Zigbee based Wireless Energy Surveillance System for Energy Savings

Won-Ho Kim, Chang-Ho Hyun, and Moon-Jung Kim

***Abstract*—**In this paper, zigbee communication based wireless energy surveillance system is presented. The proposed system consists of multiple energy surveillance devices and an energy surveillance monitor. Each different standby power-off value of electric device is set automatically by using learning function of energy surveillance device. Thus adaptive standby power-off function provides user convenience and it maximizes the energy savings. Also, power consumption monitoring function is helpful to reduce inefficient energy consumption in home. The zigbee throughput simulator is designed to evaluate minimum transmission power and maximum allowable information quantity in the proposed system. The test result of prototype has been satisfied all the requirements. The proposed system has confirmed that can be used as an intelligent energy surveillance system for energy savings in home or office.

***Keywords*—**Energy monitoring system, Energy surveillance system, Energy sensor network, Energy savings.

I. Introduction

According to the green energy policy, Energy management systems based on wireless sensor network are being introduced for home and office energy savings and high power consumption efficiency [1]-[6]. In particular, 15% of the average power consumption of OECD countries is consumed due to the connected power plugs of electric devices in homes and offices during the devices are not using. In domestically it's approximately 11% of the average power consumption of the country and if the consumption in this path is prevented, economically hundred billion won can be saved annually.

The standby power level of multi-function printer is 80W and 20W for laser printer, 100W for cable set-top box. The better way to reduce the standby power consumption is disconnect the power plugs after using the equipment. But it is cumbersome and inconvenience. So some electrical outlets and electric plugs that have power sensor and standby power off function are being researched. Conventional standby power-off controlling function is used as follows. Fixed standby power level of electric devices is saved. And then, the present measured values can be compared with saved fixed values to decide whether present value is grater or smaller. In this kind of existing method, pre-setting of different values for each device is inefficient and inconvenient in users. Also, when pre-determined standby power level and standby power level of connected device is mismatched the standby power-off may not be occurring.

In this paper, an intelligent energy surveillance device which has adaptive standby power-off function is proposed. It is key element of zigbee communication based wireless energy surveillance system to reduce power consumption in home or office environments. This energy surveillance device detects different standby power level automatically for each device to increase user convenience and to reduce unnecessary energy consumption. Reliable standby power-off can be done by setting the accurate standby power level of electric device. The energy consumption savings function and energy use monitoring function can be maximized by linking to zigbee based wireless sensor network.

II. Design of System

A. System overview

The configuration of zigbee based wireless energy surveillance system is shown in figure 1.

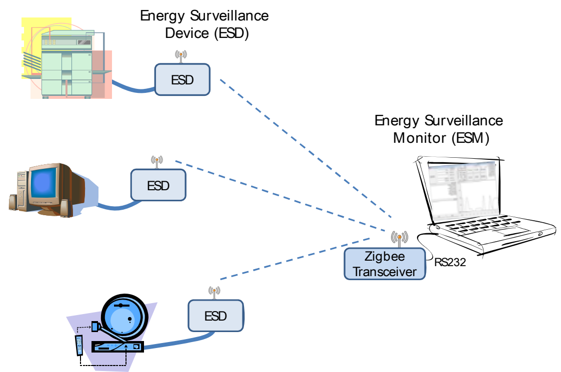

Fig. 1 Configuration of wireless energy surveillance system

The system includes an energy surveillance monitor (ESM) having zigbee transceiver, multiple energy surveillance devices (ESD). The energy surveillance monitor is used for displaying the collected data to user and the energy surveillance device has functions, such as energy consumption measurement, adaptive setting of standby power-off level and zigbee communication. The main function and performance requirements of the system are summarized as bellows.

- Adaptive standby power level setting
- Standby power-off control

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- Power consumption measurement
- Zigbee communication
- Power monitoring range: up to 2,200W (10A/220VAC)

B. Energy Surveillance Device

The functional block diagram of energy surveillance device is shown in figure 2. This device consists of five main components, such as chip shunt resistor or coil current sensor, microcontroller, 2.4G zigbee transceiver, power-off relay, power metering IC.

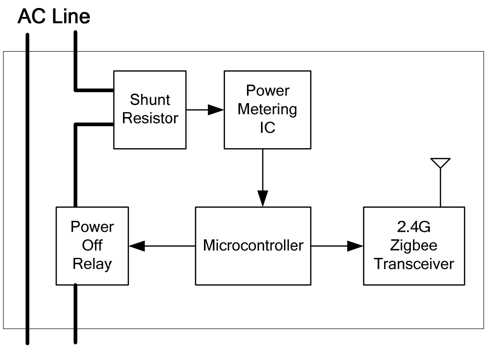

Fig. 2 Functional block diagram of ESD

The key functions of ESD are standby power-off control and power consumption monitoring. The state transition diagram of adaptive standby power-off function is shown in fig 3. The standby power-off level of each electric device is set in adaptively by microcontroller.

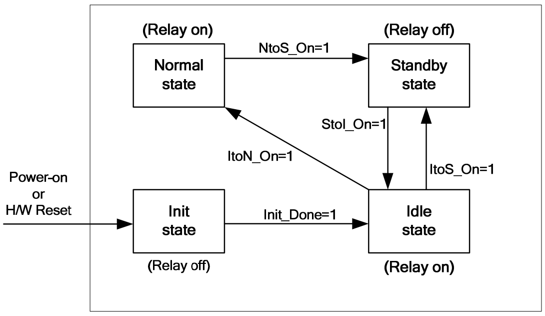

Fig. 3 State transition diagram of adaptive standby power-off function

The state transition occurs by comparing present power consumption value with previous power consumption value in every N seconds. The detailed operation of each state is as bellows.

- Init state operation: Power-on or hardware reset signal activates this state (Init_Done=1). The all parameters of ESD are initialized and power-off relay is off. In this state, power measurement function is not operated.
- Idle state operation: After initialization of ESD, this state is activated. Relay is on to supply AC power to electric device. In this state, power calculation function is operated in every N seconds. If present power level is more than weighted previous level or saved normal power level, the normal state is activated (ItoN_On=1). If present power level is less than saved standby power level, then standby state is activated (ItoS_On=1).
- Normal state operation: Relay is on and normal power level is saved. In this state, power calculation function is operated in every N seconds. If present power level is less than weighted previous level, then standby state is activated (NtoS_On=1).
- Standby state operation: Standby power level is saved for power-off operation of electric device. After standby power level is saved, power-off relay is off to prevent standby power consumption of electric device. Manually, this state is moved into Idle state to re-use electric device (StoI_ON=1).

C. Energy Surveillance Monitor

The energy surveillance monitor consists of zigbee transceiver and user computer. This device has functions to display power consumption information and status information of ESD and to set-up parameters of ESD. This information is received or sent via the zigbee wireless communication between ESM and ESD. The zigbee transceiver supports ZigBee 2006-stack and compatible to IEEE 802.15.4 protocol. The graphical user interface of computer displays control and monitoring parameters, such as power consumption value, standby power, graph of power consumption and information of mode transition.

III. Zigbee Throughput Simulator

The zigbee communication system is a wireless personal area network (WPAN) standard system (IEEE 802.15.4) which operates in 868MHz, 915MHz and 2.4GHz. In zigbee communication network, it is possible to transmit and receive information by speed of 250kbps in 50m. In the zigbee based communication network, the received signal strength indication (RSSI) between each transmitter and receiver decides the throughput of communication link. In the indoor environment, there are many obstacles between transmitter and receiver. The RSSI becomes smaller and signal to noise ratio (SNR) decreased as well as the throughput of communication link decrease. Thus, the throughput of each link needs to evaluate the amount of information for driving the wireless power surveillance system. The amount of information that exchange between ESD and ESM can be predicted by the zigbee throughput simulator.

In case of RSSI being in large environment, the amount of information the exchange between ESD and ESM is greater and SNR is increased. Meanwhile, in case of RSSI being in a small environment, the amount of information that exchange between ESD and ESM is smaller and SNR is decreased. Thus, the minimum value among the throughputs of each communication link in zigbee based wireless energy surveillance system should be set as the upper bound of amount of information exchange. If the throughput of a particular link becomes smaller than the predefined throughput in the system, some error occurred in this link and it cause malfunction of the wireless energy surveillance system.

The structure of zigbee throughput simulator is shown in figure 4. It is assumed to be acquired by measuring RSSI of link between each ESD and ESM. The SNR of each link can be calculated based on the RSSI. The throughput of each link can be evaluated by using calculated SNR and BER of IEEE 802.15.4 standard specification [7]. The BER performance of IEEE 802.15.4 compatible zigbee communication system is as shown in figure 5.

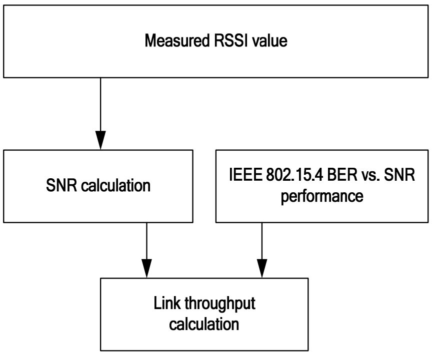

Fig. 4 Structure of zigbee throughput simulator

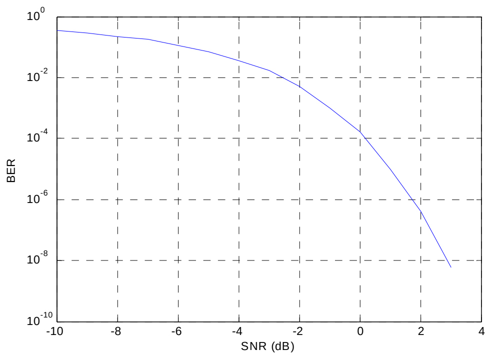

Fig. 5 BER of standard zigbee system (IEEE 802.15.4)

When decrease transmission power or RSSI, the SNR is decreased and BER is increased. Even though the transmission rate is at 250kbps at transmitter side, the receiving data rate at the receiver is reduced due to the increase of bit error rate. The practical information rate of each link can be predicted according to transmission power and RSSI by using designed simulator.

The sample RSSI chart as shown in figure 6 can be assumed in zigbee based network. Assume that ESM placed at (0, 0) and the ESDs are placed at random x-y position. According to the figure 6, as getting closer to ESM the RSSI between ESD and ESM is increased and as transmission power decrease the also the RSSI decrease at same the same place. The RSSI of most of ESD are in range of -90 ~100dBm while transmission power is -20dBm. The figure 7 shows the evaluated amount of information that exchange in link of each ESD and ESM by the simulator. Under condition of transmission power is -20dBm, some of ESD those are far from ESM have lower than 50kbps data rate. In the case of above, the data rate between ESD and ESM should be set to lower than 50kbps or the throughput between ESD and ESM must improve by increasing the transmission power. Thus, this simulator can be utilized to practical construction of the wireless energy surveillance system. It can give information of device placement, maximum data rate and minimum transmission power.

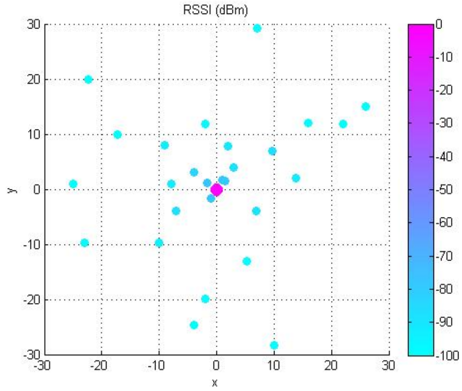

Fig. 6 Example RSSI chart for -20dBm of transmission power

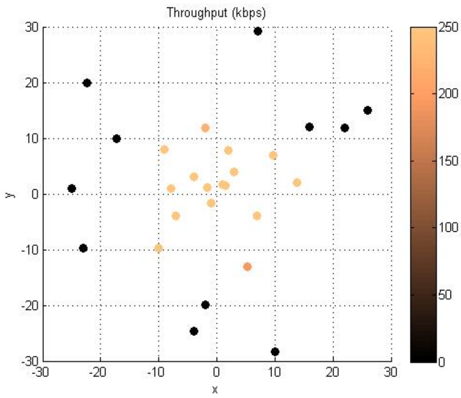

Fig. 7 Example throughput chart for -20dBm of transmission power

IV. Implementation and Test Result

The implemented board of ESD is shown in figure 8 and graphical user interface (GUI) of ESM is shown in figure 9. The ESD and ESM are implemented by using several commercial chips and a personal computer. The ESD board is manufactured in four layers. Main parts, such as shunt resistor microcontroller, power-off relay, power metering IC are placed on top side of PCB and zigbee transceiver is placed on bottom side of PCB.

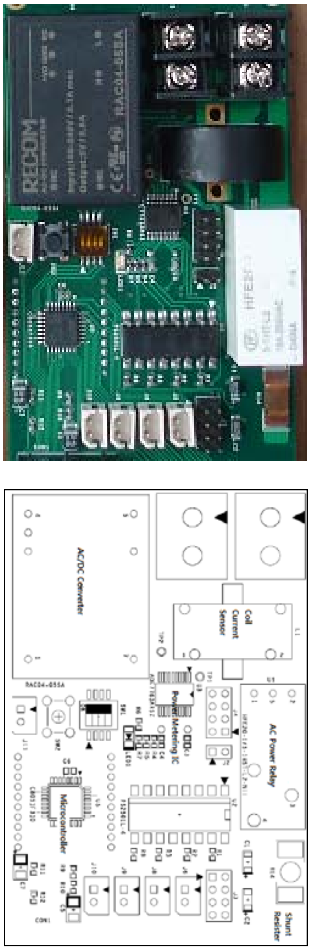

Fig. 8 Picture of ESD board and parts layout diagram (top side)

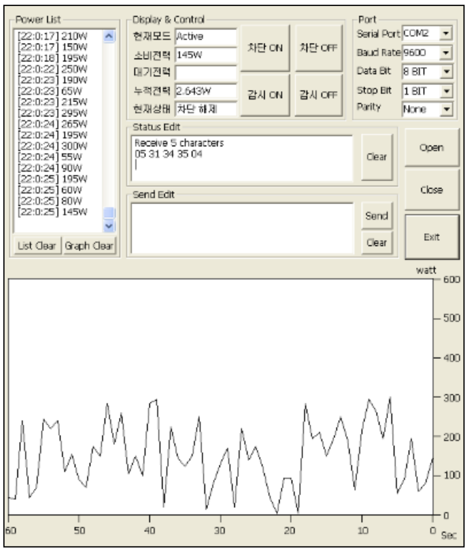

Fig. 9 Graphical user interface (GUI) of ESM

For function verification of prototype system, the power load emulator is designed and implemented. It contains two lamps, one is standby power consumption load and the other is normal power consumption load, and electric switches to emulate electric device's standby and normal operation. The test result of prototype satisfied all the function and performance requirements, such as adaptive standby power level setting, standby power-off control, power consumption monitoring, zigbee communication, AC voltage and current range, power monitoring range.

V. Conclusion

In this paper, the zigbee based wireless energy surveillance system has designed and implemented. Also, function of adaptive standby power-off control has proposed. Most of electric devices have different standby power level. So there are some inconveniences whenever setting manually the threshold of standby power-off for each electric device. The proposed adaptive standby power-off function is capable of automatically setting the standby power-off level of each different device. In addition, power consumption monitoring function is helpful to reduce inefficient energy consumption in home or office. Thus, it gives convenience to the users and it can maximize energy savings in home or office. And also, the presented zigbee throughput simulator can be utilized to evaluate data rate and transmission power in the communication link at each installation environment. Finally, the test result of prototype satisfied all the function and performance requirements and it is practically usable to reduce inefficient energy consumption in home or office environments.

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