Design and Implementation of a Wireless Automatic Meter Reading System

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Abstract-**Nowadays wireless communication has become ubiquitous around the world and its application for gauging consumption of utilities by customers is rapidly gaining pace, not only in the developed world but also in the developing countries. To introduce this concept in the Sultanate of Oman, a model of Wireless Automatic Meter Reading System (WAMRS) has been developed, in which the wireless communication is based on IEEE 802.15.4 (ZigBee) standard and security is implemented by following the Direct Sequence Spread Spectrum (DSSS) protocol. Successful demonstration of WAMRS prototype has made it possible to be implemented in Oman on a larger scale for meter reading applications.**

***Index Terms*—IEEE 802.15.4,Electricity,Wireless Automatic Meter Reading System (WAMRS), ZigBee.**

I. Introduction

Electricity is the driving force behind the development of any country. With the rapid increase in residential, commercial, and industrial consumers of electricity throughout the world, it has now become imperative for utilities companies to devise better, non-intrusive, environmentally-safe techniques of gauging utilities' consumption so that correct bills can be generated and invoiced.

Traditionally, the electricity meters are installed on consumer's premises and the consumption information is collected by meter-readers on their fortnightly or monthly visits to the premises. This method of gauging electricity consumption has the following disadvantages: (i) Sometimes the meters are installed inside people's homes and, if the consumer is not at home, the meter-reader cannot record the fortnightly or monthly consumption and then the utilities' company has to resort to considering the average bill-amount of the previous months as an indicator of the likely consumption for the current month. This results in burden for both consumer and the electricity supply company. May be the consumer has not utilized similar amount of electricity in the current month as in the previous months for reasons such as, holidaying elsewhere or being in the hospital, etc. during the month, and sending him a bill for a larger amount based on his history of electricity consumption may result in his/her financial hardship. This method of billing is also not suitable for the electricity supply company because it gives inaccurate account of the overall electricity consumption in the consumer's area and may ultimately result in errors in future planning by the company. (ii) Hiring of a number of meter-readers by utilities' companies and providing means of transportation to them is an expensive burden on the companies' budgets. Moreover, these visits of the meter-readers to consumers' premises generate pollution in the air which has negative impact on the environment and the greenhouse effect. (iii) Dissatisfaction of some customers who consider meter-readers' entrance to their homes as some sort of invasion of their privacy. This is especially applicable in countries, like Oman, where during the day most men are outside of their homes earning a living and only women are at home doing the housework.

In order to overcome these disadvantages of the traditional meter reading system, efforts are underway around the world to automate meter reading and to provide comprehensive information to the consumer for efficient use of the utilities[1,2,3]. While Italy's ENEL SpA is considered to be first utilities' company which heralded in the new era of Automatic Meter Reading (AMR) in Europe, it is by no means alone in this massive endeavor. Among other countries, Germany, Greece, United Kingdom, Australia, and Argentina have deployed several AMR projects with the aim of reducing the cost of meter-reading, improving the collection of data from the meters, and then providing timely comprehensive information to consumers about their energy usage for better load balancing and utilities' management. By 2008, all European Member States have to implement the Energy Services Directive, which requires customers to be given more information about their energy usage, and receive more timely and accurate billing.

To complement AMR initiatives underway in various countries, a pilot project called "Design and Implementation of a Wireless Automatic Meter Reading System" (WAMRS) was undertaken by a group of students and faculty at Sultan Qaboos University (Oman), with the author being the main supervisor of the project, aimed at coming up with a model of wireless electricity meter-reading system which can be implemented in Oman. The model should circumvent the disadvantages mentioned previously and be economically viable within the budget allocated for the project by the Department of Electrical and Computer Engineering (about US$500).

This paper is organized as follows: In Section II, detailed design of WAMRS project has been presented. This is followed by its implementation and testing explained in Section III. Summary and conclusion are given in Section IV which are followed by Acknowledgment and References.

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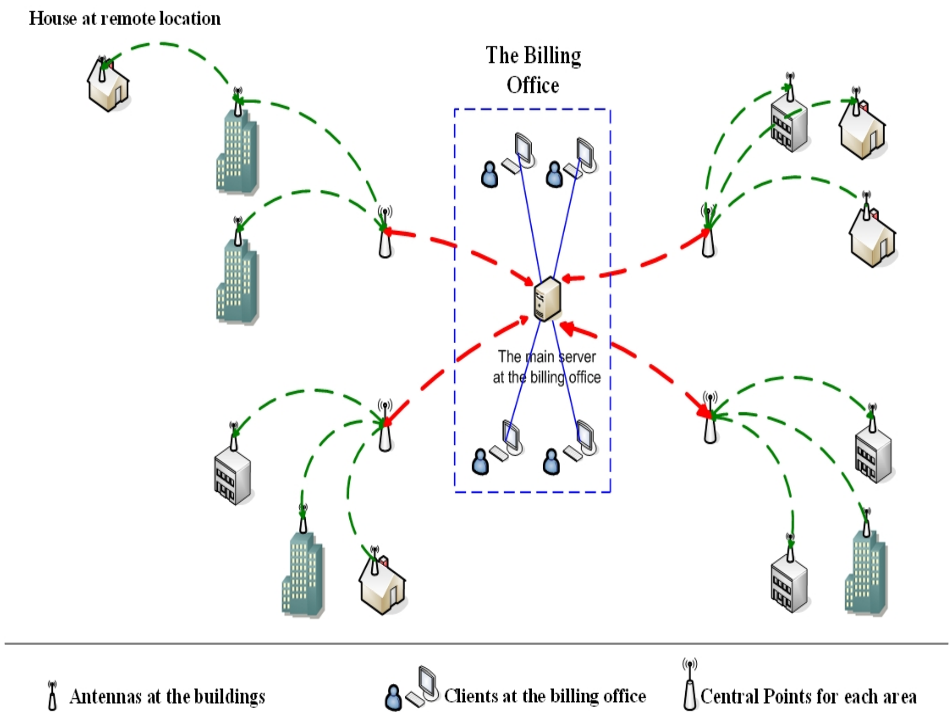

Fig. 1. Overall global view of WAMRS project

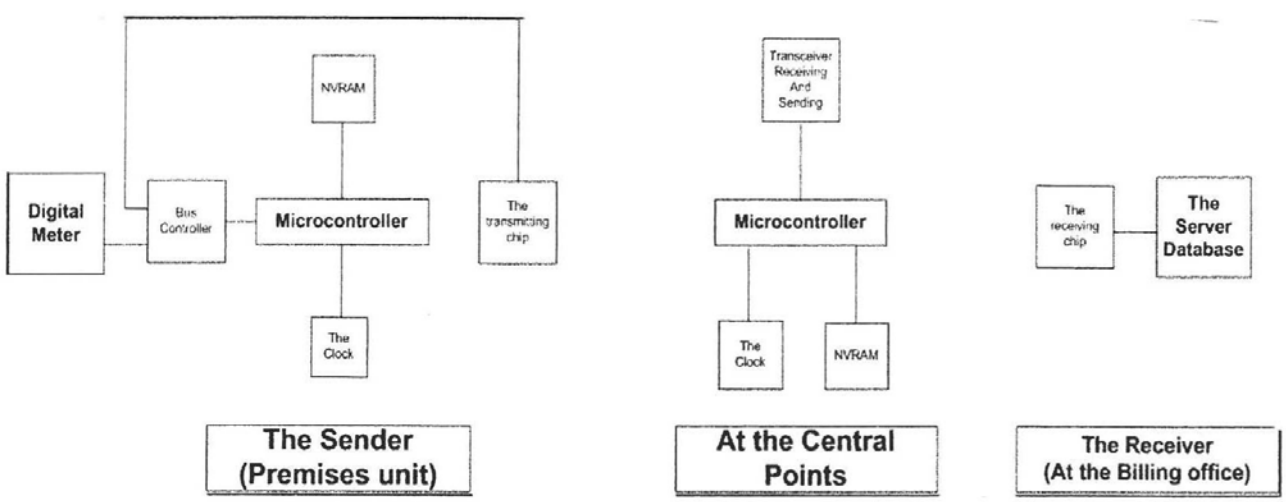

Fig. 2. Block diagram view of WAMRS design

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II. Design of WAMRS

An overall global view of WAMRS is shown in Fig. 1. The main goal of WAMRS project was to send periodical readings of an electricity meter wirelessly to a server in the billing office of the electricity supply company. There were central points covering each geographical area, since each premises unit would have limited range of wireless coverage, while the central points would have long-range wireless transmitters that could deliver the meter-reading data over long distances to the billing office. The server in the billing office had a highly secure database system which enabled authorized staff members of the electricity supply company to read and print electricity bills. For premises out of the coverage area of any central point, the solution proposed was to make the nearest premises unit (covered by a central point) as the central point for such remote premises. This added a constraint on the wireless device used for such purpose because such a device should have the capability of both sending and receiving the data.

A block diagram of WAMRS design is given in Fig. 2. It consists of three main parts, the Sender (also called Premises Unit), the Central Point's Unit, and the Receiver (server database at the billing office of the electricity supply company).

A. The Sender (Premises Unit)

1) Digital Meter: After conducting a survey of the digital kWh meters available in the international market and comparing their prices and characteristics, we decided to use a single-phase MK-60LCD digital meter, provided by the Circutor Company[4]. This meter satisfies Omani power systems requirements since it runs with 230V/50Hz supply and can handle maximum current of 60(120)A. The meter has a pulse port and a memory to store records in case of power shutdown. The cost of the meter was US$290 which was the lowest price available for digital meter and within our budget. Note that we had designed WAMRS for a single-phase system mainly because the cost of three-phase digital meter was about US$100 more than the cost of a single-phase meter, and this would have taken us out of our budget allocation. Nevertheless, the theory of implementing a three-phase WAMRS is identical to a single-phase wireless automatic meter-reading system.

2) Bus controller: A bus controller is needed to select the input to the microcontroller from either the digital meter for reading the consumption or the wireless chip which can receive data from the central point or the remote location (if it exists). A simple 2x1 multiplexer was considered sufficient to serve as bus controller for this project.

3)Microcontroller: The main function of the microcontroller is to control the communication between the Premises Unit and the Central Points, and also between different components of the Premises Unit. It is also responsible for encrypting the data before transmission and for decrypting the received message. For this project, Philips P87LPC764 microcontroller [5] was selected because it satisfied the requirements of the project (low power consumption, two-wire communication port, full duplex UART for digital meter-wireless chip communication, and low cost of about US$3).

4) NVRAM: A non-volatile RAM was chosen because it is faster compared to most kinds of ROM and is cheaper for the size of memory needed for the project. The memory was segmented into different blocks: one block of memory was used to store configuration files which can be updated remotely by the server through the microcontroller, another block was assigned for storage of the random numbers table used for authentication, another block was used for recording the daily, weekly, and monthly power consumptions, and the last block of memory contained a list of IP addresses with which the current unit can send or receive data. Philips 24LC16B [6] memory chip was used for the project which has a size of 16KB, works at 3V and needs only two wires to communicate with the microcontroller. It has the ability to store data for more than 200 years and its cost is about US$0.50.

5) Real-time Clock: The function of the clock is to "wake" the chip up at pre-determined time for transmission of power consumption and then to put it back to "sleep" to conserve power. Ricoh RV5c339A [7] was chosen for the project because of its accuracy and ignorable active mode power consumption. It has an alarm feature for interrupting the microcontroller and it was provided to us free-of-charge by Ricoh Corporation.

6) Transmitting Chip: The first step in designing any wireless network is to perform a site survey which involves an investigation of critical features and characteristics of the site (building) in terms of building material, floor dimensions, and possible sources of interference. Since the designed system was planned to be installed at a laboratory building in the Department of Electrical and Computer Engineering at Sultan Qaboos University (Oman), the following data was obtained during the site-survey phase: (a) The dimensions of each of the three floors of the building are 115.2x22.8 meters. (b) The building is made of concrete and most of the walls are made of cement-based material. (c) No metal shields are used in the building but there are a number of small metal studs around the extremities of each floor. (d) Major source of interference might be Bluetooth-enabled devices (mobile phones, PDAs, and laptops).

After comparison of various commonly available wireless communication techniques, ZigBee was chosen for our project [8]. ZigBee is very secure (uses Advanced Encryption Standard) and is self-configuring. It allows ad-hoc networks, provides reliable data transfer in noisy, interference-rich environments, and addresses the unique needs of most remote monitoring.

Among the various available ZigBee products, it was found that Maxstream's XBee-PRO chip [9] was most suitable in terms of range, data rate, security, and cost so this chip was chosen for the project. The chip is available with a whip-antenna, a low-profile chip antenna, or U.FL connector (to which external antenna can be connected). The whip antenna provides a better range compared to a chip antenna in both outdoor (1335 m) and indoor (43 m) environments so whip-antenna was selected for the project.

B. At the Central Points

When data has to be transmitted wirelessly over long distances, it is necessary to have some mechanism at pre-determined distances from the sender for temporarily receiving and retransmission of data to the designated receiver. As shown in the WAMRS block diagram (Fig. 2), at the central points, the system will consist of a transceiver, microcontroller, the clock, and a NVRAM. This hardware is similar to the hardware at the Premises Unit, so at the time of implementation of the system, each premises unit can be configured to behave both as a sender (when transmitting its data) and a central point unit (for temporarily receiving/retransmission of data coming from other neighboring premises units) at different times.

C. The Receiver (at the Billing Office)

The hardware at the billing office consisted of a receiving chip and a database server.

1) Receiving Chip: To remain compatible with the XBee-PRO transmitting chip, the XBee-PRO PKG (Receiver) [10] was selected as the receiving chip for the project. It is a small, high performance, low cost wireless data receiver operating in the 2.4 GHz ISM (Industrial, Scientific, and Medical) band and has FCC approval for operation without a license. Based on IEEE 802.15.4 standard, it uses OQPSK (Offset Quadrature Phase Shift Keying) with a half-sine pulse shaping filter as modulation.

2) Database Server: The database server requires software for communication with the premises unit of each consumer and, based on the consumption data received, it needs to generate an electricity bill.

Prior to allowing communication between the sender and receiver, it will be necessary to authenticate the administrator at the billing office and the sender at the Premises Unit. To validate the source, a very simple approach used was a three-way handshake such as that used in TCP. In TCP, this handshake is used for synchronization, but in this project, this technique was used for authentication of the source. A block of memory in NVRAM of each Premises Unit, at the central point , and the memory of the server at the billing office is used to store a 256rows x 3columns table filled with random numbers in 0-255 range (all 768 entries of the table will be the same stored at all locations of the system). The source at the Premises Unit will send an initial request including a random number selected from the first column of its stored table. The destination (at the central point or the billing office) will reply with a datagram containing the random number entry in the second column of the same row (as the sender) of its stored table. At this point, the source has authenticated the destination, so it sends its data with the random number entry in the third column of the same row of its stored table to authenticate itself to the destination.

The data packet used in WARMS consists of the following fields: (a) Source Destination (S/D) IP Addresses: A 128-bit field, which has been divided into two 64-bit unique IP addresses for both source and destination. This is important for authentication of the source using three-way handshake protocol. (b) Original Source/Original Destination (OS/OD): This is of the same size as the S/D field and is important in case of the Premises Units which are located at remote places or if the server wants to connect to a certain Premises Unit through a certain central point. (c) Power Consumption: This field is 20-bits long (to accommodate maximum meter reading of 999,999 kWh) and contains the latest digital meter reading sent by the Premises Unit. (d) Random Sequence Number: An 8-bit field, used for authentication, as explained previously.

Using password to authenticate the administrator in the billing office, he/she can generate an electricity bill for the consumer, upon receiving the consumption data,. For the project, the bill generator program was written using Visual Basic/Macromedia Flash MX, interfaced with a SQL database.

D. Power Supply Considerations

The power required for WAMRS can be divided into three parts: (i) *Digital kWh meter:* This component is powered by a built-in system and a battery in case of power shutdown. The manufacturer of MK-60LCD guarantees a battery life of 8 years for the meter. (ii) *XBee receiver antenna:* This component is powered by an adapter provided by Maxstream. (iii) *Microcontroller, NVRAM, the Clock and XBee-PRO chip:* To determine the most appropriate power supply for these components, the power requirement of each component was considered and it was found that to operate the Premises Unit, a DC power supply of 3V with current of at least 0.3A would be required. A 9V, 1.1A adapter comes bundled with XBee chips which was used in a voltage regulator circuit to obtain V_{out} of 3V with a short-circuit current of 0.75A, sufficient to drive the Premises Unit components. In case of power shutdown, a Duracell 3V rechargeable battery (CR2), which is readily available in stores and has a shelf-life of 7 years, can be used as the UPS (uninterrupted power supply) source for the Premises Unit.

III. IMPLEMENTATION AND TESTING

WARMS prototype has been successfully implemented and tested in the Department of Electrical and Computer Engineering at Sultan Qaboos University (Oman) and has generated considerable interest by the Ministry of Housing, Electricity, and Water (MHEW) for possible implementation in Oman where home privacy is considered very important by the local people and entry of the meter-readers (mostly men) into their homes for recording utilities' consumption during day time, when men of the family are at work and only the women are at home, is not always welcomed.

According to FDA [11] and CTIA [12], the available scientific evidence does not show that any health problems are associated with using wireless devices. Therefore, use of wireless automatic meter reading is not expected to yield any negative health effects on the consumers.

The overall cost of WAMRS has been calculated to be about US $441, which was within our budget range of US$500.

IV. Summary and Conclusion

An economical prototype of Wireless Automatic Meter Reading System (WAMRS) has been developed, in which wireless communication is based on IEEE 802.15.4 ZigBee standard and security has been implemented by following the Direct Sequence Spread Spectrum (DSSS) protocol. Bill generation software has been programmed using Visual Basic/Macromedia Flash MX, interfaced to a SQL database server. Successful implementation and demonstration of WAMRS has made it possible to be implemented on a large scale in Oman and efforts are already underway to achieve this objective.

Acknowledgment

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