Adaptive Home Power Management for Real Time Home Management Systems

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Abstract: Real-time pricing (RTP) enables to give consumers information about the actual cost of electricity at any given time, and electricity prices change from hour to hour. However, in order to cope well with RTP, a real-time home energy management system (HEMS) is required. Therefore, in this paper, we introduce an efficient HEMS architecture, and propose real-time home energy management and on-demand home power control. In addition, to reduce wireless standby power by idle listening, we also propose adaptive power listening (APL), which is capable of dynamically adapting listening interval according to varying electricity load. We also developed real-time HEMS test-bed. Through experiments, it is demonstrated that proposed HEMS with APL can guarantee high real time response ability despite standby power reduction.

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1. Introduction

In order to reduce peak load in electricity use, research on dynamic pricing has been actively conducted. The representative dynamic pricing includes TOU(Time of Use), CPP(Critical Peak Price), and RTP(Real Time Pricing) [1]. Unlike other dynamic pricings such as TOU and CPP which apply high rate only during specific time zone, e.g., peak zone, RTP enables to give consumers information about the actual cost of electricity at any given time, and electricity prices change from hour to hour. Therefore, RTP allows consumers to adjust their electricity usage in real time.

In order to cope well with RTP, first of all, efficient home energy management systems are required. Therefore, several research [2-7] focusing on an efficient home energy management systems (HEMS) has been conducted so far. Some of them are based on wired networks [3 - 4] such as Power Line Communications(PLC) or RS-422, and 485, but in recent HEMS systems based on wireless communications [5 - 7] such as ZigBee are more preferred due to some advantages of safety, convenience of installation and maintenance, scalability, etc. However, this wireless based HEMS might create another standby power problem that a wireless receiver should wait to listen to commands or requests transmitted wirelessly, so called idle listening problem. Even though several low power listening (LPL) methods have been proposed by various researchers [8 -10], since these are basically designed for wireless sensor networks, these are not suitable for HEMS which requires real time response to user's activity.

Therefore, this paper proposes an efficient HEMS architecture and adaptive power listening (APL) which is capable of promptly responding to on-demand commands by users or utility administrators in real time. Through experiments conducted on the developed test-bed, the performance of APL is also evaluated.

The remainder of this paper is organized as follows: Section 2 introduces the proposed HEMS architecture. In addition, an adaptive home management including real-time home energy monitoring and on-demand home power control is presented in section 3. To minimize wireless standby power consumption occurring due to idle listening, an adaptive power listening algorithm is presented in section 4. Section 5 also presents performance evaluation results, and Section 6 provides concluding remarks.



Figure 1. System Architecture

2. System Architecture

As shown in Fig. 1, the proposed system is composed of power outlet module (POM), Home Energy Manager (HEM), and home server module (HSM). POM is capable of monitoring and controlling power of individual electric devices and also communicating with HSM wirelessly. The HSM, which is associated with HEM(Home Energy Manager), plays a key role in collecting power usage information from POMs and a gateway between HEMS and the Internet. A HEM basically collects current power usage from POMs, periodically or by on-demand user requests. Based on the collected power usage information, user can identify the current electricity usage with respect to real time pricing policy by accessing to the HSM. Furthermore, users can control remotely each POM as well as identify the status of current power consumption of their homes, and eventually it leads to efficient home energy management by real time user feedback.

3. Adaptive home power management

In this section, we present adaptive home power management associated with HEMS introduced in the previous section. In particular, we propose a real-time home energy management scheme to efficiently handle real-time power consumption information aggregated from POMs, and on-demand home power control, which allows user to control each POM remotely.

3.1. Real-time home energy management

Figure 2 illustrates a message flow among user, HSM, and POMs for real-time home energy management. Normal state of each POM is periodic preamble sensing (PPS), which is used to detect preamble transmitted from a sender (HEM), and includes preamble sensing duration (active state) and sleep duration. Actually, like other low-power listening protocols, the active duration is significantly shorter than duration to process a whole packet, so that maintaining very small duty cycle is possible.



Figure 2. Message flow of real-time home energy management

Figure All POMs which are performing PPS, carry out periodic task to read latest meter value. Here, the period of task is configurable according to service requirements. For the services that require fresh meter value, frequent reading is necessary so that the shorter period of task can be applied

In addition, PEM can aggregate the meter values from POMs, periodically or on-demand. In general the periodic data aggregation is more common. To aggregate data, PEM first should transmit preamble for the preamble duration. All POMs which are performing PPS, are triggered by preamble detection and waits for request transmission. On the reception of data request from PEM, Each POM replies with its current meter value at its allocated slot. After complete of data aggregation, HSM stores this hour power consumption from the aggregated meter data. The data is managed one at a time. Therefore, total power consumed for every hour is managed at HSM.

Using a smart phone, user can estimate the expected electric charge that RTP is applied, by accessing to HSM and receiving home power consumption information. The RTP information is also provided by utility company.

3.2. On-demand home power control



Figure 3. Message flow of on-demand home power control

Figure 3 illustrates a message flow for ondemand home power control. As mentioned in the section 3.1, user can identify estimated electric charge that RTP is applied, through HSM access. In addition, user can also control home power remotely. Since the proposed HEMS is composed of a number of POMs, user cannot only identify but also control the power state (on or off) of the each POM. First, user access to the HSM and then transmits user command (e.g., POM3 OFF). To minimize wireless standby power consumption, each POM might perform PPS. Therefore, the HEM transmits the user command after triggering POM by preamble transmission. Since user command contains target POM ID and command type, only targeted POM responds to the command and the rest of POMs return to PPS mode. Finally, the targeted POM carries out the corresponding command and replies to HEM. Then, HEM estimates power consumption information based on current POM status. Finally, user can identify the estimated electric charge in which user command is reflected. Furthermore, user can control multiple POMS with a single command transmission.



Figure 4. LPL Interval comparison of Zigbee and APL with respect to varying real time pricing

4. Adaptive home power listening

As mentioned previously, the proposed HEMS architecture enables to efficiently manage home energy through real time bi-directional communications between user and HEMS. To cope well with real time user activity, each POM should be able to receive the commands or requests of users in real time. However, staying active state to listen to user commands might waste considerable energy caused by unnecessary standby power consumption. Therefore, each POM should perform low power listening (LPL), which repeatedly maintains active state for a short duration and power down state for remaining duration within a period. Long PPS interval can reduce standby power but also make long response time since sender should transmit longer preamble to trigger POMs. On the contrary to this, short PPS interval enables fast response time, but brings unnecessary standby power wastage. Therefore, the proposed HEMS utilizes adaptive power listening (APL), which is capable of adaptively controlling the PPS interval according to electricity load. Figure 4 shows a comparison of fixed interval used in zigbee and the proposed APL with respect to RTP. The APL emphasizes standby power reduction by using long interval during low price time, but enables users to monitor and control in real time by adaptively reducing interval as the time goes to peak zone.

5. Experimental result

To verify the feasibility of proposed HEMS and evaluate the performance of real-time home energy management associated with adaptive home power listening. we developed a real-time HEMS test-bed. The HEMS test-bed is composed of 20 POMs and a pair of PEM and PSM. The developed POM prototype consists of RF/MCU part, power outlet control part, and current measure part. Ultra low-power MCU with sub-1Ghz RF SoC, TI CC430F6137, ultra low-power RF SoC containing MCU and sub-1Ghz RF radio, is used for main processing unit, and individual plug in the outlet can be controlled by relay module. We also developed application software for HSM as shown in Fig. 6. HSM is basically capable of configuring and controlling HEM, which is connected through USB, and manages POMs wirelessly. Main functions of HSM software include TCP server module, command generation module, real-time power consumption viewer, and calendar for real time pricing.

Based on our test-bed, we evaluated the performances of real-time home energy management associated with adaptive home power listening capability, in terms of data gathering time, power control time, and system energy consumption. For comparative analysis, we also implemented ZigBee protocol, which is the most popular wireless home network technology, under the same test environments. Table 1 illustrates key parameters used in our experiments.



Figure 5. POM proto type



Figure 6. Server software

Table 1.	Kev	parameters	used in	experiments	
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Parameter	Value	
Supply Voltage (V)	3.3	
Current Consumption (mA)	TX	26.3
	RX	22.3
	Sleep	0.003
Zigbee Beacon Interval (sec)	4	
Zigbee Superframe Duration (0.183	
APL Interval (sec)	1 to 8	
APL Duration (sec)	0.0156	
Number of POM (EA)	1 to 20	

5.1. Data gathering time analysis

Our first observation is data gathering time with respect to varying the number of POMs. We measured total time required from HEM request until data from all POMs are received. Figure 7 shows that data gathering time is linearly increased in both methods, ZigBee and APL, as the number of POMs increases. However, compared to ZigBee, APL shows increment rate of 1/4. This is because APL performs slot based data report after triggered by HSM request. On the other hand, ZigBee devices are based on CSMA MAC so that collision probability increases and thus total delay is considerably increased due to random back-off delay and retransmission, as the number of POMs increases.

5.2. Power control time analysis

The second observation is total control processing time. Control processing time is a total roundtrip time required until HEM receives a response after command processing at the corresponding POM with respect to a control command of HEM. Actually, the Internet delay is varied according to the Internet status, so we did not consider user command delivery times though the Internet. As shown in Fig. 8, control delay of ZigBee is increasing proportionally to the number of POMs. On the other hand, APL shows constant delay without regard to the number of POM. This is because APL has the capability of concurrent multiple controls by a single trigger and command. However, in case of ZigBee, HEM should transmit individual command and individual response. Eventually, it results in increasing delay as the number of POMs increases.









Figure 9. Energy consumption

5.3. Power control time analysis

The final observation is accumulated energy consumption for 24 hours. Figure 9 shows the result of accumulated energy consumption of ZigBee and APL. The result shows that HEMS with APL can save energy about5 times more than ZigBee. This is because APL can maintain longer sleep duration than ZigBee by dynamically adapting LPL interval with respect to electricity load varied in real-time.

6. Conclusion

In this paper we emphasized that Real-time pricing (RTP) enables to give consumers information about the actual cost of electricity at any given time, and in the near future RTP will be applied over the world. However, in order to cope well with RTP, a real-time home energy management system (HEMS) is required. Therefore, we introduced an efficient HEMS architecture, and proposed real-time home energy management and on-demand home power control. In addition, to reduce wireless standby power by idle listening, we also proposed adaptive power listening (APL), which is capable of dynamically adapting listening interval according to varying electricity load. We also developed real-time HEMS Finally. experimental test-bed. the results demonstrated that our proposed HEMS with APL can cope well with trade-off between real time ability and energy efficiency.

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