background software flow chart [5]

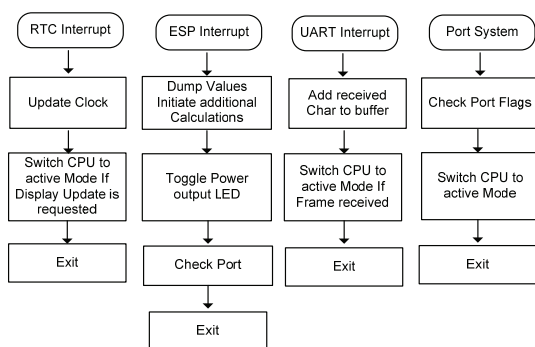


Fig. 6. Foreground software flow chart [5]

3.3. Comparison of Design Features

The proposed design is done by focusing on the suitability of wireless smart meter in the residential environment. The hardware of the proposed design is shown in Fig.7. The proposed design can be compared with previous designs of wireless smart meters or communication systems on following criteria in Table 1.

Table 1. Comparison of proposed and previous designs

	Proposed design	Previous designs
Purpose	Wireless smart metering in the residential environment to enable power data acquisition for status monitoring and control decisions.	[1] Smart metering for AMI to collect power demand data.
Design Modules	One MSP430 MCU communicates with control center computer. GUI based software enables customer interaction.	[2] Used two MSP430 MCU units without any graphical interface
Flexibility	The proposed design can be utilized to obtain smart plug functionality to turn on or turn off household appliances for DR purpose.	[1] This smart meter measures the aggregate household load so it is not suitable for the control of individual appliances.

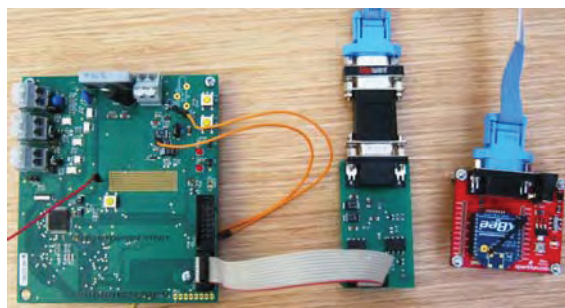


Fig. 7. MSP430FE4272 Evaluation Kit, serial interface and ZigBee module

4. Conclusion

A MSP430 MCU and ZigBee based smart meter has been designed in this paper. This system can enable the user to monitor the electricity parameters like voltage, current, real and reactive power consumption of the residential appliances. The benefit of demand response can thus be exploited with the help of smart meter by setting the usage times of deferrable loads/appliances to the off peak hours. Moreover, availability of granular data of electricity consumption of home appliances to the user helps to increase public awareness. It also empowers users to participate in decision makings regarding demand response and economic operation of the appliances. Therefore, public participation in the demand response programs can be dramatically increased by providing details picture of the behaviors of the appliances of the household. In this design of wireless smart meter, MSP430FE4272 has been selected as MSP430 MCU since MSP430FE42x2 with the ESP430CE1(A) and ESP430CE1B have been specifically developed for energy metering applications. 'XBee-1mW' with XBee Explorer Serial from Digi International was selected as ZigBee module. The system provides the real-time energy data measurement, data monitoring, two-way wireless transmission, system calibration and data upload. It is also possible to extend the use of the proposed MSP430 MCU and ZigBee based smart meter by integrating it with smart plug to enable user and/or utility to control appliances to realize demand response function. As future work, we are motivated to pursue a MSP430 MCU and ZigBee based design and implementation of a home management system capable of decision making and control to optimize the usage time of appliances to achieve demand response targets.

5. References

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