Determining Location of Appliances from Multi-hop Tree Structures of Power Strip Type Smart Meters

Hyun Sang Cho, Student Member, IEEE, Tatsuya Yamazaki, Member, IEEE, and Minsoo Hahn

Abstract — Recently, energy management has become one of the emerging services in the area of residential network service. A smart meter is the most essential component of advanced metering infrastructure (AMI) that connects the home energy management system of individual residences and a smart grid that optimizes the production, distribution, and consumption of electric power. Power strip type smart meters can be used to not only monitor but also control the electric power consumption at individual power outlet ports in the power outlet directly. They can be used to control and effectively reduce standby power consumption by the application of the direct power supply control. A smart multi-power tap (SMPT) is an advanced multi-outlet power strip type smart meter that provides important contextual information such as the identity and location of electric home appliances on the basis of the temporal power consumption data and the control of power supply to the appliances. However, the SMPT cannot be used to determine the location of appliances when the connections among SMPTs form a tree structure. In this study, we develop a mathematical model of cascade connections among SMPTs and propose a solution for obtaining the location information of the tree structure. The proposed method helps realize real applications of the SMPT for providing activity-based context-aware home network services and energy management services.

Index Terms —Smart grid, smart meter, AMI, home network, smart power strip.

1. INTRODUCTION

A smart grid is an electric power distribution system in which information and communication technology (ICT) is applied to facilitate bidirectional communication between utility companies and customers in order to optimize power generation, distribution, and consumption. The customers are classified as consumers of high voltage (HV) electricity, including factories, and consumers of low voltage (LV) electricity, including commercial establishments and individual residences. The home energy management system (HEMS) is a networked system that helps manage the power supply to residences in order to reduce power consumption [1]. Communication between the smart grid and home network services is facilitated by advanced metering infrastructure (AMI) [2], [3], where automatic meter reading (AMR) and automated metering management (AMM) are implemented using smart meters [2].

A smart meter is an essential component of the AMI and supports the AMR operation since it helps monitor the power consumption of home appliances. The smart meter sends the data to the utility companies and the utility companies use the data for decision making of power generation and distribution, and billing. The companies send the cumulative power consumption data and the corresponding price of the power consumption to the smart meter in order to display the information on an in-home-display (IHD) for encouraging customers to reduce their power consumption.

Since the AMI facilitates bidirectional communication, the utility companies can also send power control commands to the customer side of the home network control system in order to reduce power consumption, especially during periods of the peak time of power consumption, e.g., critical peak pricing (CPP) [4]. In international experiments, including the CPP in Australia [4], [5], the feedback from the AMR resulted in a 5–15% reduction in power consumption. Additional actuators that control power supply to electric appliances in residence are necessary in order to support automated appliance control for CPP. Experimental results for California showed that application of CPP resulted in a 27% reduction with the CPP that controls thermostat or power supply to air conditioners. The results indicate that without the automated response, a 5–10% reduction in power consumption was achieved [6]. Therefore, the actuator that controls power consumption is necessary for more effective power consumption and users' convenience.

Multi-outlet power strips have been recommended as an effective means to reduce power consumption by cutting off standby power consumption. Several power strip type smart meters that inherit the features of multi-outlet power strips and enable the monitoring of power consumption by power supply control have been proposed. The power strip type smart meters have one or more power outlet port (socket) [7]–[10]. The port has a current sensor and/or a voltage sensor that helps monitor the current and voltage of the power supply for power consumption monitoring or appliance identification on the basis of phase information [9]. Most of the smart meters have a relay at a port in order to control the power supply to the port. The advantage of this type of smart meter is that it enables accurate monitoring and control of the power supply to individual applications; this enables efficient standby power
contextual information about users’ behavior and thus facilitate individual power control. The contextual information is necessary for providing context-aware services. Context awareness is the capability to utilize environmental information, together with the user’s personal information and preferences, to provide truly user-centric services [11]; location information is one of the basic forms of contextual information ever since the concept of context was conceived [12] but most smart meters do not provide location information. A smart multi-power tap (SMPT) is a power strip type smart meter that provides contextual location information (hereafter, “location” refers not to physical location but contextual location [13]) not by using electric power but by using physical markers [7]. However, the SMPT is also limited by its single-hop connection from a wall socket.

In this paper, a mathematical model of SMPT operation and a computational sequence for obtaining the location information of appliances from the multi-hop tree structure of SMPTs are described. The method enables the practical use of the SMPT by overcoming its limitation. This paper is organized as follows. In section 2, related studies, including those on smart grids and power strip type smart meters, are described and the requirements of the power strip type smart meters are presented, as listed in previous papers. In section 3, the SMPT that enables simple and cost-effective appliance identification and location determination is described, and the mathematical modeling of the SMPT operation and the computational sequence for determining SMPT locations for multi-hop tree structures is described. The paper is concluded with simulation results for randomly composed tree structures presented in sections 4 and 5.

II. BACKGROUNDS

A. Smart grid

“A smart grid integrates new innovative tools and technologies from generation, transmission and distribution all the way to consumer appliances and equipment. A smart grid would create an energy system that response to local and system-wide inputs, has much more information about broader system problems, and incorporates extensive measurements, rapid communications, centralized advanced diagnostics, and feedback control to optimize the use of the grid” [2]. The initial novel developments of the smart grid were focused on distribution, especially for HV supply customers. However, the range has been expanded to the LV supply customers, including individual residences. AMR is one of the basic services of the individual residence network. In the AMR, unidirectional communication is used to send current power consumption data to the utility companies. The smart grid and the home network service are linked by AMI that facilitates bidirectional communication for sending power consumption data to the customers, implementing active power control, and demanding responses from customers. Smart meters are the core components of the AMI.

B. Smart meters

A smart meter is an advanced meter that can be used to identify and measure power consumption electronically and can communicate this information to another device [2], [6]. Some of the smart meters are equipped with a display for sending data on the amount of power consumed or the corresponding cost to the customers. The IHD is an additional display for sending information to customers. One of the types of smart meters is the power strip type smart meter; these meters have one or more ports with current and/or voltage sensors for power monitoring and a relay for power control [7]–[10]. The power strip type smart meters can be used to control the standby power consumption of electric appliances and legacy appliances that have no network communication capability because they directly control the power supply to the appliances. Automatic appliance identification is necessary for appropriate power control, for avoiding the burden of registration on users, and for preventing faults of the registration. However, appliance identification on the basis of phase information requires a large communication bandwidth, and a number of smart taps are necessary because every appliance should be connected to the power strip type smart meters. Therefore, the basic requirements for the power strip type smart meters in actual operating environments are that they should be low cost and have low communication load.

C. Context-aware service

“Context awareness is the capability to utilize environmental information, together with the user’s personal information and preferences, to provide truly user-centric services” [11]. The idea of context awareness was first considered in the early 1990s, and location information was one of the first and important types of contextual information. One of the well-known definitions of context is “Any information that can be used to characterize the situation of entities (person, place, or object) that are considered to be relevant to the interaction between a user and an application, including the user and the application themselves.” Context is typically the location, identity, and state of people, groups, and computational and physical objects” [14]; location is also an element of context. The definition also describes the importance of identification of appliances as computational or physical objects in order to provide context-aware services. Activity-based computing is a
way to extract contextual information from low-level, simple, and cheap sensors. A higher level of contextual information can be extracted from the low-level contextual information such as the sound of draining water [15] and temporal power consumption data from distributed power strip type smart meters. For example, if a light and TV in a bedroom were turned off at midnight and remain shut off for more than 30 minutes, the system can infer that the user is asleep. Further, if other lights are not turned off yet, the system could turn them off for reducing power consumption. In addition, if users’ activities are concentrated at a certain location such as a kitchen or bedroom, the power saving program that includes a guide and automatic power control for the users will vary across users.

III. LOCATION DETECTION FROM MULTI-HOP TREE

A. Smart multi-power tap (SMPT)

An SMPT is an AMI smart meter that consists of a sensor and an actuator module. As a smart meter, the SMPT provides electric power consumption data to a service server via home area network (HAN) communication links such as Zigbee, Bluetooth, or PLC. The electric power consumption data are a source of basic information on human activity that will help provide more comfortable and satisfying context-aware services and help optimize power consumption more effectively.

In addition, the SMPT also provides an easy and robust means to identify appliances and obtain contextual location information by using programmable logic devices (PLD) and physical markers on a wall socket or plugs of electric appliances; temporal electric power consumption data can also be obtained using the SMPT. A home network service server can be used along with the SMPTs to identify more concrete power consumption trends of users on the basis of power consumption data by the identification and contextual location of appliances. An SMPT can be used to obtain operation information of appliances that are connected to the SMPT itself on the basis of ontologies that include the information provided by the appliance manufacturers. The information includes normal and maximum power consumption of appliances, and thus, the SMPT can issue warning messages to users before they start to operate the appliances if the cumulative power consumption of individual appliances exceeds the power capacity of the SMPT. Although most conventional multi-taps have circuit breakers to protect against excess power consumption, the circuit breaker operates when current overflow is detected and the condition of the appliance cannot be recovered. In contrast, an SMPT can pre-detect the problem and ensure automated power management of the SMPT.

The number of appliances is continuously increasing, and the number of conventional wall sockets is not sufficient to cover all appliances. Figure 1 shows one such example. If a user works on a computer, he/she simultaneously uses the power supply to a computer, monitor, printer, modem, portable HDD, and/or lamp. Several multi-power taps are necessary in this configuration. Further, in reality, frequently used appliances are located far away from wall sockets and multi-hop connection of multi-power taps is necessary for supplying power to the appliances. Although users are frequently part of multi-hop configurations when they use multi-power taps, the SMPT cannot provide location information for the multi-hop tree structures such as the structure in Figure 1. Therefore, a method to obtain the location information in the case of the
multi-hop configuration of the SMPT is necessary for providing smart grid services in actual home network environments using SMPTs.

B. Mathematical model of SMPT operation

We restricted the connection depth to two hops (less than 6 m) in order to retain the contextual information on where the appliances are located and to ensure electric safety. Figure 2 shows a tree diagram of the maximum possible SMPT tree connections. The links between the SMPTs are not communication links but power supply links. Each SMPT is connected to the service server via separate communication links such as Zigbee or PLC.

The SMPT configuration can be symmetric or asymmetric. Figure 3 shows an arbitrary example for each of the symmetric and asymmetric tree structures. In both cases, $s_i$ is a parent of $s_j$ and $s_k$, and $s_2$ and $s_1$ are child nodes of $s_1$. The maximum number of SMPTs in layer $k$ in Fig. 2 is

\[ n(MAX_k) = 4^k \]  \hspace{1cm} (1)

where $k$ is the depth of the SMPT layer and the number of power outlet ports is four. Thus, the maximum number of SMPTs when the depth of the layers is $N$ is

\[ n(S_{TOTAL}) = \sum_{i=0}^{N} 4^i \]  \hspace{1cm} (2)

From (2), we obtain the maximum number of SMPTs with two hops: $21 \ (1+4+16)$.

An SMPT has four power ports. The power consumption at an SMPT is represented by (3).

\[ P_{s_i} = \sum_{j=0}^{N} P_{App_j} + \sum_{j=0}^{M} P_{s_j} + P_{\text{OPERATION}} \]  \hspace{1cm} (3)

where $P_{App_j}$ is the power consumption of the $j^{th}$ appliance connected to an arbitrary SMPT $s_x$. $P_{s_j}$ is the power consumption of the $j^{th}$ SMPT that is connected to $s_x$. $P_{\text{OPERATION}}$ is the power consumption of SMPT $x$ including noise. $N$ is the number of appliances that are connected to $s_x$, and $M$ is the number of SMPTs that are connected to $s_j$ ($0 \leq N+M \leq 4$). $P_{App_j}$ is the power consumption at power outlet port $p$ in $s_x$.

\[ P_{App_j} \in \{x | x = (P_{p_{\text{ave}}}, P_{p_{\text{var}}}) \}_{i=0,1,...,L} \]  \hspace{1cm} (4)

where $L$ is the number of power consumption levels at port $p$, $P_{p_{\text{ave}}}$ is the average power consumption of level $i$ at port $p$, $P_{p_{\text{var}}}$ is the variation in the power consumption level $i$ at port $p$. 

![Fig. 2. Tree structure of SMPT connection](image)

![Fig. 3. Arbitrary configurations of tree structure](image)
around the average value $P_{\text{ave}}$, and $P_{\text{err}}$ is the processing error in the power consumption level $i$ at port $p$. In (4), $i = 0$ denotes standby power consumption.

Equation (4) shows an appliance that can operate at multiple power levels. Figure 4 shows four power levels of the actual power consumption of an electric water purifier. The purifier consists of a heater and a cooler for hot and cold water, respectively. The sampling period was a random value in the range 150–250 ms.

![Fig. 4. Temporal power consumption data of a water purifier](image)

**Fig. 4. Temporal power consumption data of a water purifier**

Power consumption for 34 minutes (10,000 samples, L=4)

C. Location detection with an identifier

An SMPT sends identification information on plugged-in appliances to a service server. However, if there are branch nodes of SMPTs that have no appliances or identical appliances, the information is insufficient to extract the complete tree structure of SMPTs. For example, in the asymmetric tree of Fig. 3, $s_2$ is the branch SMPT node. The service server detects the existence of the SMPT $s_2$ as soon as the SMPT is supplied with power and starts to operate. If App$_3$, $s_1$, and $s_1$ can determine the power consumption of App$_3$, and infer its location. But the locations of $s_2$, $s_3$, and $s_4$ cannot be determined if App$_1$ and App$_2$ do not operate.

Our solution is to insert an additional device (e.g., a lamp) that consumes a certain amount of power into the SMPT so that the location of the SMPT can be determined. The power consumption of the identifier is determined by the SMPT and its parent SMPTs. For example, in Fig. 5, if the identifier of SMPT $s_3$ operates, the power consumption of the identifier is determined by $s_1$ and $s_2$, as well as $s_3$. The system can extract the complete tree structure by using the cascade power determination from the identifier operating in the SMPT at an origin.

![Fig. 5. An example of symmetric tree structure with identifier](image)

From (3), the power consumption of an arbitrary SMPT $x$ with an identifier can be represented as

$$P_x = \sum_{i=0}^{N} P_{\text{App}_i} + \sum_{j=0}^{M} P_{s_j} + P_{\text{operation}} + P_{s_i}$$  \hspace{1cm} (5)$$

where $P_{s_i}$ is the power consumption of an identifier in SMPT $s_i$. $P_{s_i}$ should be large enough for the operation of the identifier to be easily detected by the system. Figure 5 shows a symmetric tree example with the identifier. Figure 6 (a) shows the operation of the identifier in the presence of multiple appliances in an SMPT, and Fig. 6 (b) shows the power connections of the SMPT.

![Fig. 6. Power consumption of an SMPT with identifier (for one second)](image)
D. Location detection with an identifier

The sequences for tree-structure extraction for the two cases by using (5) are as follows.

(a) Case 1: from initial state

Step 1) A newly connected SMPT, as well as information on connected appliances, is registered to the service server when it first connects to an origin of power source (wall power socket).

Step 2) Whenever a new SMPT is registered, a service server identifies the SMPT in order to obtain its location by using operation of an identifier (the method for the identification of an individual SMPT is identical to that in case 2 except overall scanning).

(b) Case 2: rescanning of the tree

Step 1) Finding the origin.

\[ S_O = \{ s_1 \mid s_x = \text{SMPT: plug-in to power outlet } O_x \} \]

\[ S_O = \{ s_1 \}, \quad n(S_O) = 1 \]

Step 2) Scanning SMPTs attached to their appliances (randomly selected order). The status results obtained by scanning the appliances are as follows:

\[ S_1 = \{ x, x, App_1, x \} \]
\[ S_2 = \{ x, x, x, x \} \]
\[ S_3 = \{ x, x, App_2, x \} \]
\[ S_4 = \{ App_1, x, x, x \} \]
\[ S_5 = \{ x, x, x, App_2 \} \]
\[ S_6 = \{ App_3, x, x, App_4 \} \]
\[ S_7 = \{ App_5, x, x, x \} \]

where \( x \) denotes an unknown connection.

Step 3) Building a tree by an identifier operation: In this step, an identifier is operated in the SMPT. All SMPTs simultaneously send power consumption data to the service server. If the SMPT is located in the first layer, only one SMPT detects the operation, and if the SMPT is located in the second layer, two SMPTs detect the operation. Equation (6) shows the number of identifier operations. The number is equal to the number of SMPTs minus one, for an SMTP at the origin of power source.

\[ n(\text{identifier operation}) = n(S) - 1 \] (6)

If an SMPT with an identifier is present in the first layer, the power consumption of the identifier is determined by the SMPT in the upper layer as follows:

\[ S_2 = \{ s_{1x}, x \}, \quad S_3 = \{ s_{1x}, x \} \]

\( s_{1y} \) denotes the port number \( y \) of the SMPT number \( x \).

The term to the left is the SMPT with an identifier operation and the term on the right lists a set of SMPTs that detect the identifier operation of the left SMPT. In the second layer, the power consumption of the identifier is described as follows:

\[ S_4 = \{ s_{1y}, s_{2y} \}, \quad S_5 = \{ s_{1y}, s_{2y} \} \]
\[ S_6 = \{ s_{1y}, s_{3y}, x \}, \quad S_7 = \{ s_{1y}, s_{3y} \} \]

The results from step 2) are updated by an identifier operation. The results are as follows:

\[ S_1 = \{ x, x, App_2, x \} \]
\[ S_2 = \{ s_4, x, x, s_5 \} \]
\[ S_3 = \{ s_6, x, App_3, x \} \]
\[ S_4 = \{ App_2, x, x, x \} \]
\[ S_5 = \{ x, x, x, App_2 \} \]
\[ S_6 = \{ App_3, x, x, App_4 \} \]
\[ S_7 = \{ App_5, x, x, x \} \]

Here, “\( x \)” indicates the absence of data at the port. Thus, they can be replaced by “0.” Consequently, we can obtain the expression of the tree structure as follows:

\[ S_1 = \{ s_5, 0, App_3, s_3 \} \]
\[ S_2 = \{ s_4, 0, 0, s_5 \} \]
The results are identical to the status description at the first description before step 1, and thus, the sequence is completed. A pseudo code of the sequence is as follow.

```plaintext
start sequence
   initialization
      turn-off an identifier in all SMPTs
   find the origin
      int iMaxNumberOfSMPT = the number of SMPTs in the tree except an origin
      for i=0 to iMaxNumberOfSMPT do
         assign an arbitrary number within iMaxNumberOfSMPT to an randomly selected SMPT
         read ID of all attached appliances to the SMPT
         build initial SMPT sets S
      end for
      for i=0 to iMaxNumberOfSMPT do
         obtain attached appliance of a number for an SMPT
         turn-on an identifier in the selected SMPTs
         read all ports of all SMPT
         determine parent SMPTs of the selected SMPT
         update SMPT sets S
      end for
   finalize SMPT sets S with filling 0 to unknown ports
   build tree structure from the SMPT sets S
end sequence
```

The total operation time of the sequence is as follows:

\[
t_{\text{operation}} = n(S) \times t_{\text{identifier operation}} + t_{\text{tree building}}
\]

\[\approx n(S) \times t_{\text{identifier operation}}\]

(7)

\(t_{\text{tree building}}\) is negligible because the operation was implemented by a fast software process. Thus, \(n(S) = 6\) and \(t_{\text{identifier operation}} = 1\) s; then, \(t_{\text{operation}} \approx 6 \times 1 = 6\) s in the above example.

IV. PERFORMANCE EVALUATION OF THE INDICATOR

If each identifier operation takes 1 s, the maximum operation time for scanning in step 2) is approximately 20 s for one wall power outlet. However, since the system in a residence should manage more than one wall power outlet, more time is required in real situations. The time depends on the number of SMPTs. The scanning process involves the random selection of SMPTs because the locations of the individual SMPT in the tree structure are unknown before the rescanning sequence is completed. In order to search connections, all the SMPTs in a tree must be operated, that is, twenty SMPTs except the SMPT at an origin. If there is no identifier in an SMPT, at least one of appliances that are connected to the SMPT should operate in order to determine the power consumption of the SMPT and its parent SMPTs. If there is no appliance that connects to an SMPT, it is obvious that the location of the SMPT cannot be determined without an identifier.

In order to quantitatively compare the performance of SMPTs with and without an identifier, we developed a random number generator of exponential distributions that is widely used for random generation of events; the generator was used to verify the performance of an identifier with SMPTs. The system generated random numbers in the range 1–16 (without an origin) using an exponential distribution in order to simulate the operation of appliances in SMPTs that are labeled with the number corresponding to the generated random number. The operation is repeated until all of the sixteen SMPTs are selected. We repeated the test 20,000 times and recorded the results.

(a) Distribution of process time with respect to the number of SMPTs without an identifier, determined using R [16]

(b) Averages of process time with (right) and witho ut (left) an identifier
process time in the test in the absence of an identifier. The
provides the location information of appliances by adding
maximum values were not affected by the number of SMPTs
average time with the number of SMPTs. There are many
times the reference time (average: 1.0) and the increase in the
appliance that is connected to all SMPTs but has no unit. The
time at which a user starts to use at least one arbitrary
that is, the average time of completion. The time indicates the
distribution in the case of one SMPT was the exponential
identifier. Figure 7 (a) shows the statistical distribution of the
 Consequently, Fig. 7 (b) shows that the proposed method is valid in
real situations.
This study focuses on searching for and constructing tree
structures of SMPTs. The optimization of identifier operation
by signal processing and minimization of power consumption
at the identifier are necessary future tasks.

V. CONCLUSIONS
In this paper, a method of location determination from the
multi-hop tree structure of multi-outlet power strip type smart
meters, SMPTs, is described. The smart meter is a core
component that serves as a link between a smart grid and home
network services. In addition, the location information is basic
and important contextual information for context-aware home
services and energy management services. The SMPT provides the location information of appliances by adding
supplementary features to existing power strip type smart
meters, i.e., by enabling the use of temporal power
consumption data and the implementation of power supply
control.
Most power strip type smart meters did not provide the
location information. The SMPT provided the location
information, but if the user built a cascade connection
comprising multiple SMPTs, the locations of the connected
SMPTs and appliances that were plugged into the connected
SMPTs could not be determined. This limitation hinders the
operation of SMPTs in a real environment. In order to solve
this problem, we developed a mathematical model of SMPT
operation and proposed a method for the tree-structure
extraction of multi-hop connections of SMPTs; the method
involved the use of an additional device (the “identifier”) for
determining the location of the SMPTs.
We also conducted evaluation for comparing the performance
of a group of SMPTs with and without identifiers in terms of the
tree reconstruction time. In the case of SMPTs with an
identifier, the overall operation time depends linearly on the
number of SMPTs and is shorter than that in the case of a
group of SMPTs without identifiers. Although the reference
time of the results in the absence of an identifier was
ambiguous, it is obvious that the time is greater than at least
one minute because this time is related to human activity. The
experimental results show that the proposed method is valid in
real situations.

REFERENCES

[1] Noriyuki Kushiro, Shigeki Suzuki, Masanori Nakata, Hideki Takahara,
and Masahiro Inoue, “Integrated Residential Gateway Controller for
Home Energy Management System”, IEEE Transactions on Consumer
Smart metering workshop organized by Florence school of regulation, 6,
Challenging the Comfort and Cleanliness Habits of Households”,
[5] Sarah Darby, “The effectiveness of feedback on energy consumption: A
review for DEFRA of the literature on metering, billing and direct
[7] Hyun Sang Cho, Takekazu Kato, Tatsuya Yamazaki, and Minsoo Hahn,
“Simple and Robust Method for Detecting the Electric Appliances
[8] Henrique Serra, João Correia, António J. Gano, António M. de Campos,
Isabel Teixeira, “Domestic Power Consumption Measurement and
Automatic Home Appliance Detection”, 2005 IEEE International
[9] Masahito Ito, Rysya Uda, Satoshi Ichimura, Kazuya Tago, Tohru Hoshi,
and Yutaka Matsushita, “A Method of Appliance Detection Based on
Features of Power Waveform”, Proceedings of the 2004 International
Symposium on Applications and the Internet (SAINT’04), 2004.
[10] Joon Heo, Choong Seon Hong, Sook Bong Kang, and Sang Soo Jeon,
“Design and Implementation of Control Mechanism for Standby Power
for user-centred services”, BT Technology Journal 186, Vol. 24 No. 2,
pp. 186–194, April 2006
Survey on Context-Aware Systems”, Int. J. Ad Hoc and Ubiquitous


Hyun Sang Cho received the B.S. degree in electronics engineering from Kyoungwon University, Korea, in 1997. He joined Hynix semiconductor, where he was involved in the development of semiconductor processing systems from 1997 to 2001. Then, he joined Newer-tech Inc. and Standard technology Inc., where he was involved in the development of embedded solutions and factory automation. He received the M.S. degree from Information and Communications University (ICU), Korea in 2007. In 2008, he joined the National Institute of Information and Communications Technology (NICT), Japan, where he was involved in research on a home energy management system. Currently, he is pursuing his Ph.D at the Korea Advanced Institute of Science and Technology (KAIST), Korea. His research interests include context-aware computing, energy management systems, digital storytelling, and entertainment computing.

Tatsuya Yamazaki received the B.E., M.E., and Ph.D degrees in information engineering from Niigata University in 1987, 1989, and 2002, respectively. He joined the Communications Research Laboratory (currently the National Institute of Information and Communications Technology) as a researcher in 1989. Since 2009, he has been an executive researcher at NICT. From 1992 to 1993 and 1995 to 1996, he was a visiting researcher at the National Optics Institute, Canada. From 1997 to 2001, he was a senior researcher at ATR Adaptive Communications Research Laboratories. His areas of interest include adaptive QoS management, statistical image processing, pattern recognition, ubiquitous computing, and networks.

Minsoo Hahn received the B.S. and the M.S. degrees in electrical engineering from Seoul National University, Seoul, South Korea, in 1979 and 1981, respectively, and the Ph.D. degree in electrical and electronics engineering from the University of Florida, Florida, U.S.A., in 1989. From 1982 to 1985, he was with the Korea Research Institute of Standards and Science (KRISS), Daejeon, South Korea. From 1990 to 1997, he was with the Electronics and Telecommunications Research Institute (ETRI), Daejeon, South Korea. In 1998, he became a faculty member of the School of Engineering, Information and Communications University. Currently, he is a Full Professor in the IT Convergence Campus (ICC), KAIST, and a Director in the ICC-Digital Media Laboratory, KAIST. His research interests include speech and audio coding, speech synthesis, noise reduction, and VoIP.