Individualized Electric Power Management System Using BLE Tag at a Shared House

Hideki Kondo
Graduate School of Engineering
Soka University
Hachioji-shi, Tokyo, Japan
e17m5215@soka-u.jp

Kazumasa Takami
Graduate School of Engineering
Soka University
Hachioji-shi, Tokyo, Japan
k_takami@t.soka.ac.jp

***Abstract*— In recent years, there has been a growing interest in home energy management systems (HEMSs), which monitor and control use of power at home. The Japanese government aims to have the system adopted by all households by 2030. The system is connected to home appliances via a network, monitors the state of power consumption, and controls power consumption remotely or automatically. However, it cannot manage how much power each user has consumed. This paper proposes a system that can manage power consumption of individual users at a shared house. Specifically, each resident carries a BLE (Bluetooth Low Energy) tag all the time. Using this tag, the system identifies the person who has used home appliances per outlet, and thereby manages the power consumed by each individual. To conduct experiments, we have created a personal outlet by associating a commercially available outlet with a smartphone. We have conducted experiments for a shared house with three residents, and evaluated the system's utility and level of accuracy in identifying individual users.**

Keywords—HEMS; BLE; smart outlet; smart meter; shared house

I. Introduction

In recent years, the demand for shared houses has been growing in Japan. Many shared houses are being built in anticipation of a further demand increase towards the Tokyo Olympics [1]. The suspension of the operation of nuclear power plants since the Great East Japan Earthquake in 2011 has reduced the national capacity to supply electric power. Reducing greenhouse effect gases has become a socially important issue. In light of these developments, households are required to take measures to reduce power consumption, in particular the peak hour power consumption. This makes it important to manage power efficiently. Home power management systems (HEMSs) have been making progress [2]. The Japanese government announced that it aims to have HEMSs adopted by all households by 2030 [3]. The HEMS visualizes usage of electricity and gas on a monitor and automatically controls home appliances. However, the HEMS does not take into consideration the need to determine how much power each person has used in multi-household buildings, such as shared houses. Because of its high upfront cost, the HEMS is slow to take off. As a result, the entry of power management providers is much slower in the consumer market than in the business market.

This paper proposes an electric power management system that can indicates the amount of electric power consumed by each person. The system uses a BLE (Bluetooth Low Energy) tag to detect an individual. We have built a part of the proposed system to conduct experiments. Section II presents related technologies and studies and their problems. Section III proposes an individualized electric power management system and discusses issues that the system poses. Section IV presents solutions to these issues. Section V describes an experimental system we have developed for evaluation. Section VI presents evaluation results. Section VII summarizes the paper and presents future issues.

II. Related Technologies

A. Identification of an Individual Using a BLE Tag

In recent years, there have been intensive studies on location detection using BLE tags/beacons [4]. A beacon transmits a Bluetooth signal to smartphones. This is used to identify the locations of smartphones in an indoor area, and to push information to smartphones. A terminal that can transmit an ID is used to identify the owner of the terminal. When a user with a smartphone comes within a certain distance from a beacon, the relevant smartphone app receives the beacon signal and accesses the service-dedicated server to identify the individual. However, when a number of tags are detected, the method of determining relative distances between the beacon and the different tags has not been studied so far.

B. Smart Outlet

A smart outlet is an outlet that can manage the power source of home appliances. It makes it possible to control existing home appliances as smart appliances. The steady spread of the HEMS has prompted progress in smart outlets [5][6]. By inserting a smart outlet between an ordinary outlet and a home appliance, it becomes possible to monitor the power consumption of the home appliance, and control and remotely operate the appliance. Or, a smart outlet can serve as a smart meter that monitors power consumption. Generally, measured power consumption data are fed to an app on a smartphone or PC to display the current or past power consumption. Currently available products can measure the power consumption per outlet, but if an outlet is used by a number of people, these products cannot measure the power consumed by individual people.

III. Individualized Electric Power Management System And Issues To Be Solved

It is necessary to be able to determine the power consumed by each person. We propose a personal outlet that identifies an individual, measures the power consumed and sends these data to a smart meter. Individualized electric power management can be achieved using these data. Each resident in a house has an account for each personal outlet so that power consumed by him/her can be measured. The configuration of an individualized electric power management system is shown in Fig. 1. It is assumed that each resident carries a BLE tag.

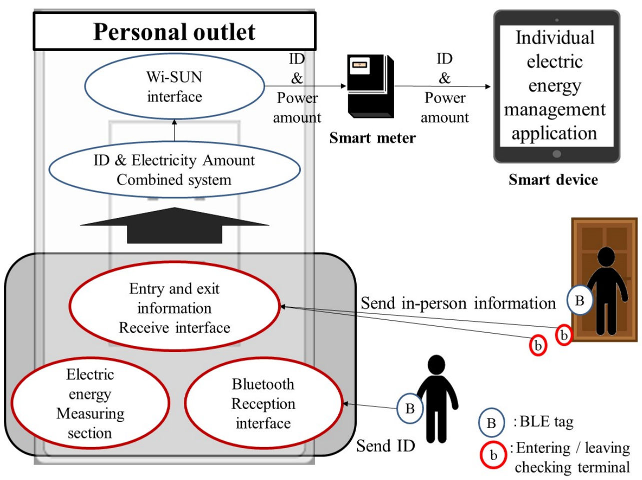

Fig. 1. Individualized electric power management system.

The following issues need to be solved in developing this system.

- Identification and management of the ID of each power user: To measure the power consumed by each resident, it is necessary to identify and manage the ID of each resident.
- Identification of the user when multiple IDs are detected simultaneously: When multiple people come near a personal outlet, the outlet may detect multiple IDs simultaneously.

IV. Proposed System

A combination of the following two schemes will be used to identify the power user accurately:

- Identification of the user from the RSSI strength in case of detecting at the same time.
- Identification of the user from the periodic measurement of the power consumed by each ID and the number of times that each ID is identified, in case of detecting sequentially.

A. *Identification from the RSSI Strength*

A personal outlet may detect multiple IDs at its Bluetooth reception interface. From among the detected IDs, the one with the highest RSSI strength is selected as the ID of the power user. Fig. 2 shows the processing flow of identifying an ID when a personal outlet detects multiple IDs simultaneously.

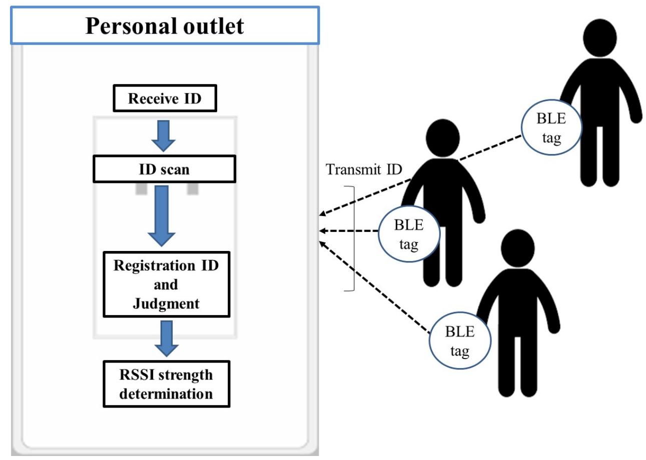

Fig. 2. When multiple IDs are detected simultaneously.

B. *Identification of the User from Multiple IDs Detected in Sequence*

There are two alternative methods for identifying the user when several IDs with the highest RSSI strength have been detected in sequence:

1) Method 1: Identify an ID based on each ID's accumulated power consumption: ID detection is carried out every N seconds and the ID with the highest RSSI strength is identified. The power consumed up to the next s seconds is assigned to that ID. The total power consumption assigned to each ID from the beginning to the end of power use is compared. The ID with the highest total power consumption is selected as the power user and is assigned the entire power consumption.

Suppose ID1 and ID2 are detected at different times. If the total of the power consumption assigned to ID1 at each ID detection up to that moment is greater than that assigned to ID2, then ID1 is selected as the power user and is assigned the entire power consumption.

2) Method 2: Identify an ID based on each ID's accumulated power consumption : When power consumption is assigned to an ID, the counter of that ID is added by 1. The ID with the largest counter value is determined to be the power user, and is assigned the entire power consumption.

For example, when ID1 and ID2 are detected at different times, the entire power consumption is assigned to ID1 if the value of ID1's counter is greater than that of ID2's counter, irrespective of whether the accumulated power consumption assigned to ID1 is smaller than that assigned to ID2.

These method 1 and 2 are shown in Fig.3. The method 1 is judged by PC. The method 2 is judged by PCC

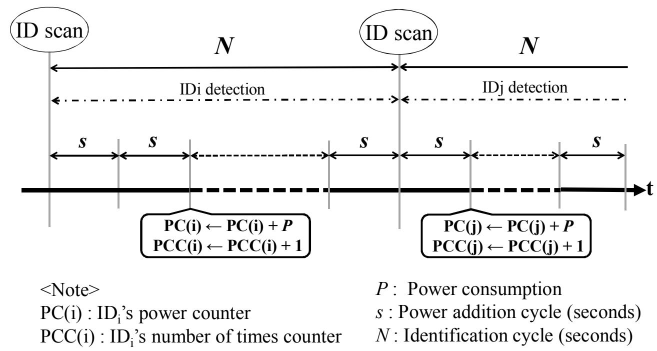

Fig. 3. Identification of the user from multiple IDs detected in sequence.

These algorithms are described in detail below. Since the steps of Methods 1 and 2 are similar, the steps of Method 1 are described with the steps of Method 2 that differ from those of Method 1 shown in parentheses. A flowchart indicating these steps is shown in Fig. 4.

STEP 1: Check whether the number of ID detections made so far at intervals of s is N.
CASE1.1: If $s = N$, go to STEP 2.
CASE1.2: If $s < N$, $s \leftarrow s+1$, go to STEP 1.

STEP 2: Detect ID_M=MAX{ RSSIn |n=detected ID }.
CASE2.1: If an ID is detected, go to STEP 3.
CASE2.2: If no ID is detected, go to STEP 1

STEP 3: Receive power consumption P from the watt checker.

STEP 4: Determine whether P is equal to or greater than the threshold x.
CASE4.1: If $P \geq x$, go to STEP 5.
CASE4.2: If $P < x$, go to STEP 6.

STEP 5: Add P to ID_M's power counter, PC(M).
(Method 2: Add the number of times ID_M was identified, C, to ID_M's number of times counter, PCC(M))
CASE5.1: If $s \neq 0$, PC(M)←PC(M) +P, $s \leftarrow s-1$,
(Method 2: PCC(M)←PCC(M)+C), go to STEP 3
CASE5.2: If $s = 0$, go to STEP 1

STEP 6 (Method 1): Compare power counters, PCs. Determine ID_{MPC}=MAX{ PC(n) |n=detected ID } that has the largest PC value.

STEP 6 (Method 2): Compare the number of times the ID has been identified, C.
Determine ID_{MPCC}=MAX{ PCC(n)|n=detected ID } that has the largest PCC value.

STEP 7: Add the value of the power of all other IDs to power counter, PC(M), of ID_{MPC}. Initialized the value of PCs other than PC(M).
(Method 2: Initialize all PCCs.)

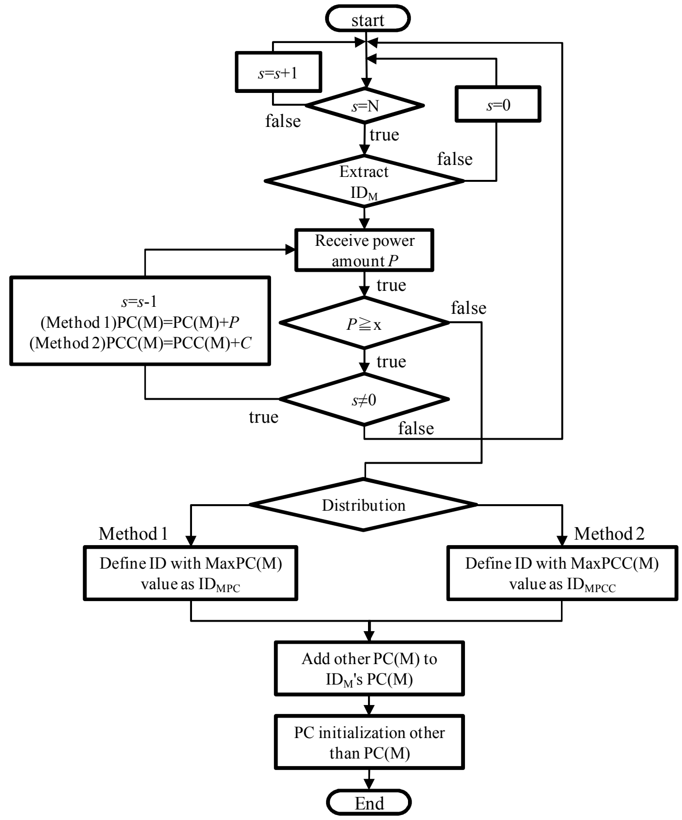

Fig. 4. Flowchart of the proposed alternative methods for identifying the power user.

V. Development Of An Experimental System For Evaluation

Methods 1 and 2 were implemented in the experimental system. A Bluetooth watt checker, REX-BTWATTCH [7], from RATOC Systems was used as a smart outlet, which measures power consumption. The power plugs of home appliances are connected to this checker. Since this product can transmit information about power consumption every second in real time via Bluetooth 4.0, it has been used in a variety of research. MyBeacon (dedicated to short-range reception) MB004 At [8] from Aplix Corporation was used as a BLE tag. The BLE was used for communication, and an ID address was assigned to each terminal. A BNP-500K from BLUEDOT was used as a terminal in which the individualized electric power management app was installed. The terminals run Android 4.4.2 and support Bluetooth 4.0. We used Android Studio2.2 for developing the individualized electric power management app, which was written in Java. We used the Watt Checker Command Specification Rev. 1.1 from RATOC Systems to analyze commands from the Bluetooth Watt Checker.

In this experimental system, a BNP-500K in which the individualized electric power management app was installed was used as the BLE reception interface of the personal outlet for receiving IDs. The evaluation experiments were carried out in a state that the Bluetooth Watt Checker and the BNP-500K were connected via Bluetooth. We did not develop a room entry monitoring system. The main specifications of the experimental system are shown in Table I. The software configuration of the experimental system is shown in Fig. 5. The system configuration is shown Fig. 6. In this figure, the text in each arrow shows information sent via Bluetooth, and the text in each box shows the name and functions of the terminal.

TABLE I. CONFIGURATION OF THE EXPERIMENTAL SYSTEM

Item	detail
OS	Android 4.4.2
App development environment	Android Studio
App description language	Java
Communication standard	Bluetooth ver.4.0
Smartphone used	BNP-500K
BLE reception terminal	MyBeacon (dedicated to short-range reception) MB004 At

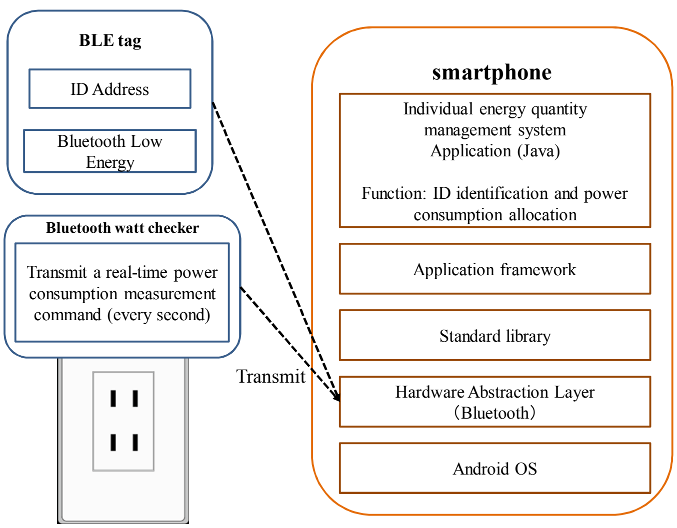

Fig. 5. Configuration of the developed software.

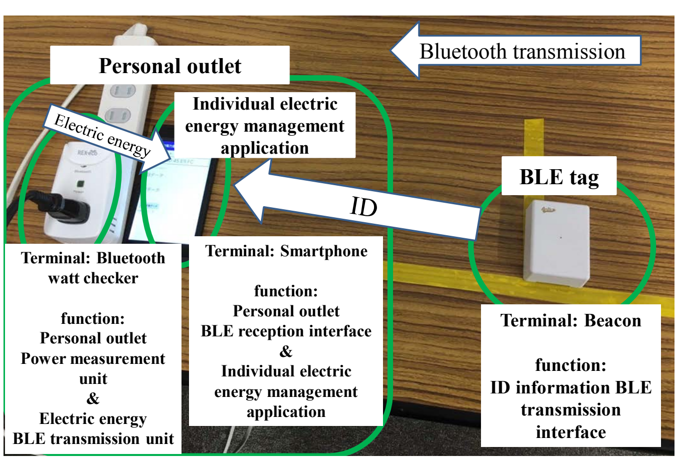

Fig. 6. Example of the evaluation system layout.

VI. EVALUATION

A. Evaluation Conditions

Under the evaluation conditions shown in Table II, we conducted the experiments shown in Table III with the experimental system using an app in which Methods 1 and 2 are implemented. Fig. 7. The BLE tag placement in experiment is shown in Fig. 7. The objective of each experiment is as follows. Experiments A to C was used to verify how the presence of an obstacle affects ID detection. Experiments D to E used a home appliance with constant power consumption to verify that the system does not assign power consumption incorrectly to the ID of a person who is not the power user when he/she comes near the personal outlet. Experiments F was similar to Experiments D to E except it used a home appliance whose power consumption was not constant. Experiments G to H conducted the same verification as Experiment F with three persons.

TABLE II. EVALUATION CONDITIONS

Item	Value
Home appliance used	Hair Dryer
Power consumption of the Hair Dryer	Cool mode: 120 W/second Hot mode: 1,200 W/second
Number of experiment attempts	5
Experiment duration	60 seconds
Obstacle	Sleeve of clothing or a human arm
Identification cycle (*N*)	5 seconds
Power addition cycle (*s*)	1 second
Threshold (x)	1 W

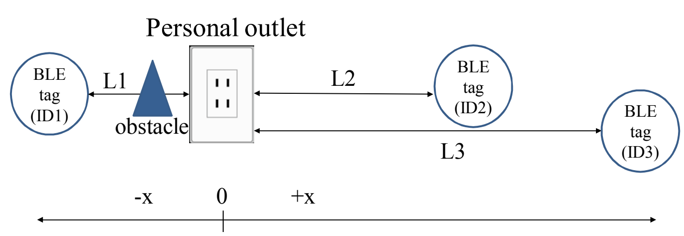

Fig. 7. BLE tag placement in experiment

TABLE III. EXPERIMENTS

Experiment A(No obstacle, Number of BLE tags: 2)
[BLE tag location] ID1: L1= -30 cm; ID2: L2=1 m. [Experiment procedure] Hair Dryer: cool mode for 60 seconds.
Experiment B(Obstacle: sleeve of clothing, Number of BLE tags: 2)
[BLE tag location] ID1: L1= -30 cm; ID2: L2=1 m. [Experiment procedure] Hair Dryer: cool mode for 60 seconds.
Experiment C(Obstacle: human arm, Number of BLE tags: 2)
[BLE tag location] ID1: L1= -30 cm (arm); ID2: L2=1 m. [Experiment procedure] Hair Dryer: cool mode for 60 seconds.
Experiment D(No obstacle, Number of BLE tags: 2)
[BLE tag location] ID1: L1= -30 cm; ID2: L2= 1 m. [Experiment procedure] (first) Hair Dryer: cool mode for 40 seconds. Interchange the locations of the two BLE tags. (second) Hair Dryer: cool mode for 20 seconds.
Experiment E(No obstacle, Number of BLE tags: 2)
[BLE tag location] ID1: L1= -30 cm; ID2: L2=1 m. [Experiment procedure] (first) Hair Dryer: cool mode for 20 seconds. Interchange the locations of the two BLE tags. (second) Hair Dryer: cool mode for 20 seconds. Interchange the locations of the two BLE tags again. (third) Hair Dryer: cool mode for 20 seconds.
Experiment F(No obstacle, Number of BLE tags: 2)
[BLE tag location] ID1: L1= -30 cm; ID2: L2= 1 m. [Experiment procedure] (first) Hair Dryer: cool mode for 20 seconds. Interchange the locations of the two BLE tags. (second) Hair Dryer: hot mode for 20 seconds. Interchange the locations of the two BLE tags again. (third) Hair Dryer: cool mode for 20 seconds.
Experiment G(No obstacle, Number of BLE tags: 3)
[BLE tag location] ID1: L1= -30 cm; ID2: L2=1 m30 cm; ID3: L3=2m 30 cm. [Experiment procedure] (first) Hair Dryer: cool mode for 40 seconds. Move the location of each BLE tag as follows: [BLE tag location] ID1: L1=2 m 30 cm; ID2: L2=1 m 30 cm; ID3: -30 cm. (second) Hair Dryer: cool mode for 20 seconds.
Experiment H(No obstacle, Number of BLE tags: 3)
[BLE tag location] ID1: L1= -30 cm; ID2: L2=1m30 cm; ID3: L3= 2m 30cm. [Experiment procedure] (first) Hair Dryer: cool mode for 40 seconds. Move the location of each BLE tag as follows: [BLE tag location] ID1: L1=2m 30 cm; ID2: L2= 1m30 cm; ID3: L2=-30cm. (second) Hair Dryer: hot mode for 20 seconds.

B. Evaluation Results

We evaluated accuracy of ID detection in each experiment. The result of ID detection accuracy for each method in each experiment is shown in Table IV. In Experiments A to E and H, the correct ID was detected with both Methods 1 and 2. Even with an obstacle that was present in Experiments B and C, the percentage of detection accuracy was 80 % or higher. In Experiments F and H, the percentage of ID detection accuracy was 20 % with Method 1 but was 80 % or higher with Method 2.

TABLE IV. ID DETECTION ACCURACY IN EACH EXPERIMENT

Experiment \ Method	Method 1	Method 2
A	80 %	100 %
B	100 %	80 %
C	100 %	100 %
D	100 %	100 %
E	100 %	80 %
F	20 %	100 %
G	100 %	100 %
H	0 %	80 %
Average	75 %	93 %

Fig. 8 shows the power consumption and the number of times each ID has been detected in Experiment A, in which the level of ID detection accuracy was high with both Methods 1 and 2. Fig. 9 shows the same items for Experiment F, in which the ID detection accuracy differed greatly between Methods 1 and 2.

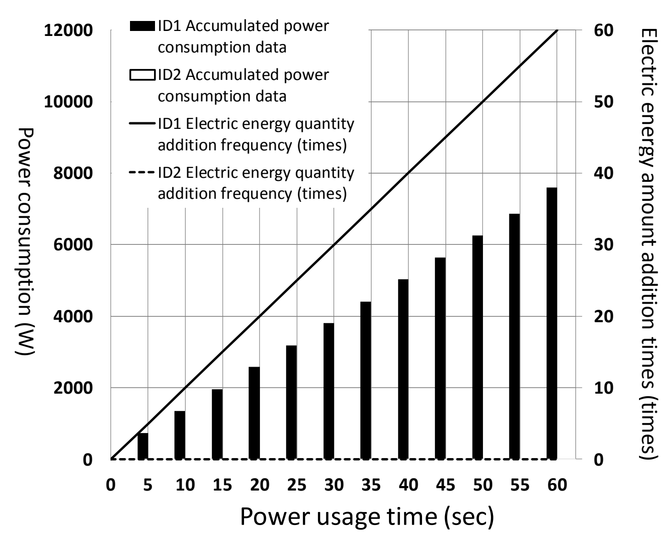

Fig. 8. Power consumption and number of times each ID was identified in Experiment A (only ID1 is detected).

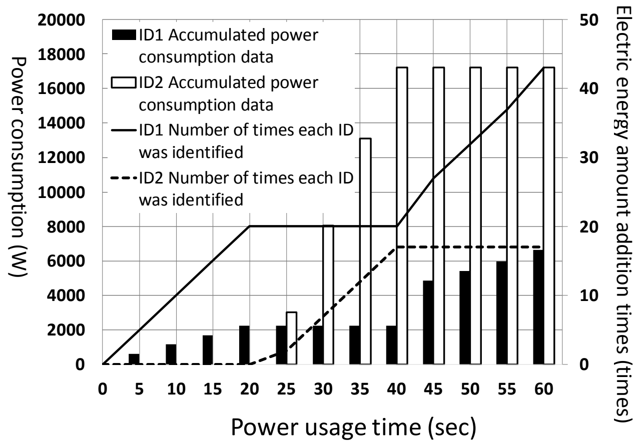

Fig. 9. Power consumption and number of times each ID was detected in Experiment F (ID1 and ID2 are detected alternatively).

In Experiment A, at every ID scan, which was carried out every 5 seconds, ID1 was identified as the power user, and the power consumption was allocated to ID1. After the use of power ended, Method 1 identified ID1 as the power user, and the power consumption was again allocated to ID1. ID2 was not identified in either Method 1 or 2. So, data on ID2 are not visible in Fig. 8. The tendency of the evaluation result was similar in Experiments B and C, which involved an obstacle. Thus, we confirmed that an obstacle, such as a sleeve or an arm, does not affect the ability for ID identification.

In Experiment F, the locations of BLE tags were interchanged. Thus, unlike Experiment A, both the number of times ID1 was detected and the number of times ID2 was detected increased as time elapsed. Since the length of time when ID1 was closer to the personal outlet was longer than that when ID2 was closer to the personal outlet, the number of times ID1 was detected was greater than that for ID2. Thus, ID1 was correctly identified as the power user with Method 2. However, during the 20 seconds when ID2 was closer to the personal outlet, the power consumption was 10 times greater than that at other times. As a result, ID2's accumulated power consumption over the 60 seconds was greater than that of ID1, which led to the incorrect identification of ID2 as the power user.

VII. Conclusions And Future Issues

This paper has focused on the problem of how the power expenses in a shared house, which is growing in popularity, should be allocated to its residents. We have studied an individualized electric power management system. We have developed two apps for an experimental system to compare two alternative methods of identifying the power user: Method 1, which is based on accumulated power consumption for each person, and Method 2, which is based on the number of times a person was identified as the power user. From our experiments, we confirmed that Method 1 identifies the power user more accurately than Method 2 when the power consumption of home appliances is constant. However, if there are many appliances at home, the power consumption can vary over time. Therefore, in real situations, the percentage of accurately identifying the power user can be lower than those in our experiments. Our experiments revealed that Method 2 can identify the power user more accurately than Method 1 even when the power consumption of home appliances vary over time because the variation in power consumption does not significantly affect the number of times a person is identified as the power user. With Method 2, the percentage of accurate identification of the power user was 93 % in our experiments, indicating that Method 2 is better at identifying the power user than Method 1 under this condition. Even when there was an obstacle, such as a sleeve of clothing or a human arm, between tags and the personal outlet, the percentage of correct identification was 80 % or higher.

Looking forward, we will make more experiments using other types of obstacle. In addition, to prevent failures to identify the power user at personal outlets while power is actually used, we will develop a room entry monitoring system and add it to the individualized electric power management system. Also, it is necessary to conduct field experiments at an actual shared house.

Acknowledgments

We thank Mr. Sakamoto of RATOC System Development Department, Inc.. Mr. Sakamoto offered a sample program of the Bluetooth watt checker REX - BTWATTCH used in this prototype.

References

[1] T. Takahashi, D. Ishiura, M. Kuroyanagi,"New value proposition in rental housing - possibility of share house," Mitsubishi UFJ Research & Consulting, http://www.murc.jp/thinktank/rc/report/consulting_report/cr_150130.pdf (accessed on 2016-02-20).

[2] "National strategy green policy outline - from the fetal movement to the growth of the green energy revolution" http://www.cas.go.jp/jp/seisaku/npu/policy09/pdf/20121127/shiryo4-1.pdf (accessed on 2016-02-20).

[3] "EMS Information Base - API Standard Specification for HEMS Data Utilization Business Operator" http://www.meti.go.jp/committee/kenkyukai/shoujo/smart_house/pdf/009_s10_00.pdf (accessed on 2016-04-20).

[4] Y. Shimo, Y. Kamiya, T. Shimokawa, "Development of location information sharing system using BLE," Multimedia, Distributed, Cooperative, and Mobile (DICOMO2016) Symposium, pp. 516-521(2016).

[5] N. Morimoto et al., "The design and implementation of a smart outlet for policy-based power management," IPSJ Transactions on Consumer Device and System (CDS), Vol3, No.4, pp.1-11(2013).

[6] A. Nakagawa, H. Suwa, M. Fujimoto, Y. Arakawa, K. Yasumoto, "Data collection and analysis for real-time behavior recognition system development," MBL, Vol.2015-MBL-77, No.9, pp.1-5(2015).

[7] "Bluetooth watt checker REX-BTWATTCH1[RATOC]" http://www.ratocsystems.com/products/subpage/btwattch1.html (accessed on 2016-04-20).

[8] "MyBeacon® Proximity area special type MB004 At-DR1 | Aplix Corporation" http://business.aplix.co.jp/product/mybeacon/mb004at-dr1/ (accessed on 2016-04-20).