Prototyping of A Personal Outlet-enabled Individualized Power Consumption Management System

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***Abstract*— In recent years, the home energy management system (HEMS) has been drawing interest as a means of monitoring and controlling energy usage at home. However, in a shared house, it is necessary to manage the amount of power consumed by individually owned appliances and power consumed by shared appliances in common spaces, such as a living room and a washroom. We have built an individualized power consumption management system, in which wall outlets measure the power consumption of individual appliances and the management server collects power consumption data from the wall outlets using HTTP. We added a Wi-Fi connection ability to a wall outlet, which we proposed earlier, so that it can serve as an IoT device. A BLE tag is attached to each appliance, and each resident carries a BLE tag. Each appliance is distinguished by a BLE tag ID. Power consumption by each person is managed by identifying the user of each appliance type. We conducted evaluation experiments, which simulated a situation in which three residents were in a shared space. We measured the rate at which electric power users were identified correctly and confirmed that the proposed system can manage the power consumption of individuals.**

Keywords— home power consumption management system, personal outlet, BLE tag, IoT, WoT

I. Introduction

Efficient energy management at home has become important as a means of saving energy. The home energy management system (HEMS) has been developed to manage energy consumption at home. The Ministry of Land, Infrastructure, Transport and Tourism in Japan announced that it would push the introduction of the HEMS so that it will be available at all homes by 2030 [1]. However, because of the high up-front cost, the HEMS is slow to spread. The entry of companies into the energy management market for consumers is also lagging behind their entry into the market for enterprises.

In recent years, there has been a growing demand for shared houses [2]. In a shared house, it is necessary to collect the power consumption data of each person in common spaces so that the energy bill can be allocated to each resident. However, the HEMS, which aims at the visualization of the electricity and gas consumption and automatic energy control of home appliances, cannot collect such data.

With advances in IoT (Internet of Things), devices capable of sensing energy use are beginning to be connected to the network, making it easy to collect data and control energy consumption. As the range of objects monitored and controlled widens, it becomes urgent to efficiently design and develop server systems that are connected to IoT devices. The concept of WoT (Web of Things) [3] has been proposed to allow efficient development of a variety of IoT-based services by expediting the development of IoT management servers and facilitating inter-server coordination. WoT adopts Hypertext Transfer Protocol (HTTP) for communication between IoT devices and servers and uses Web system platforms as IoT servers.

Our present study assumes that a Bluetooth Low Energy (BLE) tag is attached to each appliance in a shared house and every resident carries a BLE tag. We earlier proposed a wall outlet (hereafter “personal outlet”) [4] that can measure the power consumption of each appliance, which is designated by a BLE tag ID. In our present study, we add a Wi-Fi connection ability to a personal outlet to make it an IoT device. Home appliances are classified according to whether they are shared or not. A personal outlet collects the tag IDs of the appliances connected and the tag IDs of the users via Bluetooth communication and identifies the relevant IDs. We have built a prototype of an individualized power consumption management system. It collects the measured power consumption data of each user from personal outlets using HTTP. We conducted evaluation experiments, which simulated a situation in which three residents were in a shared space. We measured the rate at which electric power users were identified correctly and confirmed that the proposed system can manage the power consumption of individuals. Section II introduces related studies. Section III describes the proposed personal outlet-enabled individualized power consumption management system and its elemental technologies. Section IV explains the experimental system we have developed. Section V discusses the evaluation experiments conducted using this system and experiment results. Section VI presents conclusions and future issues.

II. Related Studies

Smart outlets are widely studied in connection with the HEMS [5]-[9]. In most of these researches, smart outlets are connected to a wired network using Power Line Communication (PLC) [5] or Ethernet [6], or to a wireless network using ZigBee [7], Wi-Fi [8], or Bluetooth [9]. They are focused on the remote control of a power switch, etc. or on the measurement of power consumption at each outlet.

However, there has been no study on identifying power users and measuring and managing the power consumption of each user when multiple persons use a single outlet.

III. Individualized Power Consumption Management System That Uses Personal Outlets

This section describes the assumptions of the proposed system, an overview of the service considered, the classification of home appliances, and the requirements for the personal outlet and the management server. It also defines information elements exchanged between the personal outlet and the management server.

A. *Individualized Power Consumption Management*

It is necessary to identify each electric power user (hereafter "power user") and each appliance. We use a wearable tag (BLE tag) to identify each person. We call the BLE tag held by each resident a "human tag" and the ID associated with this tag "hID." We call the BLE tag attached to each appliance an "appliance tag," and the ID associated with this tag "aID."

The personal outlet uses the Bluetooth address sent from a BLE tag as a tag ID. This tag ID is used to identify a person or an appliance. The personal outlet sends the identified hID, aID and the measured power consumption data to the individualized power consumption management server through an HTTP-based interface.

Information about the residents and appliances in the shared house is registered in the server. From the registered information, the server creates a table showing the association between the resident's name and his/her hID, and a table showing the association between aID and the appliance type. The server manages the power consumption, the power usage site, the power usage time, and the in-room time (duration for which a person is in the room) of each resident. A smart device can access these items of information and display the power consumption of each person. An individualized power consumption management system that has these functions is shown in Fig. 1.

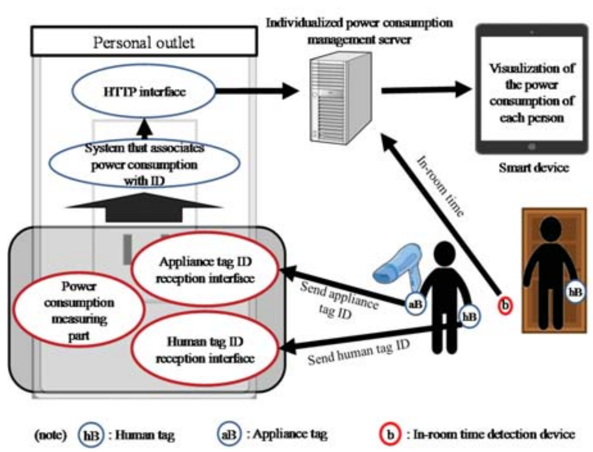


Fig. 1. Personal outlet-enabled individualized power consumption management system.

B. *Classification of Home Appliances*

There are a variety of home appliances. Some are used by a single person and some shared by several persons. The televisions and air-conditioners installed in common spaces are used simultaneously by several people. The microwave in the kitchen and the dryer in the washroom are used by several people but not simultaneously. These are always used by a single person at a time. Smartphones and tablets are owned by individuals but charged in common places. To manage appliances, we define four types of attribute: *Public*, *Public Personal 1 (PP1)*, *Public Personal 2 (PP2)*, and *Personal*. The difference between *PP1* and *PP2* is as follows. When a *PP1* appliance is plugged into a wall outlet and in use, the user does not leave the outlet. In contrast, when a *PP2* appliance is in use, the user may leave the outlet. The classification of appliances is shown in Table I.

TABLE I. Classification of Home Appliances

Attribute (Appliance examples)	**Description**	**The user location while the appliance is in use**
Public (Television)	Shared appliance that may be used by several people simultaneously	The user may leave the outlet
PP1 (Dryer)	Shared appliance used by a single person at a time	The user always stays near the outlet
PP2 (Toaster oven, Microwave)		The user may leave the outlet
Personal (Smartphone, Tablet)	Appliance owned by an individual	

C. *Use of a Tag ID to Identify the Appliance used or the User*

1) Identification of the Tag ID based on the number of Detections during a Period: When a personal outlet detects multiple IDs sent from BLE tags, it selects the ID with the highest Received Signal Strength Indicator (RSSI). If different IDs with the highest RSSI are detected in sequence, the outlet selects the relevant ID based on the numbers of detections, which the authors proposed earlier [4]. Specifically, the outlet detects the ID with the highest RSSI in each T-second period from the start to the end of power consumption. The detection counter of this ID is incremented by 1. At the end of power consumption, the ID with the highest detection count is selected as the target ID over the observation period.

2) Identification of the Appliance used and the User: The appliance used is identified by applying the method described in III.*C.1)* to appliance tags. Specifically, aID scan is executed, and the aID that has the highest RSSI and is detected the most often is selected as the aID of the appliance used.

The user is identified as follows depending on the detected appliance attribute (see Table I)

a) The appliance attribute is Public: A *Public* appliance is used by one or more persons. The in-room time of each resident is managed based on hID. The persons with hIDs that have been recorded as being in the room are identified as users. The amount of power consumption is allotted to each user in proportion to his/her in-room time.

b) The appliance attribute is PP1: A *PP1* appliance is used by a single person, who does not leave the outlet while the appliance is in use. The user is identified by applying the method described in III.*C.1)* to human tags. Specifically, in each T-second period while the appliance is in use, the hID with the highest RSSI is detected. The hID with the highest detection count at the end of the period is identified as the hID of the user. The power consumption during S ($S < T$) seconds is allotted to the hID that is found to have the highest

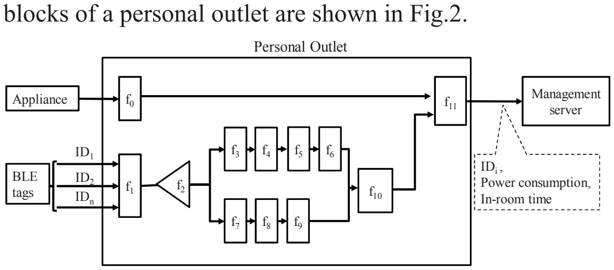
RSSI in each *T*-second period. At each allocation, the amount of power consumption is added to the power consumption counter of the relevant hID. At the end of the use of the appliance, the power consumption added to the user with an hID other than the identified target hID is subtracted and added to the user of the target hID.

c) The appliance attribute is PP2: As with a *PP1* appliance, a *PP2* appliance is used by a single person. However, the user may leave the outlet while the appliance is in use. To identify the user who leaves the outlet after a certain period, we introduce a threshold for ending the observation for hIDs. This threshold is an integral multiple of *T*. The counter used is named PP2Counter. The method described in III.*C.1)* is applied from the start of the use of the appliance to the time when the threshold is exceeded. The hID with the highest detection count is identified as that of the power user.

d) The appliance attribute is Personal: A *Personal* appliance is used only by the person who owns it. Therefore, the owner of the appliance registered in the server is identified as the power user.

D. Functional Requirements for a Personal Outlet

The authors earlier proposed the basic functions of a personal outlet [4]. We added a Wi-Fi function to make the outlet an IoT device. A personal outlet receives IDs from human tags and appliance tags, identifies the power user at the end of the use of the appliance, and sends that information to the server. At the start of the use of an appliance, the personal outlet also downloads the tag management tables of the residents and appliances from the server. The functional blocks of a personal outlet are shown in Fig.2.



f_0 : Measures power consumption (including date and time), f_1 : Receives ID,
f_2 : Identifies ID, f_3 : Identifies human tag, f_4 : Increments the in-room time counter,
f_5 and f_8 : Makes a selection based on RSSI,
f_6 : Enters the value of f_0 in the power consumption counter of the power user,
f_7 : Identifies appliance tag, f_9 : Identifies appliance attribute,
f_{10} : Identifies power user based on the appliance attribute,
f_{11} : Enters the value of f_0 in the power consumption counter of the power user identified in f_{10}

Fig. 2. Functional blocks of a personal outlet.

E. Individualized Power Consumption Management Functions

The functions required to mage users, tag IDs and power consumption are described below.

- *Registration and confirmation of users and login*: A user is registered in the server by entering the user ID, user name, password and confirmation password. A user logs in the system using the user ID and password.
- *Confirmation of power consumption*: The user can display the total power consumption associated with his/her BLE tag, as well as detailed information: location of use, the start of use, the end of use, in-room time and power consumption.
- *Registration and confirmation of a BLE tag*: The BLE tag owned by a user is registered by entering the tag name, tag ID and password.
- *Registration and confirmation of an appliance*: Each of all appliances used in a shared house is registered by entering appliance name, tag ID, appliance attribute and password.

The relations and transitions between these functions are shown in Fig. 3. Except for the transition from the power consumption detail function to the main menu function, transitions between functions can be bidirectional. There is a function to display information after the user has entered it.

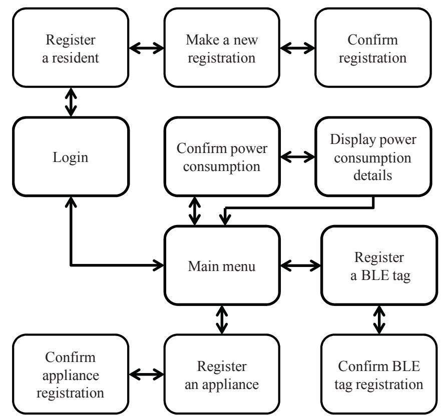


Fig. 3. Relations and transitions between functions.

F. Protocol used between a Personal Outlet and the Server

When the management server launches a personal outlet, it downloads management information, such as information about the registered appliances and residents of the shared house. At the end of power use, the personal outlet uploads observed information to the server. An overview of information exchanged between the personal outlet and the server is shown in Fig. 4. Information about measured power consumption and the presence of the user in the room is sent using HTTP to the server, which is specified by a URL. Let URL1 be the URL to which information about measured power consumption is sent, and URL2 be the URL to which information about the presence of the user in the room is sent. Information sent to URL1 is information about the power user and information about total power consumption. Information sent to URL2 is information about the appliance attribute and the in-room time of a human tag. Detailed information elements sent to the respective URLs are shown in Table II. An example of the sequence of sending measured power consumption is shown in Fig. 5.

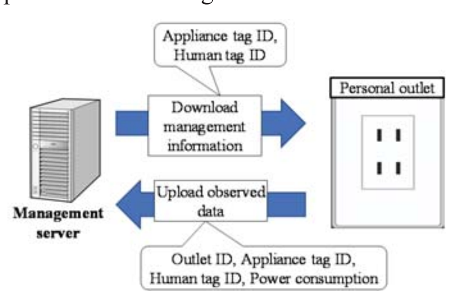


Fig. 4. Overview of information exchanged between a personal outlet and the management server.

TABLE II. INFORMATION ELEMENTS EXCHANGED AND THE RELEVANT URLS

Information element name	Description	URL1	URL2
Outlet_ID	ID of the personal outlet	Included	Included
Tag_ID	Power user identified by the personal outlet	Included	—
Start Time	Start time of power usage	Included	Included
End Time	End time of power usage	Included	—
Total	Total power consumption from the start to the end of power usage	Included	—
Attribute	Attribute of the appliance used	—	Included
Num_of_Tags	Number of tags that the personal outlet has detected from the start to the end of power usage	—	Included
Tag_ID_in_Room	Tag ID of a person in the room	—	Included
In-Room_Time	Duration in which a person stays in the room	—	Included

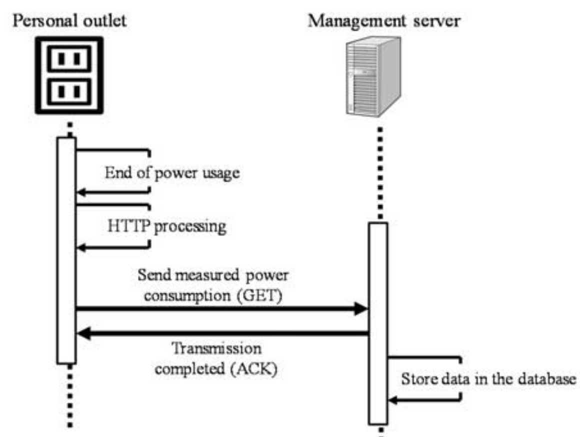


Fig. 5. Example of the sequence of sending measured power consumption.

IV. EXPERIMENTAL SYSTEM

To evaluate the proposed system, we developed an experimental system that consisted of a personal outlet and the individualized power consumption management server.

A. Personal Outlet

As shown in Fig. 6, the personal outlet [4] consisted of a Bluetooth watt checker REX-BTWATTCH and a smartphone. An appliance identification function and an HTTP communication function were newly added to the smartphone. A Bluetooth watt checker REX-BTWATTCH [10] from RATOC Systems was used as a smart outlet that measures power consumption. The power plugs of appliances were connected to this checker. The checker sends power consumption over one second to the smartphone using Bluetooth. My Beacon Proximity-type MB004 At [11] from Aplix was used as the BLE tag that was carried by a resident or attached to an appliance. HUAWEI nova lite 2 was used as the smartphone. It received a BLE tag ID, identified either the user or the appliance and also had a function to communicate with the server. Its OS was Android 8.0.0. It communicated using Bluetooth ver. 4.2 or Wi-Fi 802.11 b/g/n. We used Android Studio3.2.1 to develop the applications, which were written in Java. We used the Command Specifications Rev1.1 for the Bluetooth watt checker, which was provided by RATOC Systems. The smartphone communicated with the server via Wi-Fi. The time when a person entered the room and the time when he/she left the room were calculated from the human tag information detected by the personal outlet.

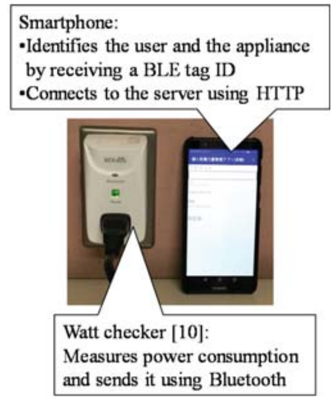


Fig. 6. The configuration of the developed personal outlet.

B. Individualized Power Consumption Management Server

The individualized power consumption management server was developed using general-purpose Web system functions. CentOS6 was used as the OS. The execution environment consisting of Apache, MySQL, PHP (Hypertext Preprocessor) was installed to create a server function, a database function, and a management function. The management function was mainly coded in PHP. The functions shown in Fig.3 were implemented as UIs (User Interfaces) on a Webpage. The software configuration of the management server is shown in Fig. 7.

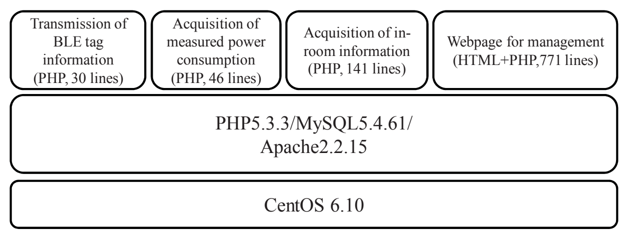


Fig. 7. Software configuration of the management server.

V. EXPERIMENTS AND EVALUATIONS

Using the experimental system, we verified the operation of the proposed system and evaluated the rate at which the user or the used appliance was identified correctly (identification rate).

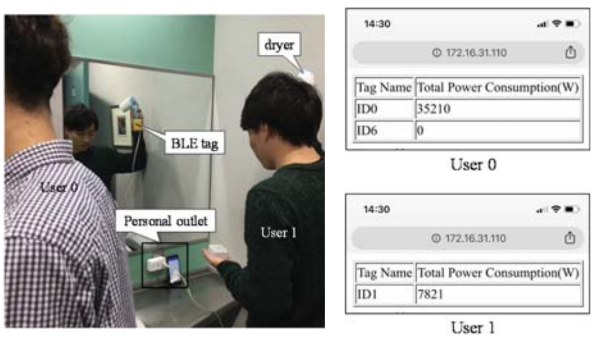
A. Usage Scenarios and Experiments to Verify the Operation

We verified the operation of the system with two users (User 0 and User 1) as follows. The changes in power consumption that occurred when the two users performed the following three scenarios in sequence were displayed on the each User's smartphone screen.

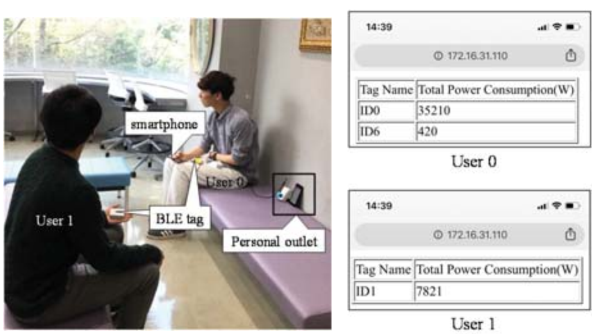
- *Usage scenario 1 (Fig.8(a))*: While User 0 (Tag_Name = ID0) was using a *PP2* toaster oven (Tag_Name = ID6), User 1 (Tag_Name = ID1) came near User 0. The power consumption during this period was allotted to User 0.

- *Usage scenario 2 (Fig.8(b))*: While User 1 was using a *PP1* dryer (Tag_Name = ID4), User 0 walked around User 1. The power consumption of User 0 remained unchanged and the power consumption during this period was allotted to User 1.
- *Usage scenario 3 (Fig.8(c))*: User 0 sat in the living room and was charging his smartphone (Tag_Name = ID6). User 1 sat in front of User 0. The power consumption during this period was allotted to User 0.

(a) Usage scenario 1 and a screen showing the measurement result



(b) Usage scenario 2 and a screen showing the measurement result



(c) Usage scenario 3 and a screen showing the measurement result

Fig. 8. Usage scenarios and measurement results.

B. Rate at which the Used Appliance or the User is Identified Correctly (Identification Rate)

We conducted two types of experiments. One was to evaluate the rate at which the personal outlet identified the used appliances correctly. The other was to evaluate the rate at which the personal outlet identified the power user correctly. It is difficult to conduct experiments that exhaustively cover all the combinations of movements of multiple residents and various appliances used. Therefore, we predefined the movements of the residents and the locations of the appliances and the personal outlet as shown in Fig. 9. The experiments of identifying the used appliances and the power user were conducted under the conditions described in V.*B.1)* and V.*B.2)*. Common experiment conditions are shown in Table III.

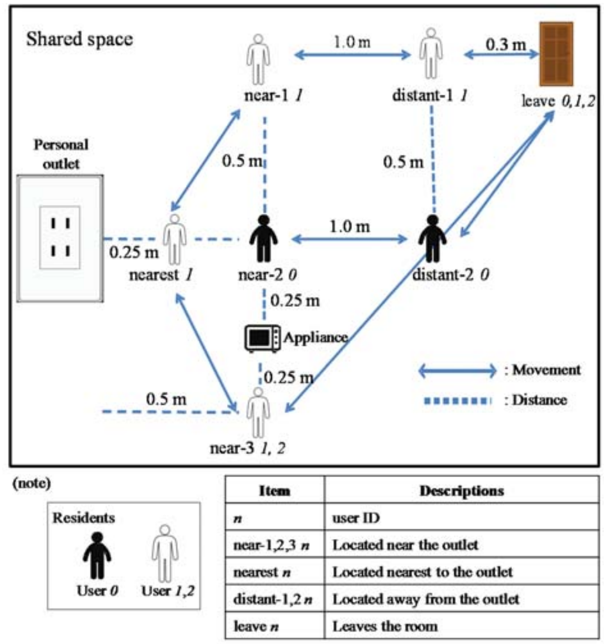


Fig. 9. Locations of the appliance and residents that simulate movements of residents in a shared space.

TABLE III. COMMON EXPERIMENT CONDITIONS

Item	Value
Experiment time	60 seconds
Number of experiments	5
ID scan cycle (*T*)	5 seconds
Cycle at which the server receives power consumption data from the watt checker (*S*)	1 second

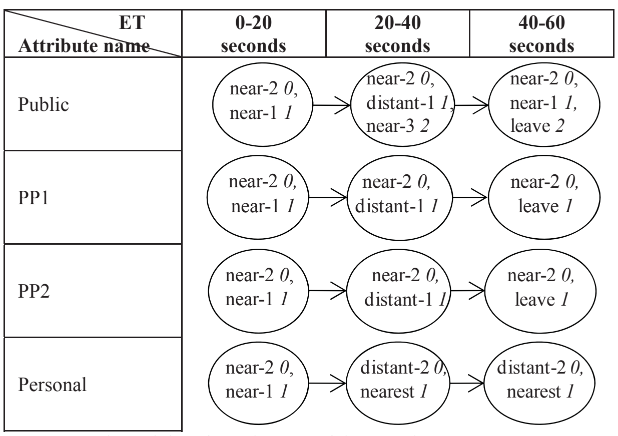
1) Conditions for Experimenting used Appliance Identification: We checked whether the appliance tag attached to an appliance sends the ID to the personal outlet and whether the personal outlet can correctly identify the used appliance. By changing the location of the appliance tag every 20 seconds, we created 9 patterns that simulated the movements of the residents. Two appliances were used in the experiments: a *PP2* appliance and a *Personal* appliance. The assumed scenario was as follows. While User 0 was using a *PP2* appliance, User 1, who carried a *Personal* appliance and was not the user of the *PP2* appliance, moved around in the room and left or entered the room. Detailed experiment conditions are shown in Table IV.

2) Conditions for Experimenting the User Identification: We checked whether the system can correctly identify the user of each appliance type (attribute) and allot the power consumption accordingly in a shared space where there were several residents and one personal outlet.

When power was being used, Users 0, 1 and 2 were located near the outlet or at some distance from the outlet as shown in Fig. 9. After that, some users moved to a place nearest to the outlet or left the space. The locations of human tags were changed every 20 seconds. In this way, the users moved around in 28 different patterns that simulated what may occur in real life. An example of an experiment pattern for each attribute name is shown in Fig.10. For example, in attribute "*Public*," during the period from the start of the experiment up to 20 seconds later, User 0 was located near-2 and User 1 was located near-1 in Fig. 9. From 20 seconds later up to 40 seconds later, User 0 remained at the same location but User 1 moved to distant-1 and User 2 entered the room and moved to near-3. From 40 seconds later up to 60 seconds later, User 0 was still at the same location but User 1 moved back to near-1 and User 2 promptly left the room. We used 4 different thresholds for the PP2Counter to see which one was the most useful. Details of the experiment conditions are shown in Table V.

TABLE IV. CONDITIONS FOR EXPERIMENTING APPLIANCE TAG IDENTIFICATION

Item	Value				
Number of experiment patterns	9				
Number of BLE tags	4	Human tags	2	User 0	
				User 1	
		Appliance tags	2	PP2	Toaster oven
				Personal	Smartphone charger
PP2Counter (seconds)	15				



(note) ET: Elapsed time from the start of the experiment.

Fig. 10. An example of an experiment pattern. The location of each user at different elapsed time from the start of the experiment.

TABLE V. CONDITIONS FOR EXPERIMENTING THE HUMAN TAG IDENTIFICATION

Item	Value			
Number of experiment patterns	28	Public	4	
		PP1	10	
		PP2	11	
		Personal	3	
Number of BLE tags	7	Human tag	3	User 0
				User 1
				User 2
		Appliance tag	4	Display
				Dryer
				Toaster oven
				Smartphone charger
Power user	User 0			
Threshold for PP2Counter (seconds)	5, 10, 15 and 20			

C. Experiment Results

1) Used Appliance Identification: Since any appliance that was being used was connected to the personal outlet with a power cord and thus did not move, used appliances were always identified correctly.

2) User Identification: The experiment results are shown in Table VI. The power consumed by the *Public* appliance was allotted to residents based on the in-room time of the ID of each human tag sent to the server. The user identification rate was 89%. Since in-room time was detected by the personal outlet in this experiment, the instability of Bluetooth communication affected the experiment results. For example, in a case where a human tag ID stayed in the room for 60 seconds during which power was used, the detected in-room time was 50 seconds.

With the *PP1* appliance, the user identification rate was as high as 98%. The user identification rate with the *PP2* appliance was also high, ranging from 96% to 100% depending on the value of the threshold for the PP2Counter. We conducted an experiment to check whether the PP2Counter was useful. In this experiment, User 0 moved away from the personal outlet 20 seconds after he began to use power, and User 1, who was not using power, came near the outlet. When the PP2Counter was used, the system identified User 0 as the power user, but when the PP2Counter was not used, the system incorrectly identified User 1 as the power user.

With a *Personal* appliance, there is no need to detect human tag IDs to allot power consumption because the owner of the *Personal* appliance registered in the server is the power user. Thus, the user identification rate is equal to the appliance tag ID identification rate. Since the ID identification rate was 100% in the experiment of appliance tag identification, the user identification rate for the *Personal* appliance was also 100%.

TABLE VI. USER IDENTIFICATION RATE

Appliance attribute and conditions			Identification rate (%)
Public			89
PP1			98
PP2	Threshold for PP2Counter (seconds)	5	96
		10	96
		15	100
		20	100
Personal			100

VI. CONCLUSIONS AND FUTURE ISSUES

We have proposed an individualized power consumption management system, which uses a personal outlet capable of measuring the power consumption of each appliance designated by a BLE tag ID. We turned the personal outlet into an IoT device by adding a Wi-Fi communication function to it so that the data measured by the outlet can be sent via Wi-Fi to the server using HTTP. A BLE tag is attached to each home appliance, and each resident in a shared house carries a BLE tag. The proposed system manages the power consumption of each resident by identifying the appliance being used and the user of each appliance type. We conducted experiments that simulated a shared house with three residents and confirmed that the person using power can be identified correctly at a rate of 89% or higher. Thus, we verified that the system can be used to manage the power consumption of individual residents.

It will be necessary to conduct experiments with cordless appliances and microwaves that use the same frequency bands as Bluetooth and to study ways to improve the stability of wireless communication with BLE tags. It will also be necessary to examine the threshold of the PP2Counter, which is used to identify the user of a *PP2* appliance because the optimal threshold can depend on the appliance.

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