

Design & Implementation of an Energy Control System for Zigbee Based Home Automation Networks

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Abstract: In order to save energy, several countries recently made laws related to standby power consumption. To success this exertion, we should consider not only power reduction of consumer electronics itself but also efficient automatic control in networked home environment. In this paper, a design approach and implementation result of control mechanism for standby power reduction is mentioned. Proposed mechanism has the Host-Agent based structure and uses the ZigBee protocol for communication and security between Host and Agents. This paper verifies reliability of proposed mechanism and reduction effect of standby power; also, implemented devices scenario which is similar to user living pattern. Experimental results demonstrate that in the proposed mechanism, standby power consumption of Agent which is connected to consumer electronics can be reduced by 203mW.

Index Terms: Standby Power Reduction, Networked Home, Control Mechanism, ZigBee, Home Automation.

I. INTRODUCTION

Standby electricity is the energy consumed by appliances when they are not performing their main functions or when they are switched off. As more and more appliances are being used in households and offices, their energy consumption during standby periods represent a significant share of the total energy used. Household appliances and office equipments such as televisions, video recorders, audio players, telephone answering and facsimile machines, computers, printers and copiers contribute to this standby loss which is relatively low, with typical loss per appliance ranging from less than 1W to as much as 25W. According to the IEA, on an average, 10% of a total household (OECD) power consumption is being wasted in the form of standby power. Moreover, due to the special characteristics of home network devices such as set top box, xDSL modem, home gateway, PC and TV can all be connected to the external communication system in standby mode; an increase of standby power consumption is expected. It is apparent that the future market will be dominated by electric or electronic devices with network functions, rather than those devices without network functions. The number of products with standby power consumption is growing rapidly in both quantity and diversity [1][5]. The increasing power consumption makes the environment worse by increasing global carbon dioxide, which is the cause of the greenhouse effect [6]. And a lot of efforts were made to reduce power consumption in the field of hardware, software, and chips [4][7][12].

A home automation system is a collection of networked home appliances. During recent years, a lot of research has been done in this area, and a lot of papers have been published [9][10][11][14][15]. In this paper, a proposed standby power control system consists of a Host and networked Agents. The Host is the brain of this system; various types of Agent which is attached consumer

electronics connected to this system communicate between each other through the Host. ZigBee is a new low rate wireless network standard designed for automation and control network. The standard is aiming to be a low-cost, low-power solution for systems consisting of unsupervised groups of devices in houses, factories and offices. Expected applications for the ZigBee are building automation, security systems, remote control, remote meter reading and computer peripherals. In this paper, a standby power control mechanism in networked home is proposed. Proposed mechanism uses ZigBee based communication between Host and Agents for sensing information and standby power control command transmission. Agent acquires the local information such as lighting, power consumption and user motion detection using the various embedded sensors and sends this sensing value to the Host; then, Host compares this sensed value with defined control algorithm and sends the standby power control command to the Agent. This paper is organized as follows. Section 2 explains about related works such as the type of standby power, increment of standby power in recent home environment, standby power waste around the globe and low power wireless unit used. Section 3 describes the proposed communication and security modules of control system; this section also explains design approaches of Host and Agent. Implementation results and prototype device are presented in section 4. Finally, we have given some concluding remarks and future works.

II. RELATED WORK

A. Type of Standby Power and Consumption Increment

Table 1 shows the standby power consumption of various devices can be categorized into no-load mode, off mode, passive standby mode, active standby mode, and sleep mode. With the current level of technology, 1W objective can be

achieved at no-load mode, off mode, and passive standby mode [16]. A new form of standby power called ‘Active Standby’ is becoming a reality that we have to face. The emergence of active standby power started with the introduction of set top boxes. It is a power mode where the consumer switches off the power (the consumer thinks the power is switched off completely) but the internal circuit still consumes standby power to wait for external cord/cordless signals. According to previous research [8], in 2020 the increased electricity consumption resulting from networking amounts to around 30% of the present-day consumption in private households in Switzerland. Britons waste the equivalent of around two power stations' worth of electricity each year by leaving TV sets and other gadgets on standby. The number of TVs in the UK is estimated to reach 74 million by 2020, meaning that there will be more televisions than people to watch them. Energy efficiency groups are urging people to carry out their own personal energy review because homes are set to place an ever increasing demand on power supplies.

TABLE I
DEFINITION AND TYPES OF STANDBY POWER

Category	Description
No Load	State of the power supply when no power is being provided to the rest of the appliances
Off	The appliances is switched off and has no capacity
Passive Standby	The appliances is off, but can be powered up remotely
Active Standby	The appliances is on, but is not providing a primary function
Sleep	Mode entered after a period inactivity

Energy efficiency groups are urging people to carry out their own personal energy review because homes are set to place an ever increasing demand on power supplies.

An idea is proposed that the standby device should be shut off after min/max 10mins. Many people think that standby power is just a tiny red dot and has no impact at all, but when considered as a whole it becomes significant. Collective standby power draw from households in the USA is around 8 gigawatts - equivalent to the electricity production of eight large power plants. Globally, standby power consumption is estimated to be responsible for about 1% of the world's carbon dioxide emissions. Carbon dioxide is a gas that contributes to global warming.

B. WHY ZIGBEE?

ZigBee is taken as the media to communicate between host and agent because of following features:

Data rate continuous duty cycle

- 1 Mbps over the air, ~700 kbps best case data transfer
- Battery life in days only
- File transfer, streaming telecom audio
- Point to multipoint networking
- Network latency (typical) New slave enumeration-20s, Sleeping slave changing to active-3s
- Uses frequency hopping technique
- 8 devices per network

III. PROPOSED MECHANISM

In this paper, Host-Agent based structure to control standby power of consumer electronics effectively is proposed; Host and Agent are the two main components. Host manages the entire system and generates standby power control command. While the Agent steer actuator according to control command received from the Host. Possible options of agent position includes

- Internal: It can be embedded with the consumer electronics
- External: As socket outlet form (e.g. wall type, movement type, button type)

The former option is better from device integration point of view. However, we have followed latter approach as the socket outlet form devices could easily be installed by the users in the real home environment. The essential goals of proposed mechanism are stated below:

- *Home automation based control*
- *Standby power of Consumer Electronics $\leq 250mW$*
- *Sensor embedded devices and operation*
- *Low power actuator, Device compatibility*
- *High reliability of control system*

Host and agent have built in sensors, therefore they can acquire all sensing and other information in the home environment. Host receives the sensed information from the agent and generates the command using standby power algorithms and threshold values.

A. Host-Agent based Architecture

This proposed mechanism is based on communication between host and agent via ZigBee. It is organized in accordance with tree topology. Figure 1 shows the proposed control network.

B. Functional Design of Host

The Host has two major tasks: One is to communicate with Agents using the ZigBee technology. The other is to determine control commands (standby power isolation or connection) using the sensing information from the Agents. To accomplish these tasks we have defined several modules for the Host e.g. MCU module, sensor module etc. Figure 2 shows:

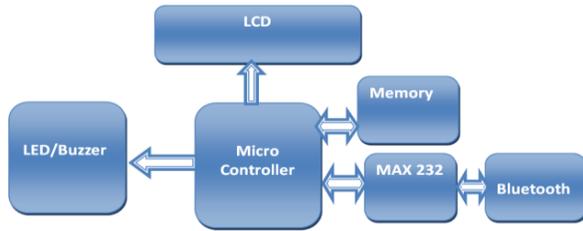


Fig. 2. Block diagram of Host

In this figure, function key and LCD (Liquid Crystal Display) serves as user interface to input the threshold value regarding sensed information and the control scenario of standby power. Therefore, user-defined threshold values can be initialized/adjusted using the function key and LCD.

B. Functional Design of Agent

Agent can be connected to the consumer electronics as socket outlet form. To accomplish the tasks of the Agent, we have defined several modules such as power, actuator, sensing and MCU. Figure 3 shows:

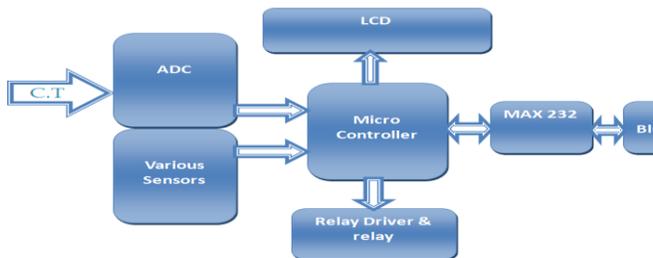


Fig. 3. Block diagram of Agent

IV. IMPLEMENTATION

In this section, we present implemented devices (Host and Agents) according to each designed module and their 182 IEEE Transactions on Consumer Electronics, Vol. 54, No. 1, FEBRUARY 2008 characteristics. Optimized ZigBee module for proposed system has been implemented in the devices. The implemented devices can be applied to real home environment easily without modifying the consumer electronics.

A. Communication and Security Module

As we mentioned before, the proposed architecture of this paper uses ZigBee for communication. Therefore, we have implemented and optimized network and security functions at prototype devices according to ZigBee specification [3]. The proposed control architecture has been organized based on tree topology.

B. Host Implementation

The size of implemented Host is 90mm in diameter and it can be installed on the ceiling. Basically, it consists of power module, RF/MCU module, PIR sensor, light sensor and USB connector. To accomplish user defined configuration, we can add equipments related to user input such as function key

and LCD display. Figure 4 shows the real shape and main module.

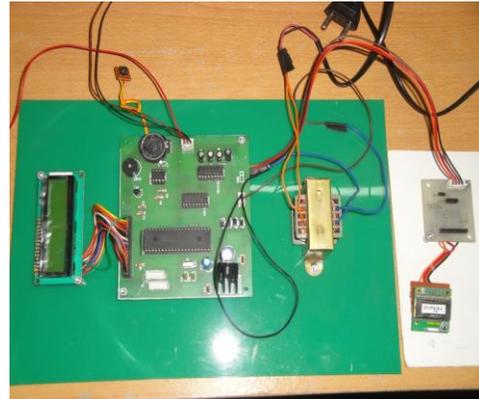


Fig. 4. Appearance of Implemented Host

Main characteristic of implemented Host are like below:

- Standby power control application
- Sensor application
- 32bit ARM Core in TCC 63 Microprocessor

C. Agent Implementation

Figure 5 shows the hardware prototype of Agent. The size of implemented Agent is 46mm in width and 86mm in height. Basically, it consists of power module, RF/MCU module, PIR sensor, light sensor and power actuator.

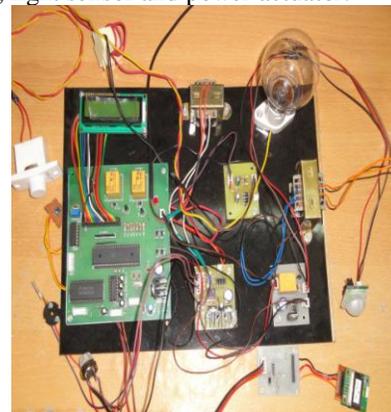


Fig. 5. Agent Unit

Main characteristics of implemented Agent are like below:

- Standby power consumption: 203mW
- Sensor application
- Leakage current detection Module
- General wall socket size

Agent has been implemented as three types (socket type outlet, movement type outlet and button type switch). Figure 5 shows the appearance of wall socket type outlet and movement type outlet. Each type can be used according to user demands.

V. CONCLUSION

As consumer electronics in home are networked, the total consumption of standby power will greatly increase. The power reduction technology of device itself has limitation. Therefore networked home automation system for standby power reduction should be developed. In this paper, a Host-Agent based standby power control mechanism. The main role of the Host is to manage entire control system and to generate control command. Agent sends the sensing information to the Host and controls standby power is proposed. According to proposed scheme, we implemented two kinds of hardware components, a Host and several Agents. Experimental results demonstrate that in the proposed mechanism, standby power consumption of consumer electronics can be reduced. As the future work, the mechanism according to various scenarios in home network and enhance the correctness of the proposed system according to user living scenarios will be analysed. We are currently developing the mechanism to reduce the standby power consumption of pc.

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