Smart Energy Management System for Home Area Networks

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Abstract **- Distributed renewable energy resources systems are becoming widely used in home area networks. These systems can intelligently select energy resources to maintain high efficiency power management at home and energy grids based on the power consumption of home appliances and availability of distributed energy harvesters. This paper demonstrates a smart strategy on energy source selection and automatic power control for decentralized electrical equipment and appliances in a home area network. The proposed smart strategy takes into account the real-time electrical pricing, environmental data from sensors and prediction of energy consumption based on Grey Model Forecasting within home. The strategy is demonstrated in a testbed that adopts uIP stack (IPv6) in CC2530 chip.**

Keywords-Energy Source Selection; Automatic Power Control; Home Area Networks.

I. INTRODUCTION

There are three main factors that characterize energy landscape: the growing energy demand, the need for sustainability and the global pressure to cut CO2 emissions. With the study, by 2030, power consumption is expected to grow from 20,000 TWh today to roughly 33,000 TWh; that's a leap of over 60 per cent [1].

Nevertheless, the traditional grid is only a one-way energy broadcasting network and usually has one energy source for users. This type of energy grid topology could seriously affect consumers' energy utilization if there is any problem in the energy supply, as there is no alternative source for consumers. Therefore, consumers and utility companies are seeking more energy efficient and sustainable solutions.

Wireless Sensor Networks (WSN) [2] have emerged as an exciting technology for a wide range of important applications that acquire and process information from the physical world. Meanwhile, increased penetration of small modular generation technologies interconnected to distribution systems form a new type of power system. The traditional architecture of one-way energy broadcasting network and single national energy source in the traditional grid will be replaced by the emerging smart grid system [3] that combines the emerging WSN application and an intelligent distributed energy resources system. A Smart Grid is an electrical grid that uses computers and other technology to gather and act on information, such as information about the behaviours of suppliers and consumers, in an automated fashion, to improve the efficiency, reliability, economics, and sustainability of the production and distribution of electricity. The smart grid system can satisfy the requirements of the flexibility in energy generation and selection, efficiency in power consumption and reliability in emergency [4].

A variety of countries and regions have proposed their development plans according to their regional features. In this paper, we briefly introduce the smart grid in USA, Europe, and China.

M. Lowe et al. [5] discuss the grid state in USA. Due to serial large outages in recent years, the industry has paid more attention to the quality and reliability of electricity. The increasing demand for national security and environment protection leads to a higher standard of grid construction and management

In Europe, the government especially addresses the environment protection. The European smart grid focuses more on the assessment of renewable resources, the impact on the wildlife and the real-time monitoring and remote control [6]. The European Technology Platforms (ETP) began to operate in 2005 [7] in formulating and promoting a vision for the development of smart grids for year 2020 in compliance with EU policy.

The grid in China exposes the weakness in dealing with the emergencies. The lack of smart power distribution leads to the regional and seasonal electricity shortage. Faced with these problems, IBM proposed that it can provide a whole scheme solution Architecture for Energy (SAFT) for the power companies in China to use the smart power grid effectively [8].

As mentioned above, smart grids in different regions in the world are trying to achieve the goal of reliability and efficiency of energy demand. Real-time analysis is one of the key technologies for achieving the goal. One of the notable features of smart grid is the rapid response to the environment changes. The supervisory control and data acquisition (SCADA) systems have been used in transmission networks for several decades. They provide control centre operators with real-time data concerning the network state and allow remote manual, automatic or semi-automatic procedures [9]. The real-time analysis is no doubt the key technique for SCADA system. The sensors collect the data of the environment and periodically

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transmit the data to near communication devices. The system makes quick analysis of the data and generates the optimal decisions, then it sends the control signals to end devices. The whole procedure is completed in very little amount of time and repeated frequently enough to guarantee the real-time of the smart grid.

Many countries have proposed to implement smart grid technology that focuses on how to validate intelligent control in the process of electrical generation, transmission and distribution, and how to access renewable sources on a large scale such as district, city or country wide. However, there is a limited development in smart energy management for home area networks.

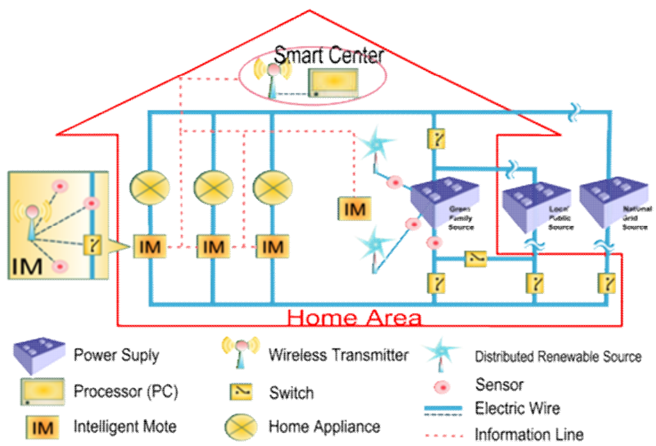

Figure 1. System Architecture of Home Area Network prototype

This paper aims at demonstrating a home area network to integrate the technology of WSN into the traditional grid, and to combine the family levelled distributed renewable sources into energy grid, meanwhile, to make power consumption more efficient. It also shows a smart strategy based on grey prediction model [10] in energy source selection and intelligent power control by predicting the future energy consumption and pricing variation. Figure 1 shows the architecture of home area network

The rest of this paper is organized as follow: Section II explains the home area network prototype and its functionalities. The hardware implementation and the smart energy management system implementation are explained in Sections III and IV, respectively. Finally, the conclusion is drawn in Section V.

II. HOME AREA NETWORK PROTOTYPE

A. *Architecture of home area network protoype*

Figure 2 shows the design of a home area network. The intelligent motes (IMs) are integrated into the electrical switches, wireless transmitters and variety of sensors. They are used to collect environment information, transmit sensing and control data.

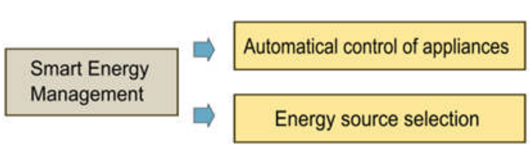

Figure 2. Smart Energy Management

There are current sensors, temperature sensors, infrared sensors, optical sensors and carbon oxide sensors in this prototype. Each sensor and mote performs according to specific condition. The prototype divides into three parts:

a) Smart Center

Smart Center is the main controller with a wireless transceiver. It can synthesize and analyze the information received from all IMs; send back data to distributed IMs, information it sends such as the real time price response to the user terminal and the control signal to the wireless switch (control the access of different loads and power sources). It also displays data via a user friendly interface.

b) Energy Supply Terminal

The household has three energy resources: a green family source, which stores electricity via distributed renewable energy harvesters for its own use and sell it to outside; a local public source, which is the neighbourhood energy storage and the neighbourhood electricity seller; and a national grid source which consistently provides power to neighbourhood household. The IM connected to green family source reports the household resource's condition to the smart center regularly and in the charge of energy source selection by controlling the five electrical switches.

c) Home Appliance Terminal

Each home appliance is connected with an IM. The IM collects sensor information from its appliance and forwards it to smart centre or other IMs; it also controls its appliance according to the suggested strategy.

B. *Main Functionalities of the prototype*

a) Data Transmission and Prediction

Energy consumption data collected by IM is sent to and stored in smart center which applies Grey Model (GM) prediction to make control decision.

b) Energy Resource Selection

Based on energy consumption prediction, condition of green family resource and the real time electrical pricing, the smart center decides the energy resources to run the household appliances and electrical equipment, and advises whether the surplus energy from the household resources can be resold to the local public resource.

c) Intelligent Power Control

Each IM can make automatic response in consideration of the characteristics of its connected home appliances and the environmental condition.

d) Remote Comtrol through Mobile Devices

Authorized users can view the household electrical condition on mobile phone in real time, to read the energy consumption and its cost. It also controls the strategy of each home appliance.

C. *Use Case*

a) Real Time Charge Response

Each IM connected to the users will transmit its power usage status to the smart meter by wireless communication, and with the aid of users' historical records of power usage (stored in a database), the Smart Center could respond to the power usage immediately based on a given algorithm and feedback the real time charge to users in time.

b) Automatic Source Access Selection

With adding the distributed renewable energy harvester, each house has options to choose source. The determination for power choice will be realized in consideration of a variety of factors:

- The future prediction and current energy consumption of user terminal;
- The energy generation prediction of the distributed energy harvester;
- The real-time price variation.

Generally speaking, the priority of energy source access is depended on the contrast of the current power charge of main grid source and the distributed source, the lower price, the higher access priority.

c) Emergency Control to User Terminal

By wireless communication, the smart meter can actively restrict some part of users' power need in some power shortage condition. For instance: if there is earthquake happened, the main grid is partly destroyed and cannot provide power to this region in time, plus the limited ability of renewable energy source, it cannot provide enough power to all the users simultaneously, and by remote controlling wireless switches, the smart meter can restrict some factories' power usage and focus the power supply to the some more important users immediately, like hospital, transport & communication station and so on.

III. HARDWARE IMPLEMENTATION

A. *Intelligent Mote*

Intelligent motes are the primary important components for achieving the distributed strategy and the execution of the command from the centre. They are connected to appliances or the energy supply and switches. Each of them consists of CC2530F256 and the peripheral circuit containing necessary sensors.

In the mote, sampling resistor circuit is used to sensing the circuit. And the output is converted to digital numbers by TM7709 which is an analogue to digital converter (ADC). The voltage value is measured in a similar way. Then the power consumed by the appliance is computed by multiplying the value of the current and the value of the voltage. The energy consumption data is sent to the centre every 3 seconds to help the smart strategy of the centre. The hardware of our motes is shown in Fig 3.

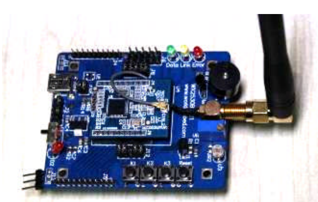

Figure 3. Hardware of Mote

B. *Smart Appliances*

The circuit in the prototype is a direct current circuit whose voltage is below 5V. There are three appliances (Figure 4) in the prototype. A led lamp panel simulates the lighting in the house. A LED simulated the washing machine. There is also a fan which can response to the environmental parameter smartly. They send their energy consumption data to the centre every 3 seconds.

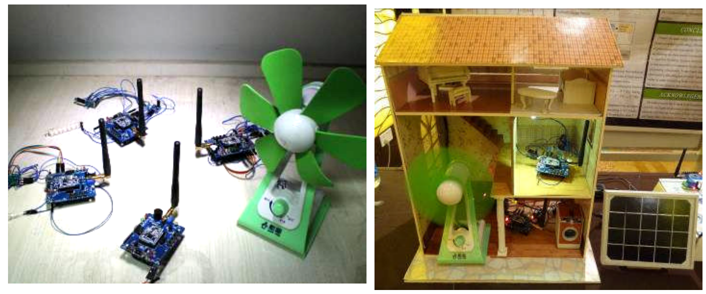

Figure 4. Smart Appliances and Information Network

a) Lighting

The lighting can decide whether to switch on or off based on the data sensed from the light sensor and the infrared sensor. Meanwhile, it send its working state (the light intensity) when it is on to the centre every 3 seconds.

b) Washing Machine

It receives the data of electricity price from the centre every 3 seconds. Customer can schedule the completion time of a washing task, set a desired threshold price. In a period before the latest starting time corresponding to the completion time, the price is regularly checked and when the price is lower than the threshold, the washing machine starts washing. It reports to the centre when it starts working.

c) Fan

The fan can decide whether to switch on or off and the speed based on the data from the infrared sensor and the temperature data sent by the centre. Similar to the lighting, it sends its working state (the speed) when it is on to the centre every 3 seconds.

C. *Energy Supplies*

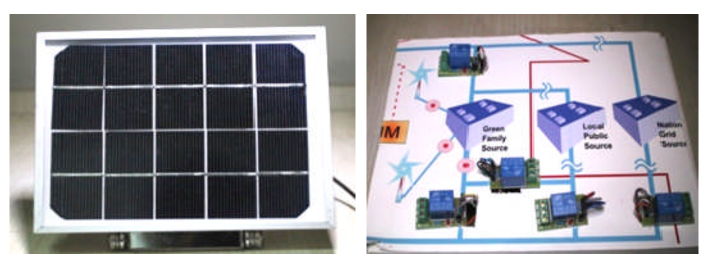

Figure 5. Solar Panel & Source Switches

In our prototype, a solar panel (Figure 5) is used as renewable energy source. An intelligent mote is connected to it, senses the value of energy generated and reports to the centre. Moreover, the switches which control the power access are connected to the mote. The centre sends commands of energy supply selection to this mote. Then the mote chooses the corresponding energy supply using the switches.

D. *Information Network.*

Two-ways communication allows the information change between the intelligent motes and the centre. Star topology network is adopted in our prototype. The intelligent motes are the children nodes and the mote connected to the centre PC is the parent node. Every node has an ipv6 address and they communicate based on 6LowPAN. Contiki is the operating system used in the mote. The standard protocol in the lower layer is 802.15.4. And we adopt the uIP stack which is a lightweight open source TCP/IP stack in the Contiki system.

IV. SMART ENERGY MANAGEMENT SYSTEM

A. *Software Design Pattern*

Figure 6 shows the design pattern of software architecture.

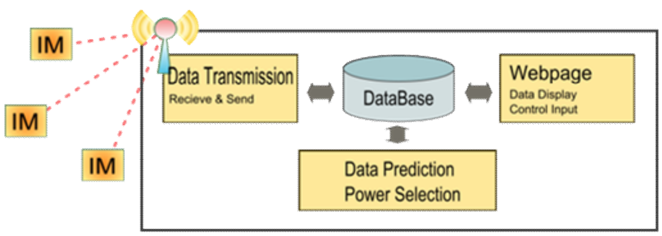

Figure 6. Software Architecture

All data including power consumption, working state from intelligent mote will be received and stored into a database. The software center will access the database every 3 seconds, making prediction and decision for power source selection, all these result data will be fed back to IM, meanwhile it will be stored into the database. Webpage can access the database, showing wanted data on the mobile terminals, which can help users check the condition for their appliance and energy whenever they want and wherever they are. They can also interact with the webpage and all their command will be sent to the corresponding mote and also stored into the database, and could be processed by the software centre for the next 3 seconds cycle.

B. *Data Flow*

Figure 7 shows the data flow chart of the proposed smart energy management.

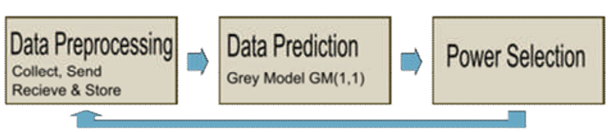

Figure 7. Data Flow Chart

Smart Center is designed for data processing and decision making. It will receive 3 kinds of data from outside environment every 3 seconds: 1) power consumption for each appliance; 2) power generation from home harvester; 3) Real-time electricity price of other power supply. And based on source 1) and 2) ,the center can make prediction for future demand and generation. When all data is ready, the center will make decision on souce selection. If the decision alters, it will send the change to the mote which controls the sower source, and update otherwise the center will process the data for the next 3 seconds.

C. *Prediction Algorithm*

The prediction takes advantage of the modelling mechanism from the traditional GM (1, 1) model [11]. Every 3 seconds, the system forecasts a series of future data by using previous collected energy consumption data as original series.

Via pre-processing, 8 individual points of average power consumption which is based on the recent 80 points. It is donated as $X^{(0)}$ $\{X^{(0)}(1), \dots, X^{(0)}(8)\}$. Taking them as raw series to get the one-accumulation series $X^{(1)}$ $\{X^{(1)}(1), \dots, X^{(1)}(8)\}$, where $X^{(1)}(k) = \sum_{i=1}^{k} x^{(0)}(i)$ $(k = 1,2,\dots,8)$. (1)

$X^{(1)}$ satisfies the following grey differential equation, of which the winterization form is $\frac{dx^{(1)}}{dt} + ax^{(1)} = b$, where a is called developing coefficient, and b is called grey input. They can be retrieved by the following equations:

$$z^{(1)}(k+1) = \frac{1}{2}\left[x^{(1)}(k) + x^{(1)}(k+1)\right] \quad (2)$$

$$B = \begin{bmatrix} -z^{(1)}(2) & 1 \\ -z^{(1)}(3) & 1 \\ \vdots & \vdots \\ -z^{(1)}(8) & 1 \end{bmatrix} \qquad Y_n = [x^{(0)}(2), x^{(0)}(3), \dots, x^{(0)}(8)]^T \qquad \alpha = \begin{pmatrix} a \\ b \end{pmatrix} = (B^T B)^{-1} B^T Y$$

(3-5)

Then deduce the subsequent series $\hat{x}^{(1)}$ by using the a, b get above, $\hat{x}^{(1)}(k+1) = \left(x^{(0)}(1) - \frac{b}{a}\right)e^{-ak} + \frac{b}{a}$. (6)

Finally, implement inverse accumulation on $\hat{x}^{(1)}(k)$ will get the prediction series: $\hat{x}^{(0)}(k+1) = (\hat{x}^{(1)}(k+1) - \hat{x}^{(1)}(k)$ $= (1 - e^{a})(x^{(0)}(1) - \frac{b}{a})e^{-ak}$, where $k = 1, 2,3 \dots 8$. (7)

Figure 8 illustrates a sample of predicted results based on the GM.

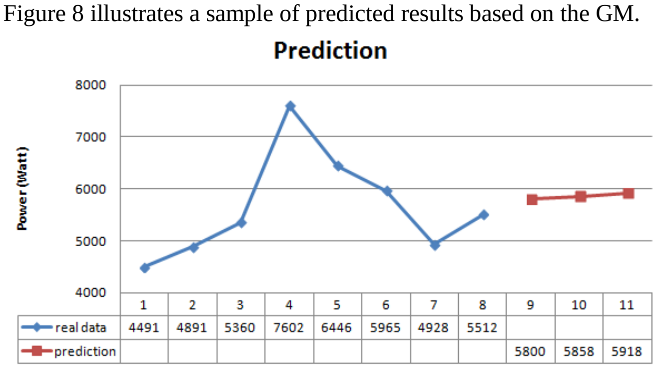

Figure 8. Sample of predicted results

D. *Energy Source Selection*

Power selection is an important part in the prototype software design. Every 3 seconds, the center will go through a decision process. Based on the overall power consumption, and energy generation, the center will first make prediction for demand and supply. On stage 1, the center will tell whether family power supply can meet the demand for short period (30s in the prototype). If yes, it will go to stage 2, otherwise it will use external power supplies. On stage 2, the center will further judge whether the home power supply can meets demand for a longer time, if yes, it will go to stage 3, otherwise it will use external

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supplies when their price are lower than the set price for home supply and family can store power in case of future lack of electricity when external price is high. On stage 3, the center will make decision whether to make money by selling electricity to other sources, so that the family can make extra profits by their green energy harvester.

E. User Interface

Figure 9 shows the user interface of the smart control for smart energy management system.

Figure 9. User Interface

The interface is implemented with PHP Language. We can remote view the state and control operation of the family appliances.

V. CONCLUSION

Overall, this smart energy management system for home area network focuses on optimizing the energy efficiency and advocating the penetration of green energy into household. This demo implements the idea by establishing wireless sensor communication network and proposing an algorithm for energy resource selection and intelligent power control in response with environmental factors, real time consumption demand and pricing information. In the future, this algorithm can be further developed by allocating part of center's prediction work to distributed nodes, to make forecasting faster with lower energy consumption, and at the same time, to improve the reliability of the control system.

VI. ACKNOWLEDGEMENTS

The authors would like to thank Joint Programme (an innovative set of jointly run degree Programme in telecommunications, systems and networks with Beijing University of Posts and Telecommunications and Queen Mary University of London) for supporting this work.

VII. REFERENCE

[1] Siemens Energy Corporation, “A smart approach to the future”, http://www.ngpowereu.com/article/A-smart-approach-to-the-future/.

[2] Y. Jia, Z. Yang and B. Cao; “Research on Distributed Renewable Energy Power System”; Power Electronics, 2005.

[3] Lowfield Heath, “Renewable Energy Commercialization: Renewable Energy in Australia, Dye-Sensitized Solar Cell” ISBN 978-1-157-71383-8

[4] Energy Future Coalition, “Challenge and Opportunity: Charting a New Energy Future,” Appendix A: Working Group Reports, Report of the Smart Grid Working Group.

[5] M. Lowe, H. Fan and G. Gereffi, “U.S. Smart Grid，Finding new ways to cut carbon and create jobs”, Center on Globalization, Governance & Competitiveness Duke University, 2011.

[6] European Commission, "Vision and Strategy for Europe's Electricity Networks of the Future". Smart Grids European Technology Platform, 2006.

[7] V. Salehi, A. Mazloomzadeh and O. Mohammed, ”Real-time analysis for developed laboratory-based smart micro grid”, IEEE Power and Energy Society General Meeting, 2011.

[8] J. Lu, D. Xie and Q. Ai, “Research on smart grid in China”, Transmission & Distribution Conference & Exposition: Asia and Pacific, 2009.

[9] D. Zhang, “The improvement of the self-healing smart grid compared to traditional grid”, Yunan Electric Power, Vol. 38, No.4, Aug. 2010.

[10] S. Liu and J. Deng, “The Range Suitable for GM (1,1)”, Systems Engineering Theory & Practice, 2000.

[11] X. Wang, H. Wang and L. Hou, “Electricity Demand Forecasting Based on Three-point Gaussian Quadrature and Its Application in Smart Grid” International Conference on Wireless Communications Networking and Mobile Computing (WiCOM), 2010.