Ubi-PowerMeter: A Novel Paradigm to Reduce Energy Consumption

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Abstract

Energy problem is becoming one of the toughest issues nowadays. In order to meet the increased demands regarding energy awareness, we have been developing a new way of representing and interacting with energy in electric products, specifically home appliances. The Ubi-PowerMeter is such a paradigm, which consists of hardware devices including smart meters and residential gateway, wireless communication based on ZigBee protocol, intelligent component to analyze gathered data, and interface design involving GSM module and the construction of web site. Using this full functional prototype, this paper also investigates the accuracy and stability of it, as well as the effect on reducing energy consumption.

Keywords: Energy Awareness, Smart Meter, Gateway, ZigBee, Data Analysis

1. Introduction

Rapid advances in electronic revolution not only transform our modern life, but also enlarge the world's appetite for energy, especially electricity. A strong motivation to meet the growing demands for energy is emerging recently. As a result, how to reduce energy consumption is becoming one of the hot spots for both industrial and academia. Various activities such as US's national energy awareness month [1], ongoing planning which mainly concerns the energy aware in state of California [2] present the fact that energy efficiency begins with energy awareness. European experts believe that households with energy aware devices could use the information to reduce their energy consumption by up to 10% after they collected and analyzed a large amount of relevant data over past years [3]. A resource conservation competition was held in students' dormitories in Oberlin College by its environmental studies, and the results of this investigation provided evidence that real-time resource feedback systems, when combined with education and an incentive, interest, motivate and empower college students to reduce resource use in dormitories [4]. Environment Change Institute in University of Oxford [5] also proves the benefit of detailed feedback on energy consumption of each domestic electrical appliance. Some further studies even figured out how and why improved feedback on electricity consumption could provide a tool for customers to control their consumption and ultimately save energy better, from the aspect of psychological [6].

With the development of WSNs (Wireless Sensor Networks), ubiquitous computing and

MEMS (Micro Electro Mechanism System), pervasive energy aware technology is walking towards us. The advent of novel systems which are able to provide us with detailed and real-time information about the electronic consumption of each home appliances respectively anytime and anywhere, are quite necessary.

In this paper we propose a novel paradigm that is energy aware and smart enough to advise people how to reduce energy consumption according to the information it gathered, no matter where they are and when it is. And the result shows this prototype is effective and efficient in reducing the energy consumption. The remainder of this paper is organized as followings. Section 2 lists relevant researches on energy awareness, energy efficiency and the approaches about how to lower electric consumption. Section 3 explains the overview of our system's framework and the definitions of five sub-systems are given in this part. Section 4 details the implementation on each sub-system respectively. The description of the experimental scenario, discusses and analysis of this work are indicated in section 5. Finally, the conclusion and our future works are stated in section 6.

2. Related work

A report presented by Ad-Hoc Advisory Group for EU (European Union) points out the ICT (Information and Communication Technologies) will play a major role to reach EU's energy and environment targets [7]. American scholars make similar themes and recommendations, which view IT (Information Technologies) as one of the fundamental and crucial issues in America's energy future, as well [8].

Fortunately, there are already some new ways of representing and interacting with energy in electric products in order to support the increased demands regarding the awareness of energy use and efficiency. Interactive Institute in Sweden have been developing Power-Aware Cord, which is a re-design of a common electrical power strip that displays the amount of energy passing through it at any given moment [9,10]. ARM-based system and WiFi technology are adopted to realize automatic meter reading and power quality management by researchers in BeiHang University [11]. Other methods using Power Line Carrier (PLC) [12], GPRS (General Packet Radio Service) \GSM (Global System for Mobile communication) [13], Bluetooth [14] etc. are also engaged in addressing such problems as power awareness.

The aforementioned solutions, however, failed to integrate isolated power meter into a union network that is universally accessible. Moreover, there are still few researches focusing on advanced feedback mechanism, which possesses the abilities to make useful advices about how to efficiently reduce energy consumption through different appliances individually without deteriorating the convenience of daily life for users.

3. Architecture

Ubi-PowerMeter system takes the responsibility of building the link between our physical world, specifically, a variety of home appliances, and the pervasive network around us. As depicted in figure 1, smart meters, which are capable of measuring and recording the energy consumption in time, and simultaneously transmitting corresponding usage data through wireless channel, build the bridge between those residential appliances and low power sensor wireless network, that is, ZigBee network in our propounded architecture. Although ZigBee has some shortcomings such as short range connection, its features symbolized by low cost, no limitation of the number of devices in one network, still make it quite adequate to set up a energy efficient mesh network in home environment [15]. Residential gateway, which acts as an entrance to either GSM network or Internet, plays another essential role in this paradigm. It converts data packets from ZigBee protocol format into GSM messages and TCP/IP protocol format, and also be able to transfer Internet sockets and GSM messages to ZigBee data. Web services are available here to supply the real time information about electric consumption and some useful advises on energy conservation according to those data. Hence, an expert system and other technologies involving data mining, distributed computing, and semantic web services are necessary. At last, based on the structure discussed above, users could obtain the feedback on the energy cost of their home appliance and related knowledge transparently, pervasively and comfortably, and furthermore they are expected to be gradually accustomed to use those appliances more efficiently and energy-savingly with the assistance of the Ubi-PowerMeter.

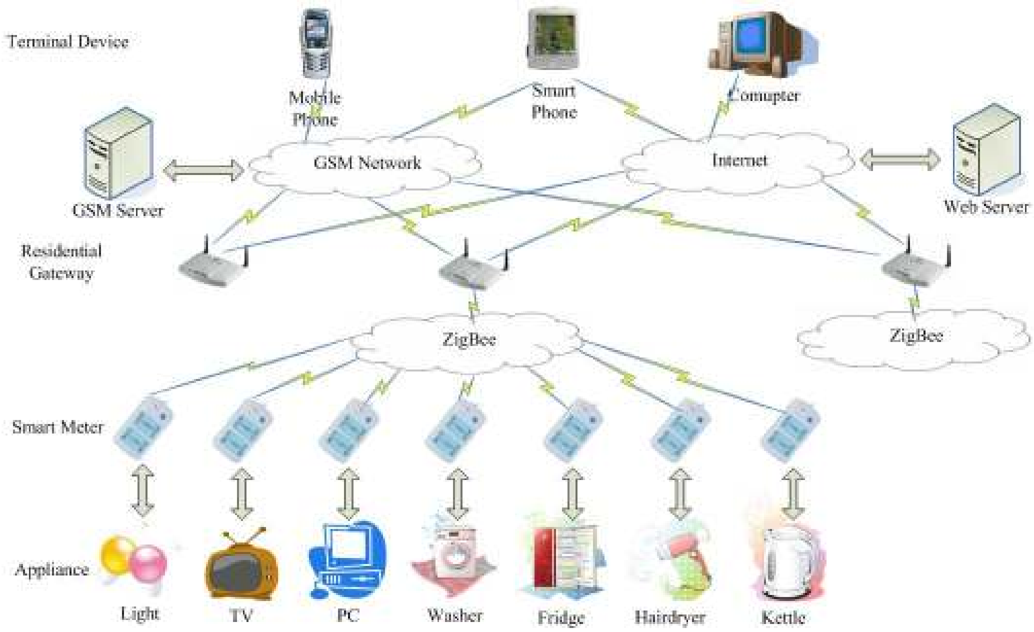


Figure 1. System Architecture

To build such a paradigm, we first divided it into several sub-systems as shown in figure 2 to facilitate our implementation. We define these sub-systems as followings.

a) Data Collection System: Its mission is to collect accurate and real-time information about the energy consumption, and to be combined into smart meters.

b) Wireless Communication System: This sub-system takes charge of receiving and transferring data based on ZigBee network reliably and timely. Wireless Communication System is one of main components of both smart meter and residential gateway.

c) Residential Gateway System: It links Wireless Sensor Networks (WSNs) with GSM networks and Internet, so that a ubiquitous solution could be achieved.

d) Data Analysis System: We import Data Analysis System into our paradigm to add some intelligence behaviors. Throughout data gathering, classifying, integrating and modeling, this sub-system is supposed to make some helpful suggestions about how to reduce users' electric cost.

e) Terminal Application System: Any system should have its own interface with users. The ubiquity of web browser, and the convenience of accessing a web application without distributing and installing software on local client computer, introduces this way to our system. For the same reason, the acceptance of SMS (Short Message Service) as notification service makes mobile phone becoming the other terminal interface. Users could easily be informed their concerned energy consumption information via Internet using web browser, as well as checking their mobile phone.

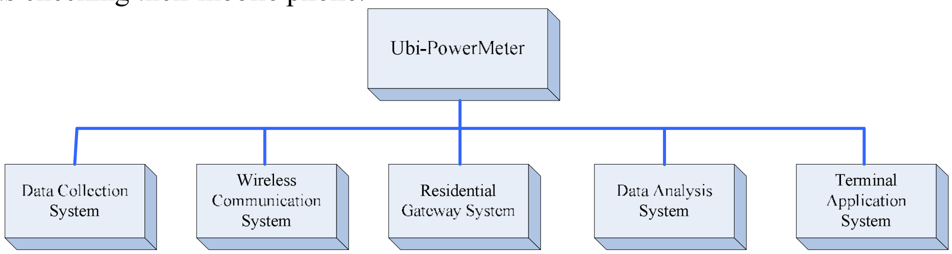


Figure 2. Sub-Systems in Ubi-PowerMeter System

4. Implementation

4.1. Data collection system

The Data Collection System consists of core power metering IC (Integrated Circuit), current channel input, voltage channel input, power inverter module and communication interface with processor. Figure 3, the hardware circuit of this sub-system, illustrates how we integrate those modules together.

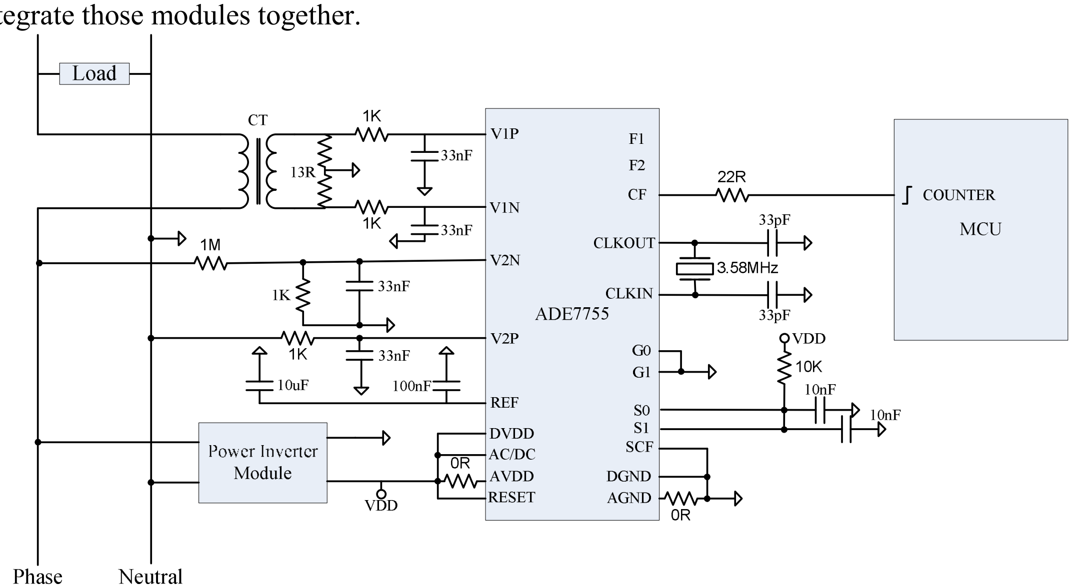


Figure 3. Hardware Circuit of Data Collection System

a) Core Power Metering IC

ADE7755 is a high accuracy electrical energy measurement IC, the specification of which surpasses the accuracy requirements as quoted in the IEC 1036 standard. ADE7755 is supplied by single 5V DC (Direct Current), and typically cost very low power. The two ADCs (Analog to Digital Convert) of ADE7755 digitize the voltage signals from the current and voltage channel. Then the instantaneous power signal could be generated by a direct multiplication of the current and voltage signals. The active power calculation is derived from the instantaneous power signal. Finally, F1 and F2 pins output the low frequency as well as CF pin's proportional high frequency generated by accumulating this active power information[16]. ADE7755 is able to handle with both sinusoidal signal and nonsinusoidal signal, as a result, superior stability and accuracy over extremes in environmental conditions is promised.

b) Current Channel Input

In our application the maximum input current of smart meter is set at 12.5A, which is high enough to home appliances. Consequently, we select a CT (Current Transform) whose turn ratio is 1:200, to give a peak differential voltage of 470mA/gain at maximum load [16], and the corresponding burden resistor is valued at 13 ohm.

c) Voltage Channel Input

ADE7755's voltage channel input is directly biased around the neutral line. The resistor divider of 1M ohm and 1K ohm provides a voltage signal that is proportional to the line voltage, which is 220V AC (Alternating Current), 50Hz.

d) Power Inverter Module

Traditionally, most power inverters use a transformer and rectifier circuit to convert an AC voltage into the DC voltage. This solution, however, has its own disadvantage, that transformers are usually expensive and take up a considerable amount of space. On the other hand, in our application, the overall current cost is assumed to be less than 50mA (ADE7755 costs around 3mA, wireless transceiver and microcontroller cost at most 30mA, and other parts cost no more than 15mA). As a result, resistive and capacitive transformerless power supply characterized by low cost, small size, and low current output is adopted.

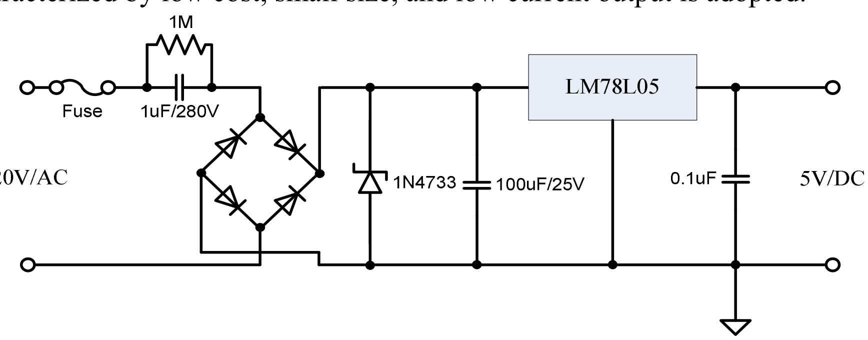


Figure 4. Circuit of Power Inverter Module of Data Collection System

Figure 4 presents the circuit of power inverter module. A fuse is placed to protect the circuit during an over-current condition. One 1uF safety capacitor is charged to step-down the input voltage as long as the circuit works, while a 1M resistor in parallel with it creates a RC discharge loop to ensure the safety when the power supply is off. Full-wave bridge rectifiers, together with a zener diode regulate the voltage at low DC voltage. At last, 78L05, a 3-terminal positive regulator, provides the accurate voltage output. This module's maximum load-carrying capacity can be calculated by the following equation.

$$I_{OUT} \le I_{IN} = V_{FLRMS} / X_C \quad (1)$$

Where V_{FLRMS} refers to the RMS (Root Mean Square) voltage of a full-wave AC sine wave and X_C is the reactance of the 1uF/280V capacitor, that is:

$$V_{FLRMS} = (\sqrt{2}V_{RMS} - V_Z) / \sqrt{2} \quad (2)$$

$$X_C = 1 / 2\pi fC \quad (3)$$

Where V_{RMS} equals 220 in China, V_Z is the voltage drop across the zener diode, f is the frequency AC and C is 1uF. So I_{OUTMAX} is valued at 67.98mA, which is enough for the load.

e) Communication with processor

We interface the ADE7755 to a micro controller by the CF high frequency output by setting SCF=0 and S0=S1=1. This frequency is given by:

$$F_C = 8.06 * V_1 * V_2 * Gain * f_i / V_{REF}^2 \quad (4)$$

Where V_1 is the differential RMS voltage signal on Channel 1, V_2 is the differential RMS voltage signals on Channel 2, *Gain* equals 1 as we set G0=G1=0, f_i equals 13.6 as we set S0=S1=1, and V_{REF} is 2.5V [16].

The average power proportional to the average frequency is given by:

$$Average\ Frequency = Average\ Active\ Power = Counter / Timer \quad (5)$$

And the energy consumed during an integration period is given by:

$$Energy = Average\ Power * Time = Counter \quad (6)$$

So we could obtain the value of V_1*V_2 according to the output frequency, and then the energy consumption could be got. We utilize one external interrupt and one timer interrupt from the microcontroller to realize this function. The programming flowcharts are as figure 5.

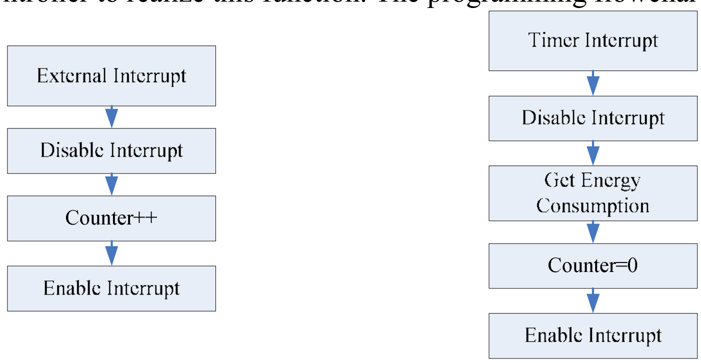


Figure 5. Flowcharts on Getting Energy Consumption

As long as there is a pulse captured by external interrupt, counter is added by 1. We set the integration period at 20 seconds, and once the time runs out, a timer interrupt is triggered, and then the energy consumption during this period is obtained.

4.2. Wireless communication system

As mentioned in the architecture section, due to lots of advantages in such applications, ZigBee based wireless communication solution using CC2430 is selected. CC2430 is a true System-on-Chip solution specifically tailored for IEEE 802.15.4 and ZigBee application [17]. CSMA/CA (Carrier Sense Multiple Access/Collision Avoidance) hardware support, AES (Advanced Encryption Standard) security coprocessor, watchdog timer and excellent receiver sensitivity are all available in CC2430. SoC solution makes the hardware design of CC2430 quite easy, which mainly involves very simple peripheral circuit and antenna design. We implement the hardware design as the circuit given by [18,19]. And LM1117-3.3V is placed to regulate the voltage to 3.3V to supply CC2430. Besides, we also use AES encryption to enhance the transmission security.

Figure 6 depicts the concrete frame of a ZigBee packet which structures of physical layer, MAC (Medium Access Control) layer, network layer and application layer. The lower two layers are designed fairly in accordance with the IEEE 802.15.4 standard. The network layer mainly takes the responsibility of routing, control of communication radius. And the upper application layer encapsulates the energy consumption data, as well as other fields, which are used to control the message type and indicate the source and destination ID of current packet. In order to limit the total length of packet to reduce network traffic, we set the length of message data at 4 bytes, which is sufficient for our energy consumption. We also take advantage of acknowledgements and timeouts to achieve relatively reliable data transmission. The number of retransmission tries is 5 for each node, that is, after failing 5 times, this packet will be dropped. And the timeout is set at 100ms, while we order the time interval of each smart meter sending data to the home gateway at 5 minutes.

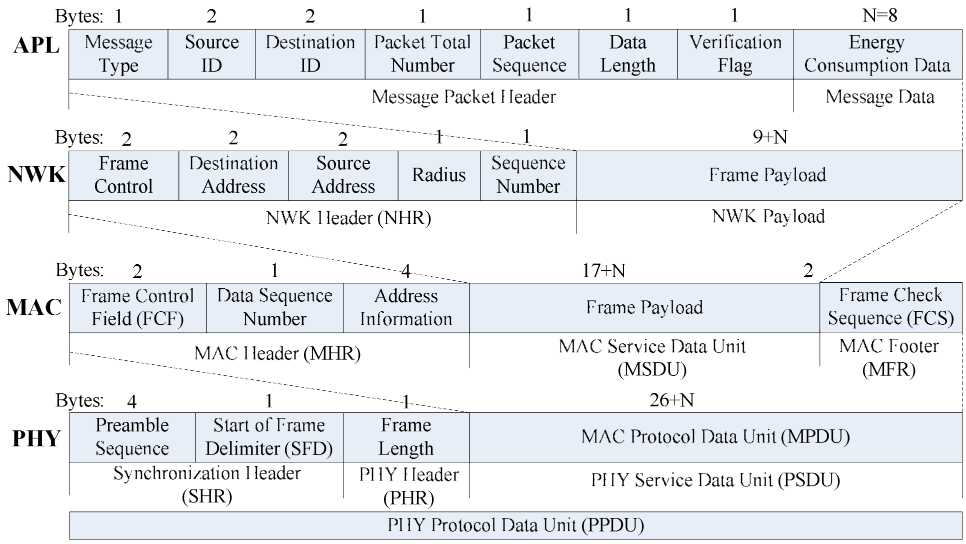


Figure 6. Frame of a ZigBee packet in Our System

The workflow of smart meter is shown as figure 7. CC2430 works at PM1 (Power Mode 1, which costs only 0.3mA whereas Power Mode 0 consumes nearly 30mA) for the most time, and only when it's time to send energy consumption information via wireless channel, it enters into PM0 (Power Mode 0). In PM1 only one external interrupt and the sleep timer are available, however it is enough to fulfill such target. As discussed above, energy consumption is obtained from the Data Collection System per 20 seconds, while Wireless Communication System transmits the information to gateway per 5 minutes.

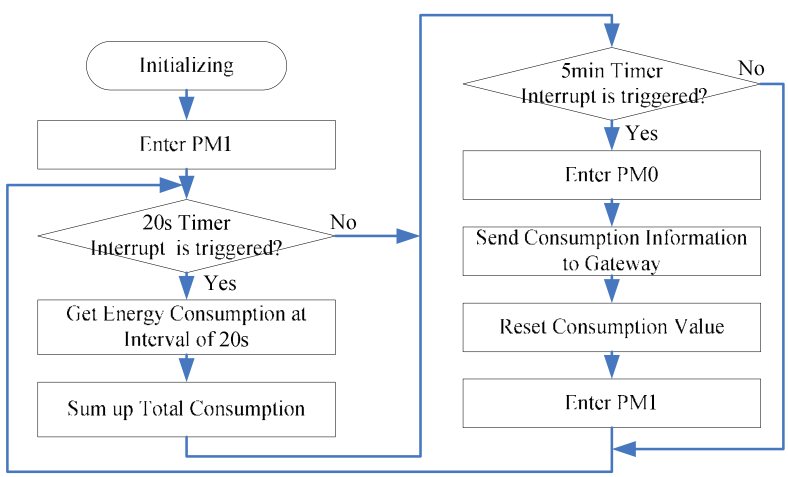
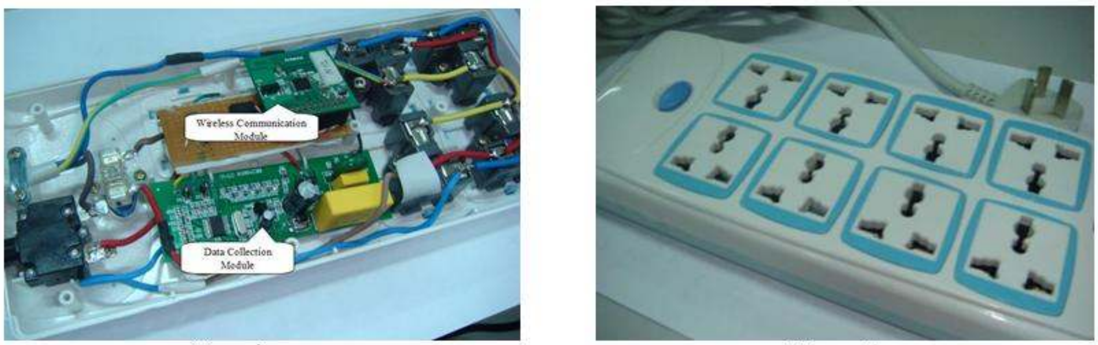


Figure 7. Workflow of Smart Meter

Smart meter is a re-designed common electrical power strip constituted by Wireless Communication System and Data Collection System. Figure 8 represents both the inner and external appearance of the prototype of our designed smart meter.



Inner image External image

Figure 8. Inner Image (left) and External Image (right) of Smart Meter

4.3. Residential gateway system

Figure 9 demonstrates the hardware architecture of residential gateway, which clearly illustrates the seven modules and the connections among them. The descriptions of the main modules of home gateway are as followings.

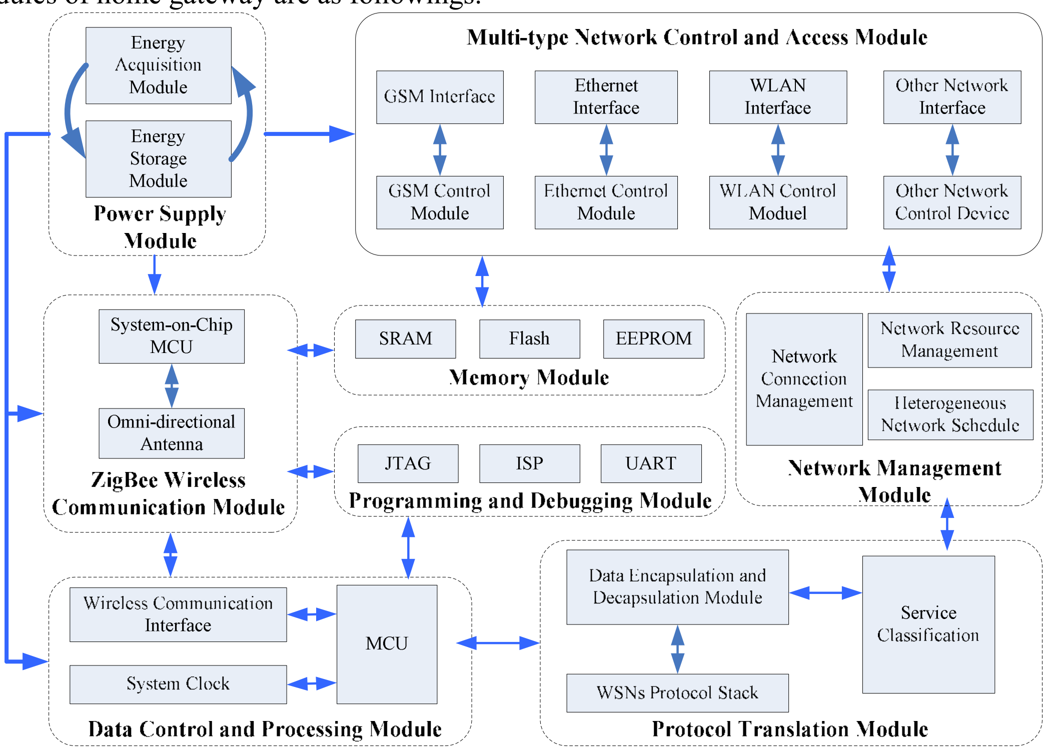


Figure 9. Hardware Architecture of Residential Gateway

a) Power Supply Module

This Module comprises two sub-modules, energy acquisition module and energy storage module. Our gateway could acquire energy either from an AC to DC adapter or a Li-ion battery. TI's IC, bq24075 is utilized to charge the Li-ion battery when AC adapter is worked, and it is also responsible for managing the battery as soon as AC adapter is disconnected. The hardware design is as same as the instructions in [20].

b) Multi-type network Control and Access Module

The interconnection and intercommunication between WSNs and multi-type heterogeneous networks is achieved by this module. According to the access standard and interlayer structure, this module includes multi-type networks access devices such as Ethernet controller and its network interface device, WLAN adaptive device as well as mobile communication network coded modulation system and its protocol interface.

c) ZigBee Wireless Communication Module

The hardware design of this module is exactly the same as the aforementioned wireless communication sub-system. Apart from wireless data transmission, this module also takes charge of the data exchange between Data Control and Processing Module and itself.

d) Memory Module

Residential gateway often has to cope with dozens of smart meters simultaneously, and it should also store the vital information such as the total energy consumption through the received data. As a result, besides the EEPROM and SRAM required by the ARM-based MCU (MicroController Unit), we add an extra Flash to solve this matter.

e) Programming and Debugging Module

The ARM-based MCU can be programmed through the UART (Universal Asynchronous Receiver/Transmitter) interface, while the program can be downloaded to CC2430 via either JTAG or ISP interface.

f) Network Management Module

This module realizes the access and interconnection of the data and services between all kinds of networks, including: 1) heterogeneous network schedule component, which realizes the schedule of multi-type networks; 2) network connection management component, which manages and realizes the connection between gateway device and multi-type heterogeneous networks; 3) network resource management component, which manages and allocates the software and hardware resources efficiently and realizes the resource sharing.

g) Data Control and Processing Module

As the center schedule fixture of the whole gateway device, this module mainly realizes the global processing, data fusion and information extraction. We use S3C2440A as the MCU, which is developed with ARM920T core, and characterized by its low power, simple and fully static design. Embedded Linux OS (Operating System) is implemented to support our development.

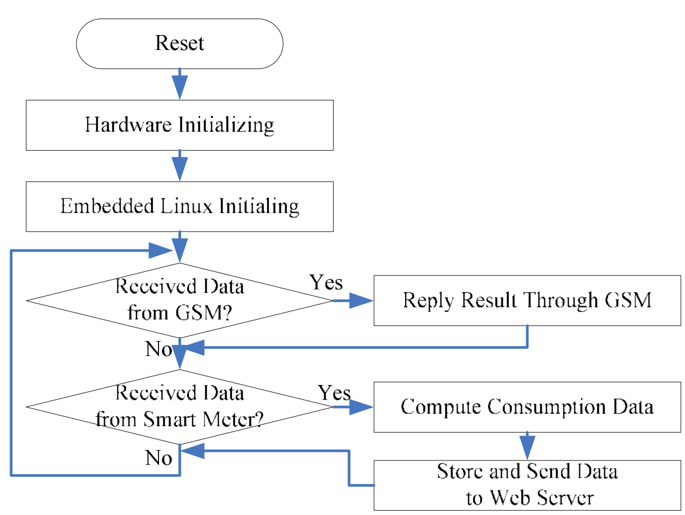


Figure 10. Gateway Software Flowchart

The software flow chart in S3C2440A is shown as figure 10. In software level, our home gateway mainly deals with the GSM messages, data from WSNs, and uploading information to web server. Besides, it also takes charge of computing and storing the energy consumption data.

h) Protocol Translation Module

This module acts as the core for gateway devices to realize their access function as well as the convergence among WSNs and other types of network protocol stack. According to the feature and hierarchical structure of all types of network protocol model, this module carries out heterogeneous network service differentiation, data encapsulation and data format conversion. The process starts from physical layer and ultimately realizes the data upload of the network integrated services and the data downstream of supporting network.

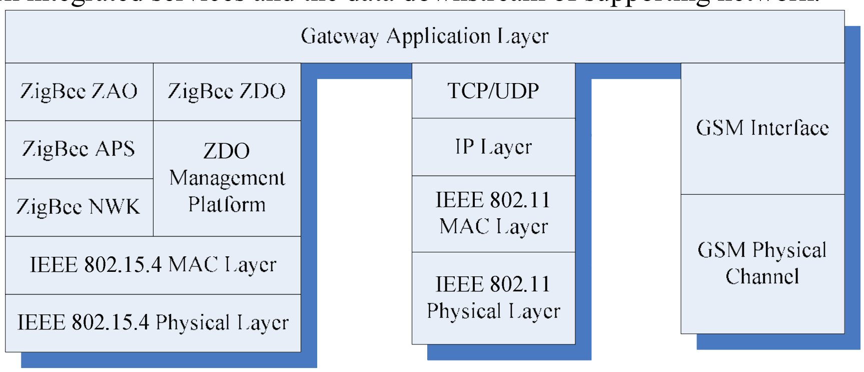


Figure 11. Architecture of Protocol in Gateway

The architecture of protocols stacks in the gateway is shown in figure 11, in which, IEEE 802.15.4 defines Physical Layer and MAC Layer (including encryption mechanism in data transmission) while ZigBee takes charge in correlated standards and interoperability testing from Network Layer to Application Layer. High rate Ethernet interface chip DM9000A acts as the Ethernet controller, while a GSM module interconnected with our gateway by UART is responsible for sending and receiving SMS.

Figure 12 shows the actual image of our designed residential gateway, interconnected with GSM module, CC2430 module, WLAN card, Ethernet interface and power supply line.

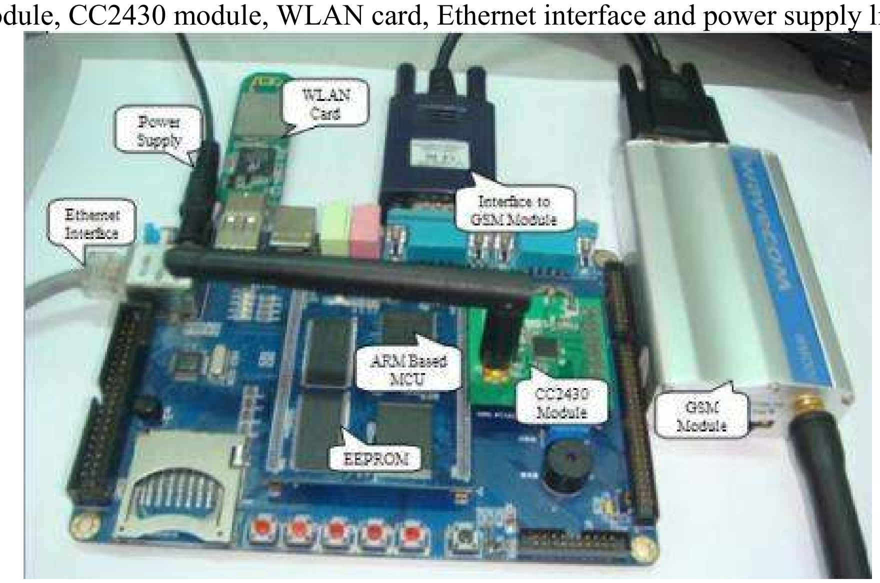


Figure 12. Image of our designed Residential Gateway

4.4. Data analysis system

There are three major steps in this sub-system, designing data tables, extracting key information from the gathering data, and sharing and obtaining helpful tips according to these key words.

a) Data Tables Design

As soon as the related data are uploaded to the web server, a database is necessary to organize this information. Figure 13 shows the data table design and the relationship among these tables. Every user has a unique account in the user table, as well as a unique identification for each appliance in appliance table. Consumption table stores energy consumption of specific user's each appliance per hour. Users also could share their experiences on saving energy, and there is a rating for each tip representing the popularity.

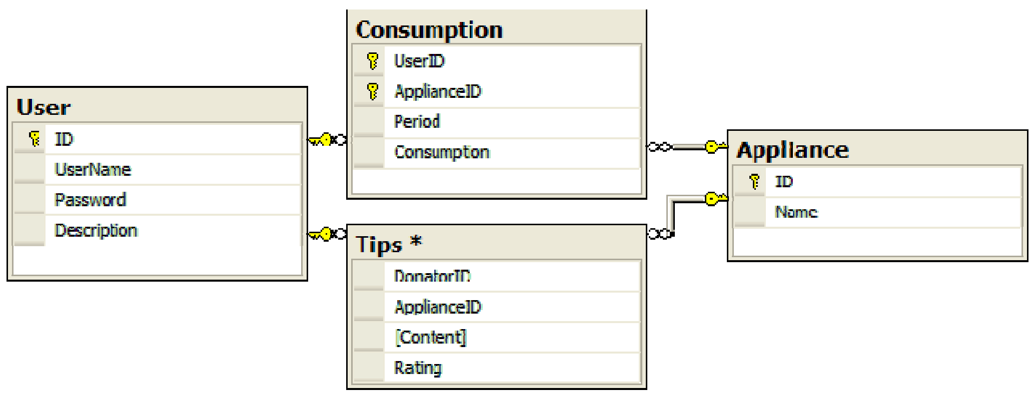


Figure 13. Database Design

b) Key Information Extractor

Before getting exactly helpful advices, key information indicating the situation of users' energy consumption must be extracted. We divided the energy consumption into 5 levels (very low, low, medium, high, and very high) according to the actual data using fuzzy logic. Figure 14 shows the membership function, in which, the mean value of all users' data for one specific appliance is viewed as the separator.

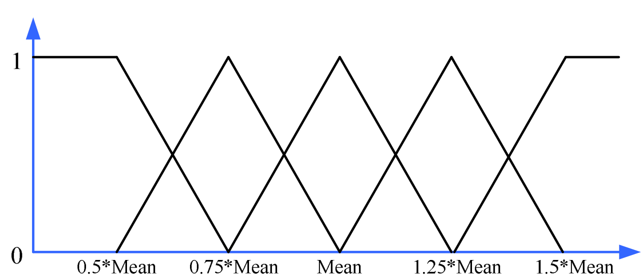


Figure 14. Membership Functions for Energy Consumption Level

The detailed functions are as followings.

$$W_{VL}(x)=\begin{cases}1, \mathit{for}\ x\le 0.5c_{mean}\\ 3-4x/c_{mean}, \mathit{for}\ 0.5c_{mean} < x \le 0.75c_{mean}\end{cases} \quad (7)$$

$$W_L(x) = \begin{cases} 4x/c_{mean} - 2, for\ 0.5c_{mean} < x \le 0.75c_{mean} \\ 4 - 4x/c_{mean}, for\ 0.75c_{mean} < x \le c_{mean} \end{cases} \quad (8)$$

$$W_M(x) = \begin{cases} 4x/c_{mean} - 3, for\ 0.75c_{mean} < x \le c_{mean} \\ 5 - 4x/c_{mean}, for\ c_{mean} < x \le 1.25c_{mean} \end{cases} \quad (9)$$

$$W_H(x) = \begin{cases} 4x/c_{mean} - 4, for\ c_{mean} < x \le 1.25c_{mean} \\ 6 - 4x/c_{mean}, for\ 1.25c_{mean} < x \le 1.5c_{mean} \end{cases} \quad (10)$$

$$W_{VH}(x) = \begin{cases} 4x/c_{mean} - 5, for\ 1.25c_{mean} < x \le 1.5c_{mean} \\ 7 - 4x/c_{mean}, for\ x > 1.5c_{mean} \end{cases} \quad (11)$$

Where W_{VL}, W_L, W_M, W_H, W_{VH} stand for the weight of very low level, low level, medium level, high level, and very high level respectively. And c_{mean} refers to the mean value of all the collected data, that is:

$$c_{mean} = \frac{1}{n}\sum_{i=1}^{n} c_i \quad (12)$$

Where n is the overall amount of energy consumption of each appliance.

Similarly, we also separate the datetime into 4 levels (morning, noon, evening, night) defined as followings.

$$T_M(x) = \begin{cases} x/6, for\ 0 < x \le 6 \\ 2 - x/6, for\ 6 < x \le 12 \end{cases} \quad (13)$$

$$T_N(x) = \begin{cases} x/6 - 1, for\ 6 < x \le 12 \\ 3 - x/6, for\ 12 < x \le 18 \end{cases} \quad (14)$$

$$T_E(x) = \begin{cases} x/6 - 2, for\ 12 < x \le 18 \\ 4 - x/6, for\ 18 < x \le 24 \end{cases} \quad (15)$$

$$T_I(x) = \begin{cases} x/6 - 3, for\ 18 < x \le 24 \\ 1 - x/6, for\ 0 < x \le 6 \end{cases} \quad (16)$$

The weights, which we use a 5 tuples $W = (W_{VL}, W_L, W_M, W_H, W_{VH})$ to exhibit, together with the datetime information expressed by a 4-tuples $T = (T_M, T_N, T_E, T_I)$ are all helpful in the next stage to provides users with effective tips.

c) Helpful Tips Sharing and Obtaining Scheme

Tips table, where a considerable quantity of users' experiences against each kind of appliances could be kept, is mainly involved in this scheme. We set the sample period at 24 hours, that is, once it is time to supply advices to users, only the last 24 hours' information are considered as the real-time energy consumption. As illustrated above, several key words including the weight of each consumption level, datetime, and appliance ID are extracted. Term Frequency Inverse Document Frequency (TF-IDF) is applied to determine which tips are most proper for every single user. The approach to calculate the TF-IDF value works as follow.

$$(TFIDF)_i = f_{i,d} * \log(|D| / |\{d : t_i \in d\}|) \quad (17)$$

Where D is the collection of tip contents, while d means an individual document, $f_{i,dj}$ equals the number of times term t_i appears in d_j, $|D|$ is the total number of documents for the same appliance in the database, and $|\{d : t_i \in d\}|$ refers to the number of tip contents where the term t_i shows up. Finally, for each tips, an overall value is given to decide which tips are most suitable. This value is calculated as following.

$$V_d = a_c \sum_{i=1}^{5} TFIDF_i * W_i + a_d \sum_{i=1}^{4} TFIDF_i * T_i \qquad (18)$$

Where a_c stands for the weight of consumption level and a_d is the weight of datetime level. In our implementation, we allocate the weight of consumption level and datetime at (0.8, 0.2). The example is as following,

Supposed the weights of energy consumption level is (0, 0, 0.3, 0.7, 0), and the datetime level is (0, 0, 0.33, 0.66), and the TF-IDF value of term medium, high, evening, night is 0, 0.31, 0.27, and 0 respectively in one given document, then

$$V_d = 0.7*0.31+0.33*0.27=0.3061 \qquad (19)$$

At last, the tip with the highest V_d is selected to display in front of users to help them lower energy cost.

4.5. Terminal application system

As described in architecture section, mobile phone, smart phone and computer are the terminal devices, which actually make users aware of our system as well as the real time energy consumption.

Figure 15. SMS Notification in Mobile Phone

Figure 15 shows the notification in SMS format received by mobile phone. AT command and a RS232 serial communication protocol is used to hit this target. Both real-time data about energy consumption and corresponding tips are sent into particular mobile phone as long as the power consumption has stayed very high level for 3 hours.

Figure 16. Ubi-PowerMeter Application in Web Portal

As to the computers, which are connected directly to Internet, we design a B/S (Browser and Server) structure to display all those information. Figure 16 exhibits the web application of our Ubi-PowerMeter, where users are able to check the energy consumption of each appliance separately as well as the total value. Moreover, different color stands for different electric use, clearly and conveniently telling which one had cost more energy while others were at low level. SQL Server 2008 is used as the database in our system. We also take the advantage of Microsoft's another platform, Expression Blend 3 to realize the web interface using Silverlight 3.0, and WCF (Windows Communication Foundation) to achieve the data exchange with database. Finally, the logic part is developed using Visual C#.Net.

5. Experimental scenario and results

We carried out 3 experiments on 3 different facets of our proposed system as demonstrated below.

5.1. Tests on data collection

For demonstration purpose, we utilize a 1000W load, which contains 10 light bulbs to examine our circuit. This load is connected with our smart power meter, which is also measured by an IEC 61036 standard Single Phase digital Watt Hour Meter Atec12. Our test lasts for 12 hours and we check the energy consumption per half an hour. During this period the load is continuously turned on. Figure 17 (left is the actual captured data, and right is the reading differential between standard meter and smart meter) points out the result of this experiment, which obviously proves the accuracy on data collection of our smart meter.

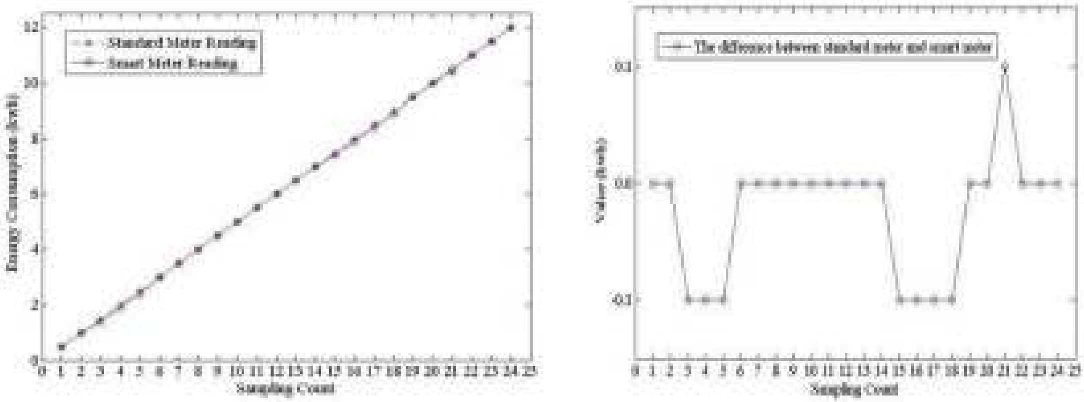


Figure 17. Standard Power Meter Reading versus Smart Meter Reading

5.2. Experiment on Wireless Communication

The quality of wireless communication is the basis of the whole system. Consequently, we test the loss rate and BER (Bit Error Rate), which is generally considered as the typical items to reflect the condition of the wireless network.

The experimental scenario is arranged in a 10*10 room, where the home gateway and 7 smart meters are placed. All the smart meters are allowed to send message to gateway at intervals of a specific period. 8 tests are carried out and each sub experiments last for 30 minutes, the differences among these tests are the intervals which are set at 350s, 300s, 250s, 200s, 150s, 100s, 50s, 10s in order. Figure 18 presents the information about the relationship between loss rate and transmitting intervals. High loss rate occurs when the interval is lower than 50 seconds, whereas there's almost no loss when the interval is higher than 250 seconds.

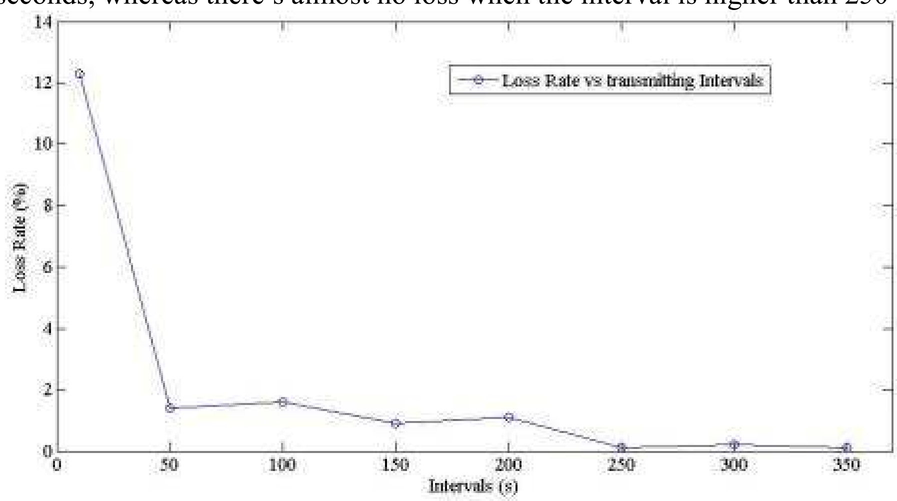


Figure 18. Loss Rate versus Transmitting Intervals

Due to the verification flag in ZigBee based frame, the EBR can be kept at a low level in spite of the high loss rate when each of our smart meters frequently send pockets to gateway at intervals of 10s. As we enlarge the transmitting intervals, our system performs a bit better in EBR, which stays at less than 1% as shown in figure 19.

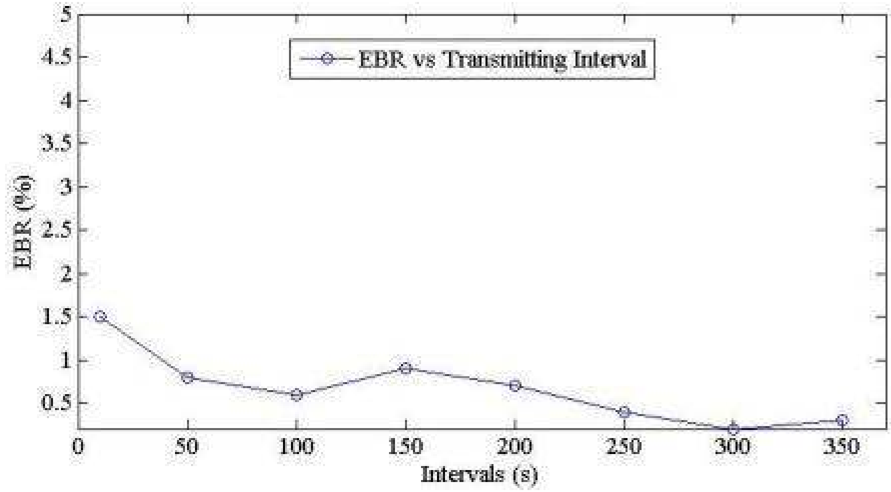


Figure 19. BER versus Transmitting Intervals

5.3. Effect on energy saving

Three dormitories, where the inhabitants didn't participate in our development, were involved in a one month experiment. Four people lived in one dormitory together, and the main appliances were television, personal computer, lights, washer, hairdryer, fridge and kettle. Those appliances were exactly the same. And the energy consumption of these dormitories was almost the same before the beginning of our test. Our experiment started at November 1st, 2009. On the first 15 days, there is no change in the first dormitory, the inhabitants were told to manage their appliances as they used to. Residential gateway and smart meters were equipped in the other two dormitories, but the inhabitants in the second dormitory were not able to access the pre-installed related advices on reducing the energy cost, while the third room could easily get them via internet. People in these three dormitories were not allowed to exchange their experience on energy consumption during this period. On the last 15 days, our full functional systems were placed in all the dormitories. Besides, the inhabitants were encouraged to share their tips in our proposed web site. We recorded the energy consumption of each dormitory every day as figure 20.

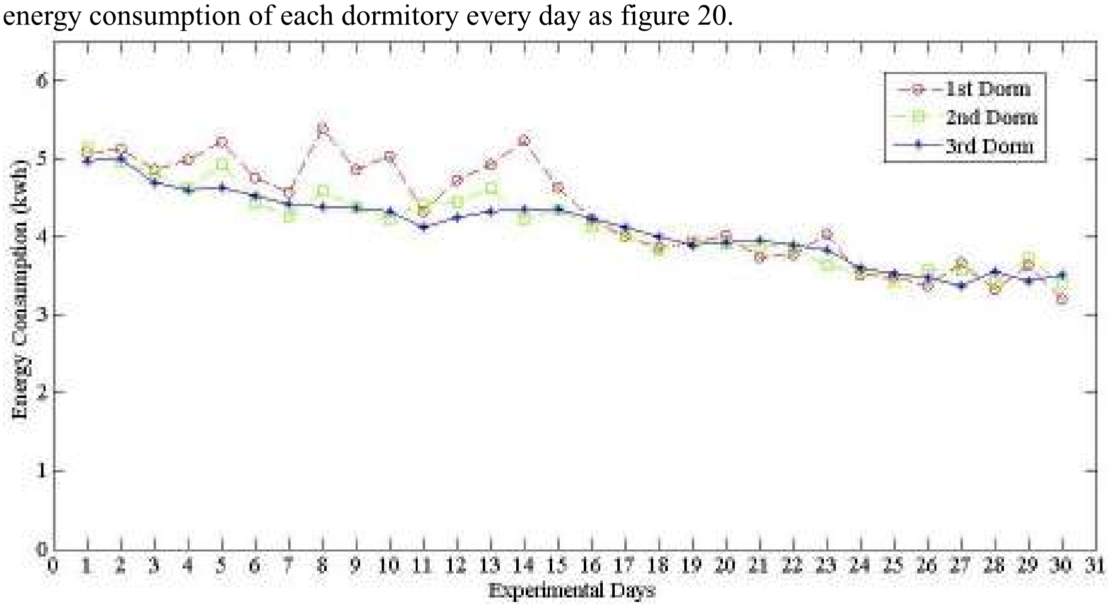


Figure 20. Experimental Days versus Energy Consumption

It is obvious that there is a clear reduction on energy consumption. The first room's line figures out the custom of energy use which cost 73.70 kWh during the first 15 days, while the second dorm was 68.42 kWh and the third dorm was 67.31 kWh. On the last 15 days, the energy consumption was 60.42 kWh, 60.28 kWh and 60.69 kWh in order. This result proves the availability of our paradigm, and it also shows the data analysis and experience share scheme is quite helpful in such system.

6. Conclusion and future works

In this paper, we proposed a novel paradigm, which is named Ubi-PowerMeter by us, to reduce the energy consumption, as well as all the technologies ranged from hardware design to the implementation of application layer. The architecture together with a few core issues such as how to capture the information about energy consumption, how to achieve wireless communication, how to connect WSNs to Internet and GSM, how to analysis data and give corresponding advices, and how to present those data to users conveniently and comfortably. Furthermore, we put our propounded system into practice, and the results address that our paradigm performs quite well in accuracy, stability and availability.

Our future work experimental program includes the plans about carrying out another experiment which comprises more dormitories and more inhabitants. In addition, we also intend to test the effect of our proposed system in other environments like factories, offices and classroom. Besides, adding the ability of automatic operation to our smart meter is in our schedule as well.

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