# SHE: Smart Home Energy Management System for Appliance Identification and Personalized Scheduling

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## Abstract
The home appliance scheduling is a promising energy saving technique that has significant commercial potential. In this demo, Smart Home Energy Management System (SHE) is developed on Android platform to schedule users' appliances. SHE monitors the power consumption to identify the operations of home appliances using a privacy preserving technique called Non-Intrusion Load Monitoring (NILM). The operations are integrated with dynamic electric price and environment data to mine users' personal demand and preference on appliance operation. Finally, SHE generates personalized scheduling strategies to meet the different users' demands at the minimal cost.

## Author Keywords
Smart Home, Personalized Scheduling, Energy Saving, Non-intrusive Monitoring, Ubiquitous Computing

## ACM Classification Keywords
H.5.m. Information interfaces and presentation: Miscellaneous.
H.5.2. Information interfaces and presentation: User interfaces

## Introduction
In the modern age, worldwide energy shortage has become one of the major global problems. Since home appliances account for 42 percent of all electricity

consumed in U.S. households [1], effective scheduling is considered a promising energy saving technique with significant commercial potential.

The ongoing modernization of power grid, namely the smart grid, provides a new perspective to realize home appliance energy saving. Firstly, real-time pricing mechanism motivates more residents to plan their appliance usage. The customer can save as much as 50% of the electricity cost due to the fact that the off-peak electricity price can be 1/3 of the peak price. Moreover, the cost of electricity generation can be dramatically reduced, since generators running at economy zone present much higher efficient than at maximum capacity. Therefore, home appliance scheduling that avoids peak time usage is one of most anticipated techniques for utility companies [2]. Secondly, the development of smart meters makes it possible to obtain information at breaker level and explore users' profile and operation pattern [3].

The key factor of home appliance scheduling is to satisfy the individual demands of users. However it is challenging to meet such requirement because of two aspects: 1) User demand, such as the list of appliances, the timing of being turned on. It is the basis of appliance scheduling. Unfortunately, most users either cannot abstract their operation patterns, or refuse third parties to deploy sensors to monitor and profile their appliance usages due to privacy concerns. 2) Operation preference. Besides the technical restraints of the appliances, the operation preference can be drastically different based on different lifestyles. For example, most housewives in Shanghai turn on the washers after 10:00 PM when the price is 50% off. On the other hand, most boys will turn on air-condition after playing basketball regardless of electricity price. Therefore, the scheduling scheme, designed without operation preference, is difficult to meet user's satisfaction and be accepted by most users.

In our work, a privacy preserving method called non-intrusion load monitoring (NILM) is applied to identify the operation of various home appliances. Five indices are proposed to profile user's operation preference. Optimization is applied to design personalized scheduling scheme. In this demo, we develop Smart Home Energy Management System (SHE) on Android platform to identify the type and operation of home appliances, and generate personalized scheduling scheme.

## Design and Implementation

SHE is composed of four modules: Load Monitor, User Demand Analyzer, Operation Preference Analyzer and Load Scheduler, as shown in Fig 1.

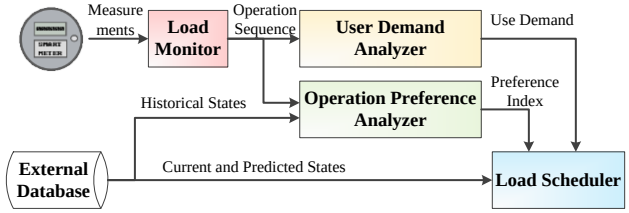


**Figure 1:** Overview of SHE system

*Load Monitor*

Load Monitor loads four measurements: active power P, reactive power Q, power factor PF and harmonic waves H in time, by accessing home power meters. Meanwhile, NILM is applied in Load Monitor to identify home appliance as following: 1) The differences of P and Q

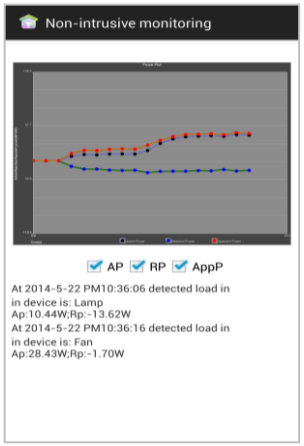


**Figure 2:** Home appliance identification on Load Monitor

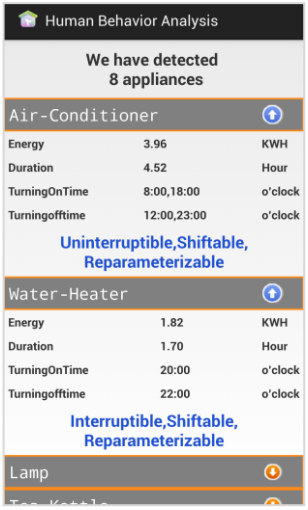


**Figure 3:** User demand and operation preference of various appliances

are calculated to detect the switch event and select possible devices. 2) Current PF and H are used to accurately identify home appliances. From Load Monitor, we can obtain the load information of switch events, total energy consumption and duration time. 3) The operation sequences of all appliances are updated in time, as shown in Figure 2. NILM is acceptable for most users to set up their electricity profiles, since power meters have been widely deployed and power consumption data are usually not sensitive.

*User Demand Analyzer*

The appliance operation sequence is analyzed to abstract user's operation patterns, such as average running power, switch time, and working duration. Next user demands on various appliances can be profiled using statistical methods. For example, by monitoring the turn-on/off time of a water heater, we can obtain the knowledge when the customer regularly uses it and estimate the temperature from the electricity consumption data. This is also true for other appliances such as washers, dryers, and air conditioners. The result will serve as constraints in the scheduling model, which leads to a reasonable scheme. Figure 3 shows the screenshot of the module.

*Operation Preference Analyzer*

To achieve smart residential load scheduling, it is essential to obtain users' operation preference [4]. Besides the technical attributes of the appliances, the different operation preference may lead to drastically different usage behavior. Soares et.al. gave a qualitative description for operation preference: reparameterizable, interruptible, shiftable and so on [5]. In our work, five quantitative indices are proposed to evaluate the operation preference of various appliances:

1. Power-level distribution (PLD): statistical analysis on the working power of an appliance, which indicates whether the load is reparameterizable.
2. Duration time distribution (DTD): examination of the operation duration following fixed number of cycles, which indicates whether the appliance is interruptible.
3. Switching-time distribution (STD): examination of the work duration following a fixed pattern.
4. Price-Relevance (PR): indication of whether the operation is respondent to the price changing.
5. Weather-Relevance (WR): indication of whether the operation is respondent to the weather.

For instance, if an appliance shows high DTD and PR, it is highly possible that its users will accept the scheduling scheme. Thus, the preference indices are employed to estimate the costs and savings of scheduling in Load Scheduler.

*Load scheduler*

Load scheduler, as depicted in Figure 4, produces personalized scheduling strategies for different users. It aims to meet users' demands while saving the cost. The objective cost fuction is composed of three parts: electricity cost $C_E$, delay cost $C_D$ and comfort requirement cost $C_C$. The coefficient $i$ represents the calculated preference index related to each cost. Through this objective fuction, it achieves a trade-off among cost, delay and comfortness.

$$\min: \quad C = i_{PR}C_E + i_{WR}C_D + i_{STD}C_C \tag{1}$$

$$\text{subjects to:} \quad \begin{cases} \textit{if power level is discrete or not} \\ \textit{if duration time is interruptble or not} \\ \textit{comfort requirements} \\ \textit{physical condition of the load} \end{cases} \tag{2}$$

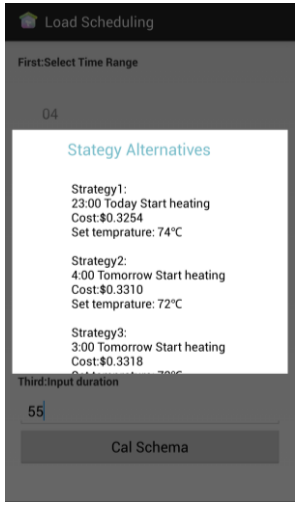


**Figure 4:** Scheduling scheme for a water heater

**Figure 5:** Demonstration setting up

The first two constraints can be obtained by Demand Analyzer and Operation Preference Analyzer. The third and forth constraints are different for each load due to their own attributes. As shown in Fig 4, if a user takes a shower at 7 AM, SHE suggests user to set working time at 23 PM the night before and a target temperature at 74℃. Around 4% electrical cost can be saved once.

## Demonstration Setting

The demo system setting is shown in Fig 5. A smart meter is deployed to monitor power consumption of the loads. SHE is installed on an Android smart phone to analyze users' preference and generate personalized scheduling scheme. Through the Modbus/TCP, the smart phone is able to connect to the smart meter.

The air-condition operation data from [6] is analyzed to profile the user operation preference (User 1 turns on the air conditioner all day while User 2 turns on it only occasionally). As shown in Table 1, User 1 presents much higher WR than user 2 which indicates user 1 has a strict requirement of comfort. So SHE classifies air-condition of User 1 as unshiftable without providing scheduling suggestion while air-condition of User 2 is classified as shiftable. STD in the following table is none because STD can only be analyzed using history data.

| index | STD | PLD | DTD | PR | WR |
|---|---|---|---|---|---|
| User 1 | None | 0.660 | 0.103 | 0.657 | 0.975 |
| User 2 | None | 0.076 | 0.153 | 0.527 | 0.377 |

**Table 1:** Operation preference analysis for 2 different users

## Conclusion and Future Work

We develop a prototype to schedule home appliances and reduce electricity consumption. NILM is applied to identify users' power usage patterns with few privacy concerns. User demand and preference are profiled to ensure satisfaction on generated scheduling. We believe SHE presents a novel and practical solution for home energy management in smart grid. Currently, we are analyzing various appliances to improve the load identification accuracy, monitoring electricity usage to profile users' demand and preference. We will further investigate the relationship between appliance operation and environment data such as date, time and location to design more preference indices.

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