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Informatics Society

Aims and Scope

The purpose of this journal is to provide an open forum to publish high quality research papers in the areas of informatics and related fields to promote the exchange of research ideas, experiences and results.

Informatics is the systematic study of Information and the application of research methods to study Information systems and services. It deals primarily with human aspects of information, such as its quality and value as a resource. Informatics also referred to as Information science, studies the structure, algorithms, behavior, and interactions of natural and artificial systems that store, process, access and communicate information. It also develops its own conceptual and theoretical foundations and utilizes foundations developed in other fields. The advent of computers, its ubiquity and ease to use has led to the study of informatics that has computational, cognitive and social aspects, including study of the social impact of information technologies.

The characteristic of informatics' context is amalgamation of technologies. For creating an informatics product, it is necessary to integrate many technologies, such as mathematics, linguistics, engineering and other emerging new fields.

Guest Editor's Message

Osamu Takahashi

Guest Editor of Fifteenth Issue of International Journal of Informatics Society

We are delighted to have the fifteenth and special of the International Journal of Informatics Society (IJIS) published. This issue includes selected papers from the Sixth International Workshop on Informatics (IWIN2012), which was held at Chamonix, France, Sep 4-7, 2012. The workshop was the sixth event for the Informatics Society, and was intended to bring together researchers and practitioners to share and exchange their experiences, discuss challenges and present original ideas in all aspects of informatics and computer networks. In the workshop 28 papers were presented at eight technical sessions. The workshop was complete in success. It highlighted the lasts research results in the area of networking, business systems, education systems, design methodology, groupware and social systems.

Each paper submitted IWIN2012 was reviewed in terms of technical content and scientific rigor, novelty, originality and quality of presentation by at least two reviewers. From those reviews 15 papers are selected for publication candidates of IJIS Journal. This thirteenth includes five papers of them. The selected papers have been reviewed form their original paper presented in IWIN and accepted as publication of IJIS. The papers were improved based on reviewers' comments.

We hope that the issue would be interest to many researchers as well as engineers and practitioners in this area.

We publish the journal in print as well as in an electronic form over Internet. This way, the paper will be available on a global basis.

Osamu Takahashi is a professor at the Department of System Information Science at Future University Hakodate. He worked for NTT in 1975-1998, worked for NTT DoCoMo in 1999-2003, and joined Future University Hakodate in 2004. His research interest includes ad-hoc network, network security, and mobile computing. He is a member of IEEE, IEICE and IPSJ, respectively.

Development of an Integrated Control System Using Notebook PC Batteries for Reducing Peak Power Demand

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Abstract -In this paper, we propose an integrated control system that reduces peak power demand by using the internal batteries of notebook PCs. The system forecasts multiple power demand curves based on the power consumption of an office, and plans a charging/discharging schedule for each PC battery by considering the forecasts and information about the notebook PCs. By controlling the charging and discharging of PC batteries, the system reduces the peak power demand without restricting usability. We also evaluated the efficiency of peak power demand reduction in the simulation experiments and during field testing.

Keywords: Peak power demand reduction, control of charging and discharging, internal batteries of notebook PCs, demand forecasting, and optimization.

1 INTRODUCTION

To address power supply shortages resulting from the impact of the Great East Japan Earthquake, Japan's energy conservation regulation was revised to reducing just peak power demand from reducing overall power demand. In the future, it is anticipated that numerous energy storage devices will be placed in a wide range of locations, such as buildings and houses. Therefore, there is greater need for a mechanism to enable peak power demand reduction by charging energy storage devices (storing energy) during off-peak periods and discharging them (utilizing stored energy) during the peak time.

Here, to save power urgently, the use of the internal batteries of notebook PCs is attracting attention. This is because early dissemination of energy storage devices is difficult in terms of cost and operation, while lots of notebook PCs already exist in offices and homes. In the summer of 2011, many computer manufacturers released peak shift applications that can control the charging and discharging of a notebook PC battery. Figure 1 shows the peak shift setting utility released by Fujitsu Limited [1]. Such application charges and discharges a PC battery during periods each specified by the PC user. In this paper, "discharge a PC battery" means "force a notebook PC to be powered by its battery." Therefore, if these applications discharge PC batteries during the peak time and charge them during off-peak periods, we can save the power consumed by notebook PCs during the peak time and reduce the peak power demand.

This approach, however, has two problems. First, in a small-scale environment like an office, power consumption

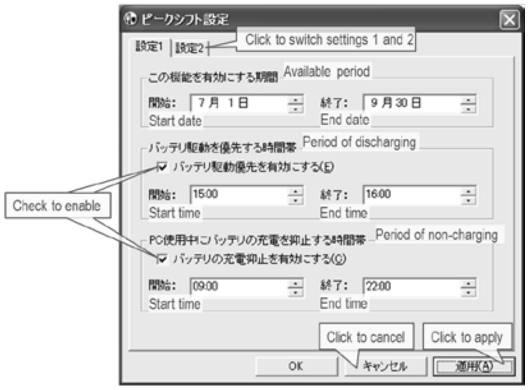


Figure 1: Peak shift setting utility released by Fujitsu Limited.

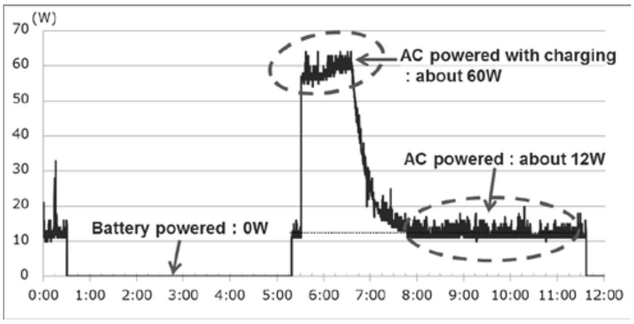


Figure 2: Power consumption of a notebook PC.

will change significantly depending on the number of users and electronic devices utilized, making it difficult to accurately forecast such fluctuations and decide when to charge and discharge PC batteries. In addition, since the power consumed during charging of a PC battery is very high (see Fig.2), there is a risk of increasing the peak power demand when multiple notebook PCs charge their batteries at the same time. Also, frequent charging/ discharging and long-term discharging of a PC battery may cause the battery to deteriorate and be empty when needed (e.g., outside).

In this paper, we propose an integrated control system that reduces the peak power demand without restricting usability by controlling the charging and discharging of PC batteries based on the power consumption of an office. The reminder of the paper is organized as follows. In section 2, we propose an integrated control system. In section 3, we present the implementation of the proposed system and give the evaluation results after using the implemented system. In section 4, we discuss some related works; then in section 5, we conclude the paper.

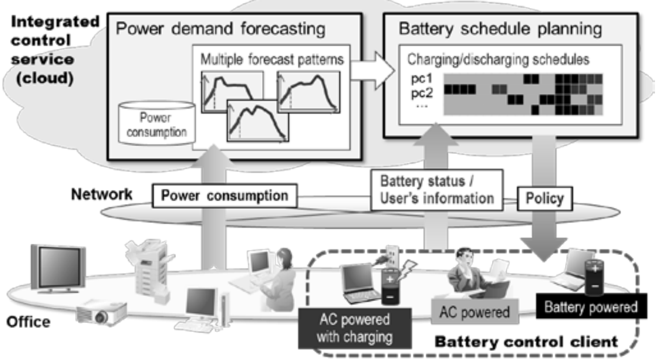


Figure 3: System schema.

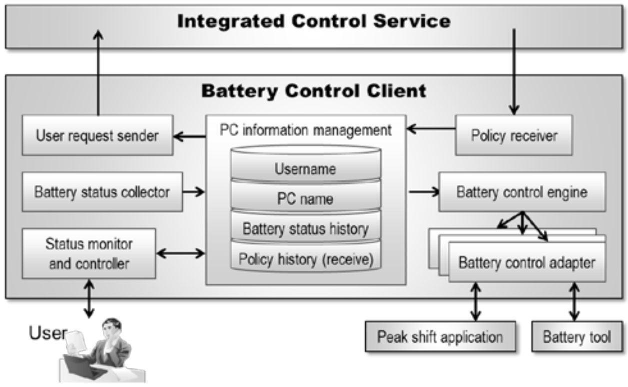


Figure 4: Architecture of battery control client.

2 INTEGRATED CONTROL SYSTEM

An overview of the integrated control system is given in Fig.3. The system consists of a battery control client that works at each notebook PC and an integrated control service that works as a cloud-based service.

The battery control client periodically collects the PC battery level and the user's information, and sends them to the service. The client also controls the charging and discharging of the PC battery based on the received policy (the control information to charge and/or discharge the PC battery) from the service. The client does all these things without any help from the PC user.

On the other hand, the integrated control service collects data sent by clients and the office power consumption data over a network. Based on the collected data, the service performs power demand forecasting and battery schedule planning, and sends the policy to each client. Here, the cloud-based service has the advantages of ensuring data collection and integrated control, and easily applying to multiple offices.

In the following, we further explain the battery control client, the integrated control service, and two algorithms to solve the problems described in section 1.

2.1 Battery Control Client

Figure 4 shows the architecture of the battery control client. The function of each module is as follows.

1. PC information management
   This module manages the following information on the battery control client.
   - **Username:** The username of the PC user.
   - **PC name:** The hostname of the notebook PC.
   - **Battery status history:** The history of battery statuses collected at [2. Battery status collector].
   - **Policy history (receive):** The history of policies received at [4. Policy receiver].
2. Battery status collector
   This module periodically collects the power configuration (battery powered / AC powered / AC powered with charging), the battery level [%], and the remaining battery lifetime [sec]. The module stores them together with the present time in [1. PC information management].
3. User request sender
   This module sends to the service the username, the PC name, the latest battery status (these are managed at [1. PC information management]) and the present time. The module periodically sends them in order to help the service to grasp information about the connecting clients.
4. Policy receiver
   This module receives a policy from the service, and stores it and the receipt time in [1. PC information management]. The module also notifies [5. Battery control engine] of the policy.
5. Battery control engine
   This module transfers the notified policy to one of [6. Battery control adapter] which is available at the notebook PC, except in cases in which control is temporarily suspended.
6. Battery control adapter
   This module controls the battery tool that charges and discharges the PC battery based on the transferred policy. Since there are many battery tools (include peak shift applications), this module masks the differences among them and is transparent to [5. Battery control engine].
7. Status monitor and controller
   This module shows the PC user the change of state (a service is connected or a policy is received), the current status of the PC battery, and the control status. The module also accepts user instructions for temporarily suspending and resuming control, and terminating the client.

2.2 Integrated Control Service

Figure 5 shows the architecture of the integrated control service. The function of each module is as follows.

1. Information management
   This module manages the following information on the integrated control service.
   - **Power consumption history:** The history of power consumption collected at [2. Power consumption collector].
   - **Demand forecasting history:** The history of forecasts (power demand curves) and their related parameters created at [3. Power demand forecaster].
   - **User request history:** The history of user requests received at [4. User request receiver].

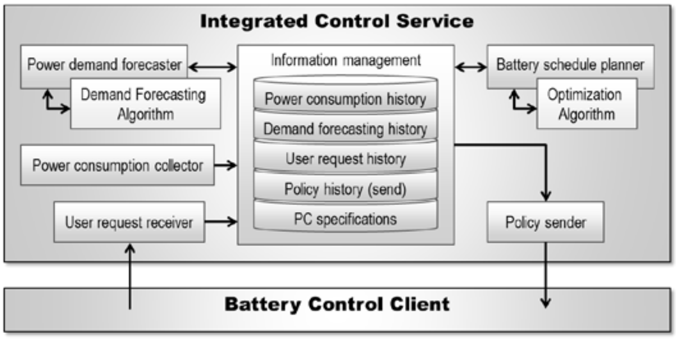


Figure 5: Architecture of integrated control service.

- **Policy history (send):** The history of policies sent at [6. Policy sender].
- **PC specifications:** The following specifications of notebook PCs with which the clients will work.
  - *Power consumption of each power configuration* (battery powered / AC powered / AC powered with charging) [W]
  - *Battery capacity* [Wh]
  - *Maximum battery level* [%]:
    The highest battery level to which a PC battery can be charged. By setting the level lower than 100, the system prevents the PC battery from being fully charged (a factor that accelerates battery deterioration).
  - *Minimum battery level* [%]:
    The lowest battery level to which a PC battery can be discharged. By setting the level slightly higher, the system prevents the PC battery from being discharged for a long time which might make it empty when needed
  - *Starting battery level* [%]:
    The highest battery level at which a PC battery can start to charge. By starting to charge only at a lower than specified level, the system prevents the PC battery from being repeatedly charged and discharged (a factor that also accelerates battery deterioration).
  - *Charging and discharging battery curves*:
    The curves showing the relation between the elapsed time and the battery level, where a PC battery is charged/discharged.

2. Power consumption collector
   This module periodically collects current power consumption and stores it together with the present time in [1. Information management].
3. Power demand forecaster
   This module forecasts multiple power demand curves by invoking the demand forecasting algorithm described in subsection 2.3.
   - **Inputs**: All daily power consumption (these are managed at [1. Information management]).
   - **Outputs**: Multiple power demand curves and their related parameters (these are to be stored in [1. Information management]).

   The module periodically performs this procedure because the size of the power consumption history increases with time.
4. User request receiver
   This module receives user requests from clients, and stores each of them and their receipt times in [1. Information management].
5. Battery schedule planner
   This module plans charging/discharging schedules by invoking the optimization algorithm described in subsection 2.4.
   - **Inputs**: Power consumption of the day, latest forecasts and their related parameters, PC specifications, and user requests (these are all managed at [1. Information management]). To ensure peak power demand reduction, the PC specifications and the user requests are limited to those of the connected clients, where a connected client denotes the client that has sent the user request to the service within a set period.
   - **Outputs**: Charging/discharging schedules for PC batteries of the connected clients.

   After planning schedules, the module creates a policy for each connected client from the corresponding schedule, and notifies [6. Policy sender] of the policy. The module periodically performs these procedures because users carry around their own notebook PCs and connected clients vary over time.
6. Policy sender
   This module sends a client the notified policy, and stores it together with the present time in [1. Information management]. The module performs these procedures when the policy is notified not only from [5. Battery schedule planner] but also from other external programs.

2.3 Demand Forecasting Algorithm

In a small-scale office, as described in section 1, power consumption will change significantly depending on the number of users and electronic devices utilized, making it difficult to forecast a power demand curve in a simple way. Moreover, since the service plans charging/discharging schedules based on a forecast, a wrong forecast may increase the peak power demand by charging PC batteries during the peak time.

Therefore, the demand forecasting algorithm forecasts the multiple power demand curves of the day. As shown in Fig.6, the algorithm initially classifies daily power consumption based on the peak time and the range of power consumption in the daytime. Using Ward's Method [9], daily power consumption is classified into five patterns, i.e. a pattern in which power consumption during the morning, before noon, early afternoon, and evening is high, and a pattern in which power consumption does not vary much throughout the day. Then, the algorithm calculates the Euclidean distance between daily power cnsumption and the power consumption of the day, and extracts the similar days in which the Euclideand distance is short. Finally, the service calculates the power demand curve and the parameter for each classified pattern. In this paper, the power demand curve of a pattern is the hourly-averaged power consumption of the extracted days in the pattern, and the parameter is the ratio of the extracted days in the pattern.

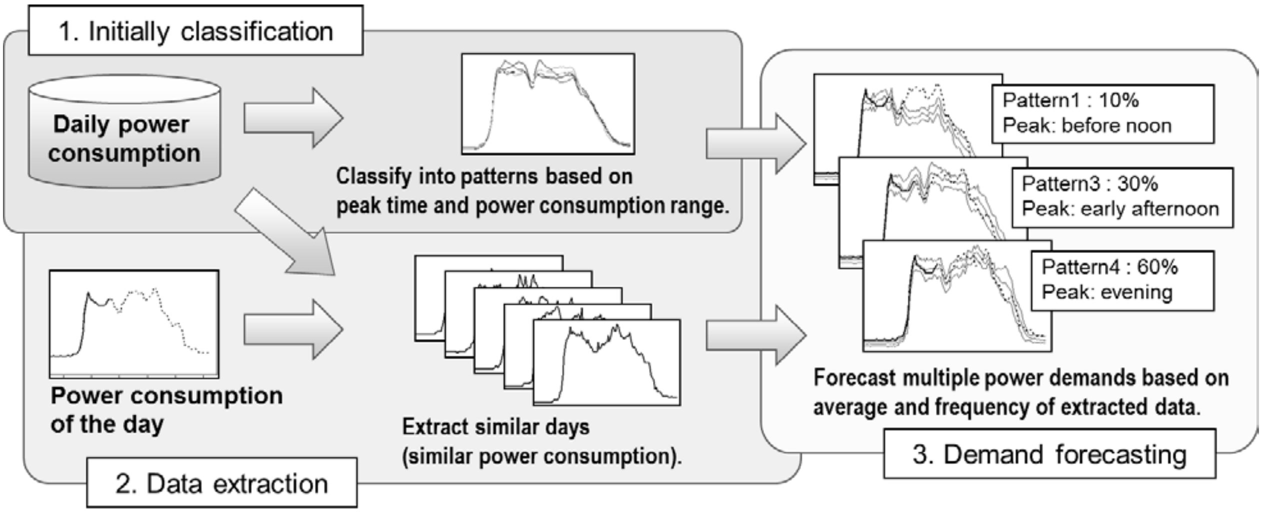


Figure 6: Diagram of demand forecasting algorithm.

Since the service plans charging/discharging schedules based on multiple forecasts, it can handle any potential level of power consumption and reduce the peak power demand even in a small-scale environment like an office.

2.4 Optimization Algorithm

To reduce the peak power demand for power using PC batteries, it is necessary to efficiently control the charging and discharging of them based on power demand. Moreover, not to restrict usability, the service has to prevent PC batteries from deteriorating and being empty when needed.

Therefore, the optimization algorithm regards the planning schedules as a multi-objective combinatorial optimization problem and finds approximate solutions using a local search algorithm as follows.

- **Objective functions (**listed in order of priority**):**
  1. Minimizing the peak power demand.
  2. Maximizing battery levels of notebook PCs at the end of the day. This function makes the service charge PC batteries to prepare for peak power demand reduction of the following day.
  3. Minimizing the overall power demand. This function indirectly prevents PC batteries from deteriorating by not charging and discharging more than necessary.
  4. Maximizing the minimum power demand. Combined with 1., this function balances the power demand.
  5. Minimizing the number of times power configuration is switched. This function also improves the usability.
- **Constraints:** The features of the PC battery including the variation and the range of the battery levels. The range constraint prevents PC batteries from being empty.
- **Solutions:** The power configuration of each notebook PC at each time interval of the day.

In each iteration, the local search algorithm chooses one solution from candidates by comparing the values of each objective function in order of above priority order (the lexicographic order). Specifically, the algorithm chooses the solution with the lowest peak power demand, and it chooses the one with the highest battery levels only when the peak power demands of all candidates are same. The detailed algorithm is proposed in Ref.[4].

Using the optimization algorithm, the service can reduce the peak power demand without restricting usability. Moreover, by setting the constraint based on each user's usage pattern, the service can keep higher battery levels for notebook PCs which are frequently used without a power supply (e.g., when the PC users are out of the office), and prevent PC batteries from being empty when needed.

3 IMPLEMENTATION AND EVALUATION

We implemented the integrated control system described in section 2, and evaluated the efficiency of peak power demand reduction using the implementation. In the following, we describe the implementation details of the system, and the results of simulation experiments and field testing.

3.1 Implementation Details

We implemented the battery control client as a Java application on Windows. We also implemented two battery control adapters that control the peak shift setting utility (Fig.1) and the Fujitsu system extension utility that supports system extension functions for Fujitsu notebook PCs. To facilitate usability, the client automatically starts on logon and puts its icon in the system tray. It also shows a message balloon during a state change, a tooltip of the current status when the PC user hover the pointer over the icon, and a control menu when the PC user right-clicks the icon.

On the other hand, we implemented the integrated control service as a Java servlet running on Tomcat 6.0. The service obtained the office power consumption data from the ftp server that collected data from each power distribution board. We also implemented the demand forecasting algorithm as an R script and the optimization algorithm as a Java plug-in.

3.2 Simulation Experiments

We evaluated the ideal efficiency of peak power demand reduction. For this purpose, we used the power consumption of our office on a weekday in August, 2011, and regarded it

Item		value
Power consumption [W]		
	AC powered	12
	AC powered with charging	60
	Battery powered	0
Battery capacity [Wh]		63
Maximum battery level [%]		100
Minimum battery level [%]		20
Starting battery level [%]		89

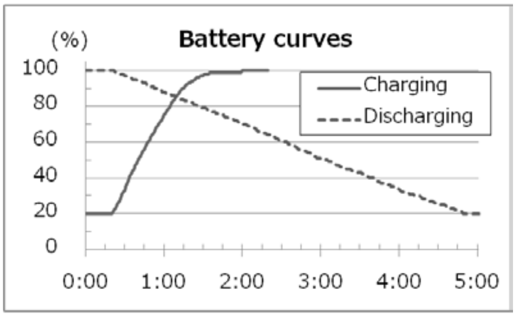
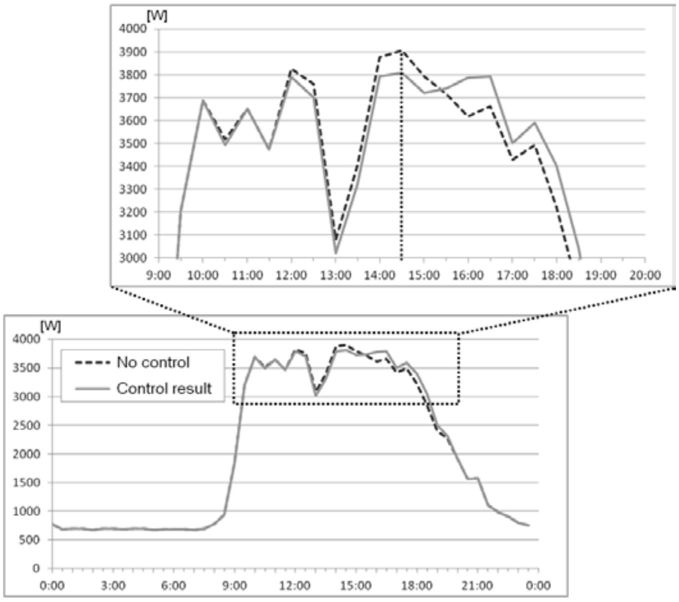
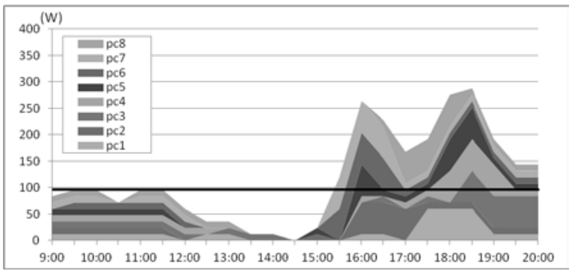


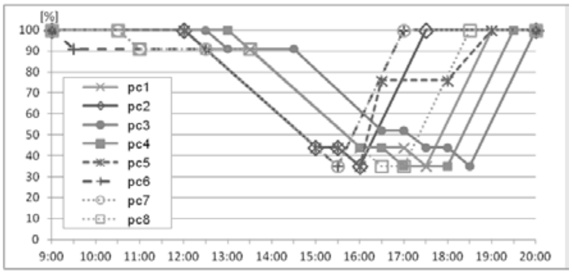
Figure 7: Specifications of a notebook PC (Fujitsu LIFEBOOK A561/C).



(a) Office power demand.



(b) Power consumption of notebook PCs.



(c) Battery level of each notebook PC.

Figure 8: Effectiveness of peak power demand reduction.

as a forecast (in other words, the service did not invoke the demand forecasting algorithm).

We simulated the power consumption after controlling the charging and discharging of PC batteries according to the planned schedules. We assumed that there were *N* controllable notebook PCs and that they had the uniform specifications described in Fig.7. Here, the power consumption of each power configuration was measured using the smart power strip [6], and the charging and discharging battery curves were created by periodically measuring the battery level while charging and discharging the PC battery. In addition, we assumed that the service controlled the charging and discharging of a PC battery only from 9:00 to 20:00, for example assuming that users put their own notebook PCs in the locked box after work for security reasons.

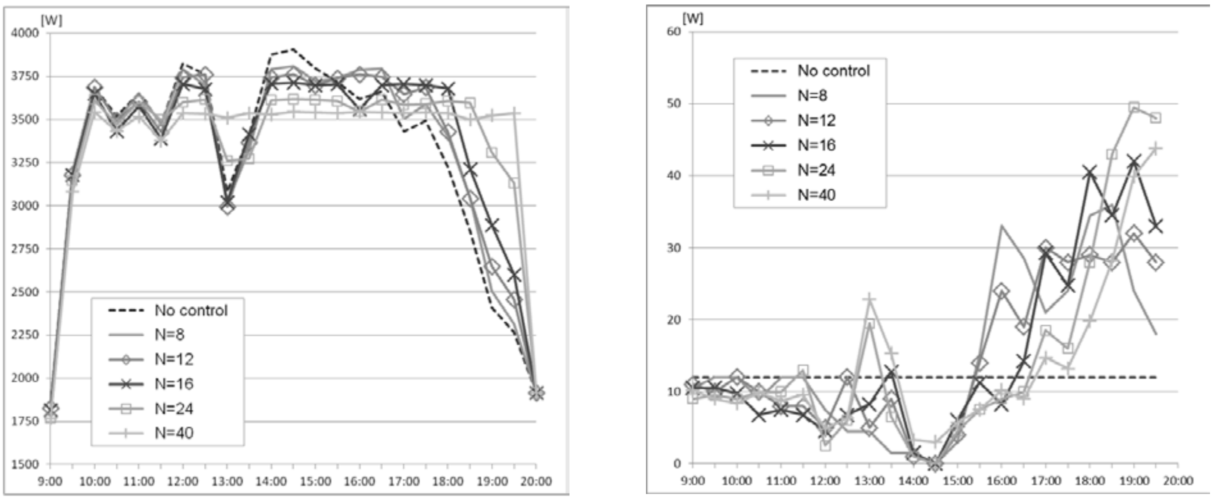
3.2.1. Effectiveness of the System

First, we examined the experiment where *N* (the number of controllable notebook PCs) is 8. Figure 8 shows the simulation results. In these graphs, the horizontal axis indicates the time. The vertical axes indicate the office power demand, the power consumption of the notebook PCs, and the battery level of each notebook PC, respectively.

In Fig.8(a), the peak power demand is reduced 96W (about 2.5%) from 3906W to 3810W. In Fig.8(b) and (c), at the peak time (14:30), the system discharges all PC batteries and saves the most power, in other words, the power consumed by the notebook PCs is 0W. Moreover, at the time of the 2nd highest peak power demand (12:00), the system also discharges some PC batteries and saves some power in order not to exceed the reduced peak power demand. After 15:30, the system charges the PC batteries that have low battery levels because of discharging. Even though the controllable time range is restricted, the system can charge all PC batteries to 100% without exceeding the peak power demand. The overall power demand is increased 240Wh (about 0.5%) from 48032Wh to 48272Wh due to the loss of energy by charging and discharging PC batteries.

3.2.2. Effects of *N*

Next, we examined the experiments while changing *N* from 8 to 40. Figure 9 shows the office power demand and



(a) Office power demand. (b) Average power consumption of each notebook PC.

Figure 9: Effects of number of controllable notebook PCs.

Table 1: Priority order of objective functions in each pattern.

Objective functions	Pattern			
	A	B	C	D
Minimizing the peak power demand	1	1	1	1
Maximizing battery levels of notebook PCs at the end of the day	2	5	2	2
Minimizing the overall power demand	3	**2**	4	4
Maximizing the minimum power demand	4	3	**3**	5
Minimizing the number of times power configuration is switched	5	4	5	**3**

the average power consumption of each notebook PC, respectively.

In Fig.9(a), as *N* gets larger, the peak power demand gets lower because the system saves more power by discharging PC batteries. Moreover, when *N* is 40, the system balances the power demand by charging the PC batteries at the time when the power demand is low (around 13:00).

In Fig.9(b), except when *N* is 40, the system discharges all PC batteries at the peak time and saves as much power as the system can. On the other hand, when *N* is 40, the system does not discharge all PC batteries at the peak time. This is because the power demand is balanced, and there is no time to charge the PC batteries that have low battery levels because of discharging. Actually, the amounts of the peak power demand reduction in the case when *N* is 8, 12, 16, 24, and 40 are 96W, 144W, 192W, 288W, and 360W, respectively, and when *N* is less than or equal to 24, the amount is proportional to *N*. These results also show that, in this office, the peak power demand is not reduced any more even when *N* is more than 40.

3.2.3. Effects of Priority Order of Objective Functions

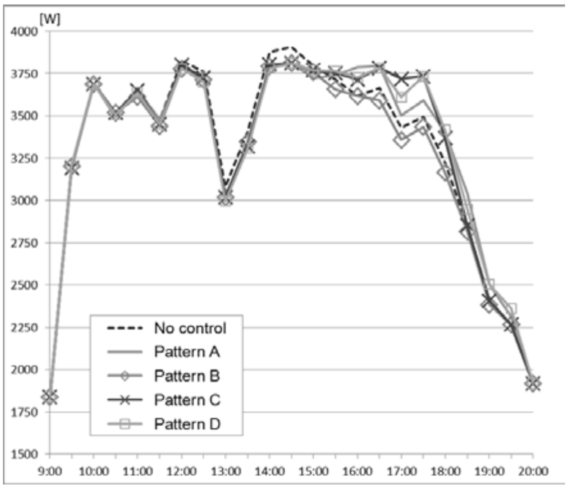
Finally, we examined the experiments while changing the priority of the objective functions as shown in Table 1. The order of a pattern A is the default priority order described in subsection 2.4. Figure 10 shows the office power demand, the average power consumption of each notebook PC, the battery level of each notebook PC in a pattern B, and that in a pattern D, respectively.

In Fig.10(a) and (b), the peak power demand in each pattern is reduced 96W (about 2.5%) by discharging all PC batteries at the peak time because orders of all patterns give the highest priority to "minimizing the peak power demand."

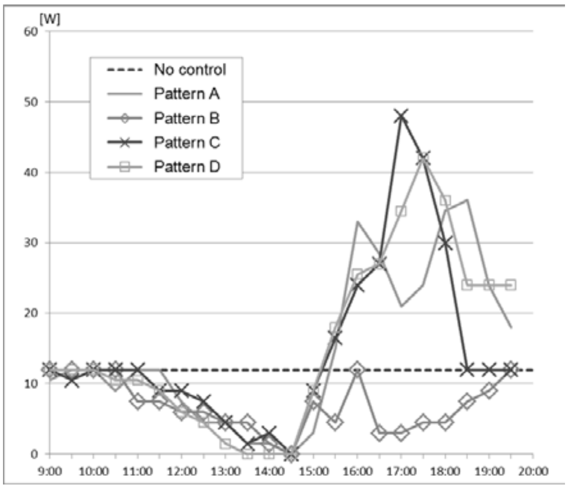
The order of a pattern B gives higher priority to "minimizing the overall power demand" than to "maximizing battery levels of notebook PCs at the end of the day." As a result, in Fig.10(c), the system charges very few PC batteries, and the power consumed by notebook PCs is always low shown in Fig.10(b). In fact, the overall power demand in a pattern B is reduced 444Wh (about 0.9%) from 48032Wh to 47588Wh. In this pattern, the system cannot reduce the peak power demand of the following day because all notebook PCs have low battery levels at the start of the day. However, the order of pattern B is effective in cases where PC batteries will be charged during that night and forecasts of the following day is low.

The order of a pattern C gives the highest priority to "maximizing the minimum power demand" in the lowest three objective functions. In spite of above priority order, the minimum power demand in a pattern C is the same as that in other patterns. However, since the system balances the power demand when *N* is large in subsubsection 3.2.2, we need to examine more experiments to evaluate the effect of this priority order in the case where *N* is large.

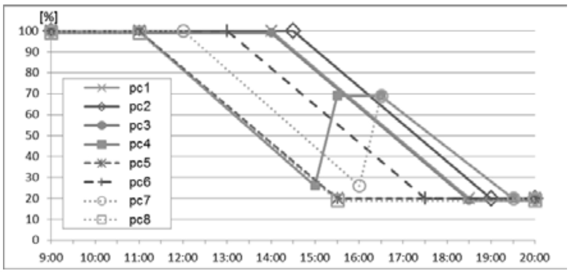
The order of a pattern D gives the highest priority to "minimizing the number of times power configuration is



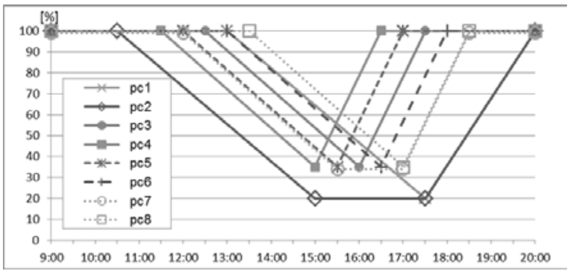
(a) Office power demand.



(b) Average power consumption of each notebook PC.



(c) Battery level of each notebook PC (pattern B).



(d) Battery level of each notebook PC (pattern D).

Figure 10: Effects of priority order of objective functions.

Table 2: Specifications of notebook PCs used in field testing.

Item		pc1	pc2	pc3	pc4	pc5	pc6	pc7	pc8	pc9	pc10
Model name		A561/C			A540/C	S761/C			P770/B	S8490	S560/B
Power consumption [W]											
	AC powered	11			11	10			13	22	14
	AC powered with charging	70			65	79			68	89	70
	Battery powered	0			0	0			0	0	0
Battery capacity [Wh]		63			56	67			63	63	63
Maximum battery level [%]		100	100	100	80	80	100	100	100	80	80
Minimum battery level [%]		20	25	23	20	40	40	40	40	40	40
Starting battery level [%]		89	89	89	69	69	89	89	89	69	69

switched" in the lowest three objective functions. As a result, in Fig.10(d), the system switches the power configuration as few times as possible. The order of a pattern D is effective to reduce the number of times the screen brightness changes and user stress occurred by above changes.

3.3 Field Testing

During the period from September 21th to October 20th, 2011, we conducted field testing at our office of 40 employees. The service obtained the power consumption data of our office. There were 10 notebook PCs with which the battery control clients worked during the field testing. Table 2 shows their specifications (all Fujitsu LIFEBOOK series). Here, different from the simulation experiments, the power consumption of each power configuration is the value given in the product catalogs. In addition, the maximum and the minimum battery levels are set based on users' activities (e.g., the frequency of the use without a power supply). Table 3 shows the parameters and their values used in this field testing.

Figure 11 shows the result of one day. The upper graph shows the office power demand while the lower table shows the power configuration collected at each notebook PC at each time interval of the day. In the graph, the line indicates the forecasts, and the bars indicate the actual power consumption. In the table, the black cells, light gray cells and dark gray cells indicate whether the power configurations of the notebook PCs are battery powered, AC powered, or AC powered with charging, respectively.

Table 3: Parameter configuration.

		Parameter	Value
Battery control client			
	Battery status collector	Time interval of collecting battery status	1 minute
	User request sender	Time interval of sending user request	10 minutes
Integrated control service			
	Power consumption collector	Start time and time interval of collecting power consumption	8:44, 10 minutes
	Power demand forecaster	Start time and time interval of invoking demand forecasting algorithm	8:45, 30 minutes
	Battery schedule planner	Start time and time interval of invoking optimization algorithm	8:46, 30 minutes
		Time range of a charging/discharging schedule	From 9:00 to 20:00
		Time unit of switching power configuration	10 minutes
		Time period to define the connected client	15 minutes

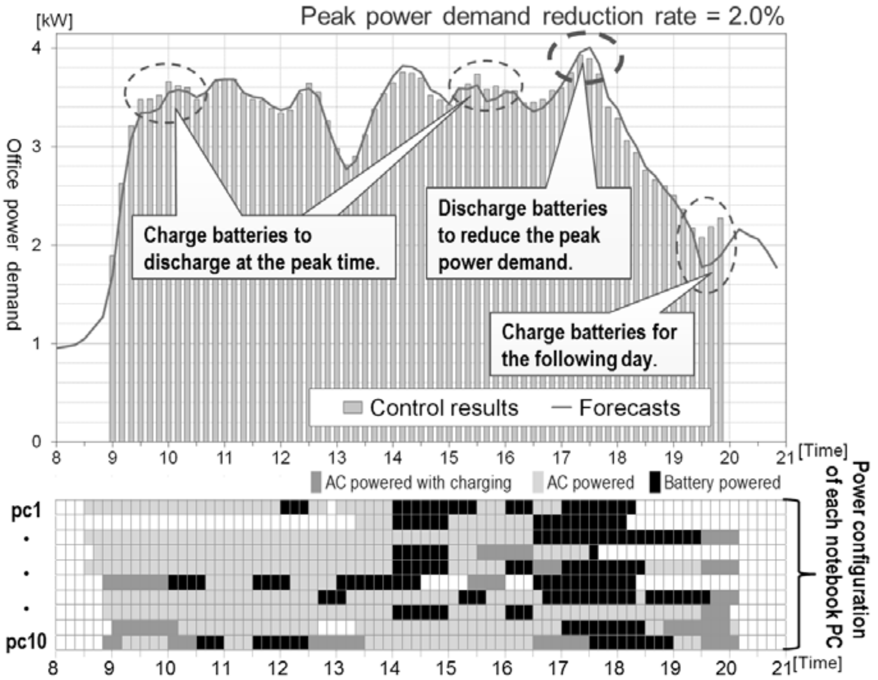


Figure 11: Result of a field testing.

Meanwhile, a white cell indicates the status in which the notebook PC does not connect to the service at the corresponding time due to a network disconnection or system power-off.

In Fig.11, the peak power demand was reduced 80W (about 2.0%) from 4006W to 3926W. At the peak time (17:30), the system discharged 9 PC batteries (except for the battery of pc8) and saved the consumption power of these notebook PCs. Moreover, at the 2nd peak time (14:10), the system discharged 6 PC batteries in order not to exceed the reduced peak power demand.

We analyzed the reason why the system did not discharge the battery of pc8 at the peak time. First, from 16:00 to 16:30, the user of pc8 attended a meeting and used pc8 without a power supply, making the battery of pc8 discharged regardless of the charging/discharging schedule (in other words, the system failed to control the battery of pc8). Moreover, because of the above discharging, the battery level of pc8 was less than its minimum battery level, and the system cannot discharge the battery of pc8 at the peak time. However, it also did not charge the battery for not increasing the peak power demand.

After 18:50, the system charged 6 PC batteries (all notebook PCs that charged their batteries were connected clients) to prepare for peak power demand reduction of the following day.

Here, the system charged several PC batteries before 18:50. We analyzed this result and found that these batteries can be separated into two groups. One group is the PC batteries with battery levels that are already low in the morning (e.g., the notebook PCs did not charge their batteries during the previous day or were used without a power supply during the last night). The other group is the PC batteries with battery levels that are also low because of discharging before the peak time. As a result, the system charged the PC batteries that had low battery levels so that they could be discharged at the peak time.

These trends occurred in other testing days even though the peak power demand and the power configurations of the notebook PCs were different during these days. Therefore, in any case, our system reduces the peak power demand by discharging PC batteries at the peak time.

4 RELATED WORKS

Until recently, while many studies on power demand forecasting have been made, most studies forecast the peak power demand for optimized operation of power generators and power supply stabilization. After the Great East Japan Earthquake, some studies forecasted the power demand curve for peak power demand reduction using energy storage devices. In [7], we proposed a forecasting method that forecasts the power demand curve with high accuracy. In this method, the curve is created by combining the power consumption of days which characteristics are similar to that of the forecasting day, and then revised based on the peak power demand forecasted by multiple regression analysis. These studies may forecast the wrong curve in our environment because, in their assumed environment, the law of great numbers is applicable and the power consumption does not change significantly.

Generally, an optimization problem such as a planning schedule can be solved as a mixed integer programming problem. In our assumed environment, however, it is difficult to solve as a mixed integer programming problem because there are minimax type objective functions and the symmetry of the problem is high. On the other hand, it is also difficult to find the global optimal solution by an enumerative method. In this paper, therefore, we found approximate solutions using a local search algorithm. The detailed algorithm is proposed in [4].

Some studies on the control system of energy storage devices have been made for not only reducing the peak power demand but also for the compensation of power demand. In [5], the authors proposed a compensation system that controls the charging and discharging of the lithium-polymer batteries based on whether or not the provided power is larger than the power demand. In [8], the authors proposed a supply/demand control system that plans the operation based on generation and demand forecasting by using a neural network and fuzzy systems. Since these studies do not assume other uses of the energy storage devices, the energy storage devices may be empty when needed, for example when needed during a power outage. Moreover, early dissemination of energy storage devices is difficult in terms of cost and operation as described in section 1.

Recently, many peak shift applications were released by computer manufacturers, such as Fujitsu Limited [1], IBM Japan [3], and NEC Corporation [2]. These applications can reduce the peak power demand by controlling the charging and discharging of a notebook PC battery. The following are parameters of the peak shift setting utility [1] as shown in Fig.1. (Other applications also need similar setting.)

- **Available period:** The start and end dates. During this period, the utility enables control.
- **Period of discharging:** The start and end time of discharging. During this period, the utility forces the notebook PC to discharge its battery, i.e., to be powered by its battery.
- **Period of non-charging:** The start and end time of non-charging. During this period, the utility does not allow the notebook PC to charge its battery.

However, in most applications, these parameters need to be set manually by a PC user. Although the peak shift setting tool [2] can set these parameters by considering the power demand forecasted by electric power companies, it may increase the peak power demand because the forecasted power demand is almost different from the office power demand.

5 CONCLUSION

In this paper, we proposed an integrated control system (a battery control client and an integrated control service) that controls the charging and discharging of PC batteries based on the power consumption of an office. The integrated control service performs power demand forecasting and battery schedule planning based on the collected data, and sends the policy (the control information) to each client. On the other hand, the battery control client controls the charging and discharging of its battery based on the received policy from the service.

We evaluated the efficiency of peak power demand reduction in the simulation experiments and during field testing. From the results, at the peak time, the system discharges many PC batteries and reduces the peak power demand about 2.5% in a simulation experiment (2.0% in field testing). Moreover, during off-peak periods, the system charges the PC batteries that have low battery levels because of discharging.

As part of our future work, we plan to extend the system and conduct additional field testing to verify the efficiency of peak power demand reduction in various office environments. We also plan to consider the control of the energy storage devices for deployment in smart cities.

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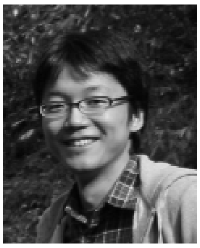

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Seamless Application Push with Secure Connection

- System to realize effective usage of smart devices for business class sustainability -

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Abstract –We need to do jobs equally both inside and outside the office when using Application push. Here, push notifications should be reached on smart devices even if they are on different network domains. In addition, because push gateways that issue notifications deal with privacy and sensitive data and the application server stores applications including confidential data, these data should not be placed on the Internet. Therefore, when smart devices download applications from the Internet, a secure connection to a company's intranet is required. Notifications also need to be received while using secure connections.

We propose an architecture of seamless application push that enables notifications to be sent to smart devices regardless of whether they are on the Internet or intranet. We implemented the architecture using an Android smartphone and server. We confirmed from our evaluation that it could accomplish seamless push notifications and the required time through the intranet on the longest path was reasonably low at 157.4 [msec].

Keywords: Android, smart device, VPN, intranet, seamless push

1 INTRODUCTION

Both consumers and companies have been replacing their devices with smart devices [1] such as smartphones and tablets with today's rapidly expanding technology. However, users occasionally waste too much time in setting up such devices when they use them. We propose an "Application Push & Play (APnP)" to solve this issue, which is a concept of dynamic installing and executing applications without user operations for smart devices in IWIN2011 [2]. We also expanded this concept securely [3]. Push notifications represent the baseline technology when smart devices connect to push gateways (P-GWs) with transmission control protocol (TCP) sessions and smart devices can receive push notifications during continuous sessions [4]. The uniform resource locators (URLs) of allocated applications are transmitted using the notifications of push messages. After a push message is received, a smart device downloads an application indicated by a specified URL.

The system works well in situations where both smart devices and servers consisting of the P-GW to send push notifications and the application server to store applications are on the same network domain.

We need to do jobs equally both inside and outside the office in business, where push notifications should be reached on smart devices even if they are on different network domains. In addition, since P-GWs deal with privacy and sensitive data such as the identifiers and passwords of servicers, these data should not be placed on the Internet. i.e., P-GWs on the Internet should not contain private data.

Further, the application server should not be on the Internet either because business applications contain confidential data. Therefore, when smart devices download applications from the Internet, a secure connection to companies using services such as virtual private networks (VPNs) [5] would be required to connect to intranets. Push notifications also need to be received even when using VPNs.

2 RELATED WORK

Android cloud to device messaging (C2DM) [6] is a service that sends data from servers to their applications on Android devices. However, it does not deal with business uses. In addition, a Google account is required to use C2DM. This may not occasionally be preferable because some companies do not allow dedicated accounts to be used for business.

Mobile IP [7] is a network protocol that can transfer packets with the same IP addresses even if the destination of the device has moved to another network domain. There are two types of protocols: mobile IPv4 [8] and mobile IPv6 [9]. The home agent in the definition of mobile IPs is located on the same network domain as the sender and the foreign agent is on the same network domain as the receiver. A packet is capsuled between the home agent and foreign agent and is able to be sent to the receiver even if it is located at a different network domain. However, research has identified two issues with current mobile IPs that could be obstacles to their wider use [10]. The first is in providing a home agent where the network environment around it is faced with various difficulties, one of which is the home agent needs to have a global and fixed IP address of all smart devices, and the second is the conflict with current Internet security mechanisms such as firewalls [11]. In addition, another reason mobile IPs are not suitable for introduction is because they are implemented in network layer 3, which requires dedicated network switches.

3 PROPOSED ARCHITECTURE

This section summarizes the requirements described in Section 1 and presents the proposed architecture that meets these requirements.

The proposed architecture is the same as that for mobile IPs in terms of the necessity for servers both on the intranet and Internet. However, the proposed architecture has three main advantages that enable companies to adopt it more easily than mobile IPs for their network environment.

- It is unnecessary to replace network equipment. The proposed architecture is achieved in the application layer, and does not require the IP packet format to be changed. However, mobile IPs need the IP packet format to be extended because they use the IPv6 destination option. Therefore, network equipment such as routers and gateways must be renewed to use mobile IPs.
- No additional network ports are required for company firewalls. The proposed architecture uses HTTP for communication between the intranet and Internet. HTTP is typically permitted to pass communications on company firewalls. However, mobile IPs must use port number 434 in UDP for communications such as registration requests for terminals between the intranet and Internet. Nevertheless, this port number may not be permitted on company firewalls.
- Our architecture does not require to have a global nor fixed IP address of smart device because it is achieved in the application layer and assigns a destination address which is independent with the precious IP address.

3.1 Requirements

The three main requirements to implement the system are:

(a) Smart devices should receive push notifications regardless of whether they are on the Internet or intranet.

(b) They should be able to receive notifications even VPN connections are established.

(c) Neither confidential nor private data should be stored on the Internet.

3.2 Architecture

We propose an architecture for seamless application push that enables push notifications to be sent to smart devices regardless of whether they are on the Internet or intranet.

The architecture for the system is outlined in Fig. 1.

Four components are defined in APnP [2]. However, their use in this system is slightly different from that in conventional use.

- A private P-GW is equivalent to a conventional P-GW. A private P-GW is located on the intranet and accepts connections from the push client, receives requests for push notifications, and sends push notifications to smart devices. Private data such as user information and push messages are stored in the private P-GW.
- An application server stores applications and is located on the intranet.
- A push client is a function in a smart device that connects to the P-GW through a TCP session, receives push notifications, and transmits the URLs of applications through notifications. It extracts URLs from notifications if the notifications request download applications and the extracted URLs are passed to the application downloader.
- An application downloader is a function in a smart device and it downloads applications from the application server based on URLs.

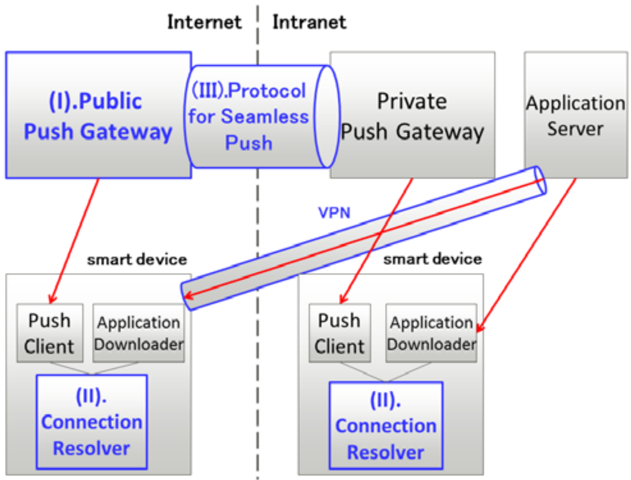

Figure 1: Architecture for Seamless Application Push

The proposed architecture has three additional new features:

(I) There is a public push gateway on the Internet in addition to a private P-GW that manages the connection to a smart device and notifies of push messages. The public P-GW is a contracted version of a private P-GW that particularly eliminates data related to privacy.

(II) A connection resolver identifies whether the network for a smart device is connected to the Internet or intranet and it switches the connection to a public P-GW or private P-GW. In addition, the connection resolver establishes a VPN connection to the intranet if necessary. When a smart device is on the intranet, it determines whether the push client should connect to the private P-GW without establishing a VPN connection to download an application. However, when a smart device is on the Internet, it determines that the push client should connect to the public P-GW and it makes the VPN client establish a VPN connection to download an application.

(III) A protocol for seamless push notification is used to synchronize the state of the private P-GW and public P-GW to maintain consistency.

The system should have features (I), (II), and (III) to satisfy requirement (a). A smart device connects to a public P-GW when it is located on the Internet and a private P-GW when it is located on the intranet (I). A connection resolver detects where the smart device is and identifies which P-GW it should connect to (II). If the smart device is located on the Internet, the private P-GW receives a push request and forwards it to the public P-GW (III).

The system should have features (I) and (II) to satisfy requirement (b). When a smart device is located on the Internet, the connection resolver is responsible for establishing a VPN connection. Once a VPN connection is established, the connection resolver asks the push client to switch the connection to a private P-GW. After the VPN connection has terminated, the connection resolver asks the push client to switch the connection back to the public P-GW.

The system should have features (I) and (III) to satisfy requirement (c). Although private data are required to send push requests, the public P-GW should not store them or have an interface to register them. Therefore, the private P-GW receives the request and forwards it to the public P-GW by using the protocol for seamless push notifications. In addition, although the private P-GW has the delivery status for push notifications, the public P-GW should not have this because the delivery status includes privacy information. Consequently, the public P-GW needs to ask the private P-GW about its status.

4 IMPLEMENTATION

This section describes the components, protocols, and workflows for the implementation of the proposed system.

4.1 Components

Figure 2 outlines the implementation of the proposed system.

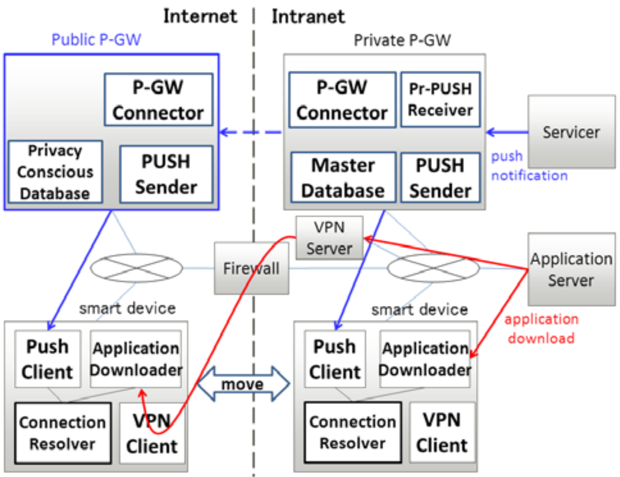

Figure 2: Implementation of proposed system

The system consists of five components: the private P-GW, public P-GW, application server, VPN server, and smart device. The private P-GW, the application server, and the VPN server are located on the intranet. The public P-GW is located on the Internet. The smart device moves between the Internet and intranet.

The private P-GW consists of four components.

The private push receiver (pri-push receiver) receives a push request and an inquiry as to whether a smart device is connected to the P-GWs or not from a servicer. The pri-push receiver authenticates the servicer in a push request and checks whether the destination address is pre-registered. The pri-push receiver checks whether the smart device is connected in an inquiry.

The push sender is an access point for the push client when the smart device is on the intranet. While the push client is connected to the push sender, the smart device can receive push notifications. It authenticates the smart device to prevent connection to malicicious devices. It also encrypts communication with the secure socket layer (SSL) to protect push notifications [12].

The P-GW connector handles the protocol for seamless push notifications. See the protocol for seamless push notifications in Subsection 4.2 and the workflow on the Internet in Subsection 4.3 for the protocol and its use.

The master database (MDB) manages private data such as those for the registered identifier and password for the servicer, the destination address that the private P-GW assigned to the smart device, and message queue including confidential data such as the URL of the in-house application required to send push notifications. These data should only be stored in the private P-GW. The pri-push receiver, push sender, and P-GW controller handle notifications through the MDB.

The public P-GW consists of three components.

The push sender is an access point for the push client when the smart device is on the Internet. It has the same functions as the private P-GW.

The privacy conscious database (PC-DB) is a DB that only manages the connection information of smart devices to send push notifications. There is no need to treat connection information as privacy information if the P-GW creates the connection information and changes it regularly because malicious users cannot relate the user to the smart device by using the connection information. The P-GW in our architecture creates the connection information and changes it regularly. Therefore, we do not need to treat the connection information as privacy information. There is no data shared between the MDB and PC-DB, so those DBs do not need to be synchronized for keeping the consistency.

The P-GW connector has the same functions as those for the private P-GW.

The smart device has four components for handling push notifications.

The VPN client manages to establish and disconnect a VPN connection by using the direction from the connection resolver. We need to be able to receive the direction from other applications to directly establish and disconnect VPN connections from the connection resolver.

The connection resolver contains the registered service set identifications (SSIDs) of access points on the intranet in advance. When the smart device connects to the network, the connection resolver checks the type of connection. For example, if the connection is third generation (3G) or long-term evolution (LTE), the connection resolver identifies the

Table 1: Protocol for seamless push

Protocol	Description	Source	Destination
FORWARD	Forward push notification from private P-GW to public P-GW. Public P-GW only accepts FORWARD command from private P-GW.	Private P-GW	Public P-GW
FORWARD_SUCCESS	If push notification to smart device is completed, public P-GW replies to private P-GW with FORWARD_SUCCESS.	Public P-GW	Private P-GW
REQUEST_RESEND	Inquiry to private P-GW is issued to check whether or not push notification is resent to smart device, which is needed to connect to public P-GW stored in private P-GW to resend notification when smart device is connected to public P-GW.		

smart device is on the Internet. If the connection is Wi-Fi, it checks the SSID of the access point (AP) and confirms whether the SSID was registered, and then the connection resolver identifies the smart device is on the intranet. Otherwise, it considers the smart device is on the Internet. It requests the VPN client to establish a VPN connection for the intranet. If we can use VPN even when the smart device is on the intranet, the mode changes, and it switches the behavior of the client regarding whether the client is using the VPN or not. Therefore, it may not need our architecture. However, our architecture needs the mode to change because of the lower power consumption of the smart device. As we want to use the smart device as long as possible, lower power consumption is important. If we use VPN even when the smart device is on the intranet, the VPN client is constantly running and establishing a VPN connection. Therefore, unnecessary CPU and memory resources are wasted and the power consumption of the smart device increases. Consequently, we implemented changes to the mode because we minimized the opportunity of establishing VPN connections and decreased the power consumed by the smart device.

See Subsection 3.2 for the push client and application downloader.

4.2 Protocol for Seamless Push

Table 1 summarizes the protocols for seamless push conveyed by the hypertext transfer protocol (HTTP) POST. Because a firewall generally blocks most communications such as the transmission control protocol (TCP) of customer-defined sessions, we use the HTTP protocol that is typically permitted by the firewall.

4.3 Core Workflow for Proposed System

Our system has two P-GWs, a private P-GW on the intranet and a public P-GW on the Internet as seen in Fig. 2. However, the application server is only on the intranet. Moreover, the smart device moves between the intranet and Internet. Therefore, the smart device needs to identify whether it is on the intranet or Internet and it connects to a suitable P-GW to receive its push messages regardless of its position. The smart device also needs to establish a VPN connection if it is on the Internet to download applications regardless of its position. The choice of connectable P-GW and a necessary VPN connection are core workflows for our architecture. Therefore, we will explain these workflows.

First, we will explain the method of choosing connectable P-GW. The connection resolver needs to identify whether the smart device is correctly connected to the intranet or Internet to choose a suitable P-GW. First, the connection resolver checks information for the type of network. If the type of network is a mobile network such as 3G or LTE, the connection resolver identifies whether the smart device is on the Internet and the smart device connects to the public P-GW. If the type of network is a Wi-Fi connection, the identification is complex and the connection resolver needs to check the SSID of the Wi-Fi AP. The user sets the SSID preliminarily treated as the intranet to the connection resolver. If the SSID of the Wi-Fi AP fits the setup SSID to the connection resolver, the connection resolver identifies that the smart device is on the intranet and the smart device connects to the private P-GW. If not, the connection resolver identifies that the Wi-Fi connection is the Internet such as a hot spot and the smart device connects to the public P-GW.

For example, consider the case of setting “FUJITSU LAB” as the SSID to the connection resolver. If the smart device connects to the Wi-Fi network where the SSID is “FUJITSU LAB”, the smart device connects to the private P-GW. Other than this, the smart device connects to the public P-GW.

Next, we will explain the method of choosing whether the smart device has established a VPN connection or not when the smart device downloads applications.

The connection resolver also uses information on the type of network and the SSID of the Wi-Fi access point to identify whether it needs to establish a VPN connection or not. If the smart device connects to a mobile network or a Wi-Fi connection where the SSID is not the setup SSID to the connection resolver, the connection resolver identifies that the smart device is on the Internet and the smart device establishes a VPN connection when the smart device downloads applications. However, if the smart device establishes a Wi-Fi connection where the SSID is the setup SSID to the connection resolver, the connection resolver identifies that the smart device is on the intranet and the smart device does not establish a VPN connection. When the smart device establishes a VPN connection, it temporarily connects to the intranet. Therefore, the connection resolver makes the smart device connect to the private P-GW while it is establishing a VPN connection. In this way, the smart device can continuously receive push messages even when it has established a VPN connection.

For example, consider the case of setting “FUJITSU LAB” as the SSID to the connection resolver. If the smart device connects to a Wi-Fi network whose SSID is “FUJITSU LAB”, it does not establish a VPN connection and directly downloads applications from the application server. However, if the smart device connects to the mobile network or Wi-Fi network where the SSID is not “FUJITSU LAB”, it establishes a VPN connection and downloads applications. Further, the smart device connects to the private P-GW while it is establishing the VPN connection.

Lastly, we discuss the impact of SSID impersonation. When a Wi-Fi AP which has the same SSID defined in this system is placed, the smart device may connect to the wrong Wi-Fi AP. In this case, the push client cannot reach the P-GW and the smart device cannot receive a push notification. A way to avoid this issue is that the push client terminates the Wi-Fi connection if the push client fails to connect to P-GW in the Wi-Fi network and switches over to the mobile network for the continuous push service.

Our system receives push messages and downloads applications when the smart device is both on the intranet and Internet by using these methods. Furthermore, the smart device is establishing a VPN connection.

5 EVALUATION

This section presents the hardware, software, and network environments we used to evaluate the system and the performance of push notifications.

5.1 Qualitative Evaluation

First, we compared the proposed system with the conventional push system. The new system has two main advantages to the conventional push system. The first is its capabilities for seamless push as listed in Table 2.

Table 2: Capabilities for seamless push

	intranet, included via VPN	**Internet**
Proposed system	Yes: Refer to Subsection 4.3	Yes: Refer to Subsection 4.3
Conventional push system on intranet	Yes	No: *1
Conventional push system on the Internet	No: *2	Yes

*1: VPN connection is always required.
*2: Port used by conventional push is required to open in firewall.

“Yes” indicates the smart device can receive push notifications without a VPN connection and a firewall is established between the intranet and Internet when using push notifications. “No” means the smart device cannot receive push notifications.

The proposed system enables the smart device to receive push notifications regardless of whether it is connected to the Internet or an intranet. Even when it is connected to the intranet via VPN, the connection resolver switches to connect the private P-GW. Further, the smart device cannot receive notifications across networks by using the conventional push system.

Another advantage is protection of both confidential data and private data as summarized in Table 3.

Table 3: Protection of data

	intranet	**Internet**
Proposed system	Yes: see MDB in Subsection 4.1.	Yes: see privacy conscious DB in Subsection 4.1.
Conventional push system on intranet	Yes: *1	No: *2
Conventional push system on Internet	No: *2	No: *3

*1: DB stores private data, but DB is on intranet.
*2: Push notification cannot be received.
*3: DB stores confidential and private data.

“Yes” means that the system fulfills the first requirement that confidential data and private data are not stored on the Internet and the second that the smart device can receive push notifications both on the intranet and Internet.

“No” means that the system cannot fulfill either requirement.

The proposed system allows both confidential data and private data to only be stored on the intranet. No smart device can receive push notifications on the Internet without storing private data there while using the conventional push system as it is.

5.2 Quantitative Evaluation

We measured the delivery time for push notifications from an application server to a smart device that may affect user experience. Each component presented in Section 4 was operated on the following hardware to evaluate the system:

<u>Private P-GW, Public P-GW, and Application Server:</u>

- ✧ A Fujitsu LIFEBOOK E-8290 was used as the Private P-GW. It had an Intel Core2Duo processor T9600 operating at 2.80 GHz, 4 GB of main memory, and 160 GB of HDD.
- ✧ A Cent OS 6.2 [13] was used as the operating system (OS). Apache and the Java application server (Tomcat) were used for the Pri/Pub-push receiver and P-GW controller. The Pri/Pub-push receiver and P-GW controller were placed as servlets on top of the Java application server. A C-based program handled communication with the PC for the push sender. These were communicating with a socket between the three functions. MySQL was used for the DB. The application server was a general Web

server. Apache and the Java application server (Tomcat) were used.

Smart device:

✧ A Fujitsu F-10D [14] was used as the smart device. It had a 1.5-GHz quad core and had Android 4.0 installed that supported the VPN client application programming interface (API) [15]. Android native applications such as the connection resolver could control the establishment and disconnection of VPN connections by the VPN Client API.

✧ The push client, application downloader, connection resolver, and VPN client were created as Android native applications with Java.

VPN Server:

✧ A Fujitsu LIFEBOOK A550/A was used as the VPN server. It had an Intel Core i5 processor 540M operating at 2.53 GHz, 4 GB of main memory, and 128 GB of capacity on a solid state disk. Fedora was used as the OS.

Figure 3 outlines the network environment we used for the evaluation.

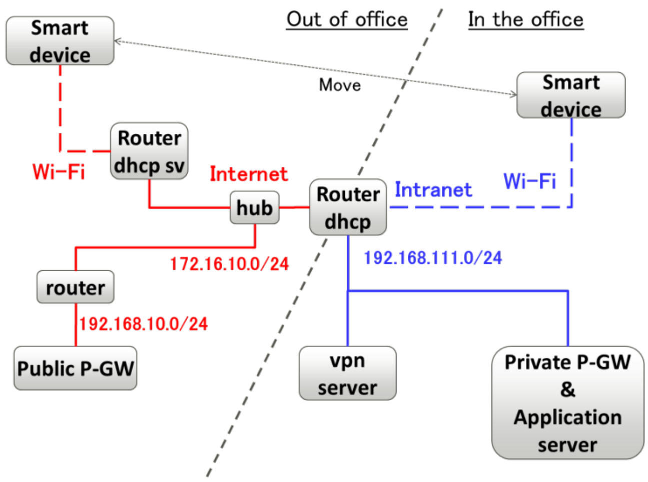

Figure 3: Network environment

We can see that it has two network segments. The first is treated as the intranet and the address is 192.168.111.0/24. The second is the Internet and the address is 192.168.10.0/24. Other than the HTTP for the protocol of seamless push application, it cannot transmit between the two networks. Refer to the hardware described above for the P-GWs, servers, and smart device. The information on network devices is as follows:

Router dhcp:

✧ A WN-G54/R3 was used as the router dhcp. It supported 100Base-TX/10Base-T as a LAN and 802.11b/g as a wireless LAN. It supplied the IP address of the intranet to the servers and the smart device as a Dynamic Host Configuration Protocol (DHCP) server and it assigned the IP address of the Internet from the Router dhcp sv. Only HTTP requests from the public P-GW to the private P-GW were accepted.

Router dhcp sv:

✧ The Aterm WM3400RN was used as the router dhcp sv. It supported 100Base-TX/10Base-T as a LAN and 802.11n/b/g as a wireless LAN. It supplied an IP address of the Internet to the router dhcp, the public P-GW, and the smart device.

Router:

✧ The Aterm LAN-W150N/RSPS was used as the router. It supported 100Base-TX/10Base-T as a LAN and 802.11n/b/g as a wireless LAN. It supplied an IP address to the public P-GW. HTTP requests from the private P-GW to the public P-GW and the TCP session from the smart device on the Internet were accepted. Although the public P-GW could directly connect to the Internet, a buffer such as a "demilitarized zone" (DMZ) is commonly organized for servers on the Internet. Therefore, we used a router.

Hub:

✧ FXG-05IMV was used as a hub that was used to increase the number of ports on the Internet.

First, we evaluated the system by using the delivery time for push notifications when the smart device was located on the Internet. Table 4 lists the results for the delivery times of push notifications both on the intranet and Internet when the servicer requested a thousand push notifications.

Table 4: Delivery times for push notifications

	Delivery time on intranet [msec]	Delivery time on Internet [msec]
Average	104.9	157.4
Maximum	391.0	387.0

The average time on the Internet was 157.4 [msec] and the maximum time was 387.0 [msec].

Application downloads came with the service by considering the use of APnP described in Subsection 6.1. An application download may take several seconds on the Internet using a 3G connection. However, the delay time is about 150 [msec] and it only has a small impact compared with the time for the download. Therefore, we concluded that the delay for the delivery time was acceptable.

Second, we compared the times notifications are received on the Internet and on an intranet to evaluate the performance of public P-GW. The average time is 104.9 [msec] on an intranet in Table 3 and the results for the Internet are inferior to this by 52.5 [msec]. An increase in the delivery time for push notifications was assumed because a public P-GW was added to the communication path on the Internet. We measured the processing time for the private P-GW, public P-GW, and communication when sending a push notification to verify whether the public P-GW caused the increase or not. Figure 4 and Table 5 have the results for processing times.

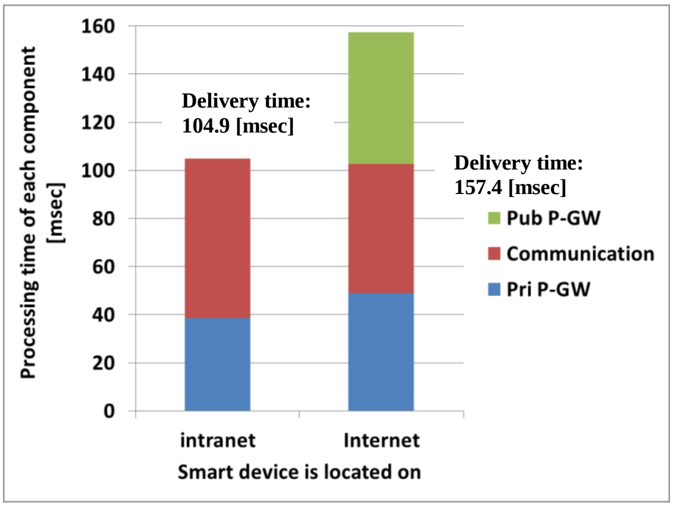

Figure 4: Processing times for each component

Table 5: Processing times

	Processing times on intranet [msec]	Processing times on Internet [msec]
Pri P-GW	38.6	49.1
Communication	66.3	53.4
Pub P-GW	-	54.9
Total	104.9	157.4

The results reveal that the total time for private P-GW and communication is almost the same for the intranet and Internet. Therefore, the times measured on the Internet for private P-GW and communication added to the processing time for public P-GW are longer than those for the intranet and are as expected.

The performance of push notifications was sufficient to function as APnP from these results and the structure of the proposed system and public P-GW was appropriate in terms of the delivery time for push notifications.

6 USE CASE

6.1 Use Case of Seamless Application Push

Figure 5 has an example of a use case for seamless application push, where the applications delivered with APnP, a URL of application is transferred by push notification then the smart device downloads the application from the URL transferred, are the editor of a presentation file on the intranet and the viewer of a presentation file on the intranet or Internet. Use only on the Internet is not assumed in this scenario. A user can only make a presentation file on the intranet using the editor and he or she can view a presentation file on the intranet or Internet. If the user views the presentation on the Internet, the file is downloaded via VPN from the server on the intranet.

The performance shown in Table 5 is enough that this use case should be workable. The requirement of this case is to maintain real-time notification to the smart device. A service requests a push notification when it detects the timing of sending an application. The delivery time is at most 150[msec] and the delay of push notification has no affect to keep the real-time notification.

Regarding the scalability, even if the number of smart device is increased, the public P-GW can accept the connection from many smart devices by increasing only the push sender. In addition, unlike mobile IP which has the issue on the home agent that has a bottle neck by the triangular routing and that would require sole DB [10], our architecture does not need to have the routing in the Public P-GW because it does not need to capture the change of IP address, so it can be achievable the scale by introducing additional independent DB.

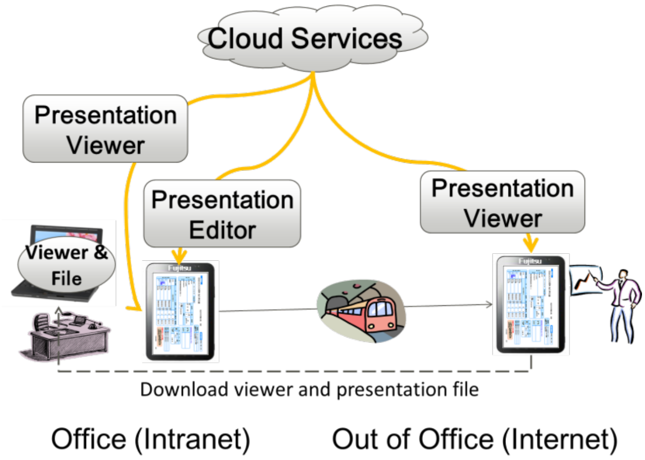

Figure 5: Use case of seamless application push

6.2 Multi-tenant Push Service

This section presents an extensive use case of the proposed system especially focusing on a general push service. Figure 6 outlines an example of multi-tenant push services that have multiple private P-GWs and a single public P-GW.

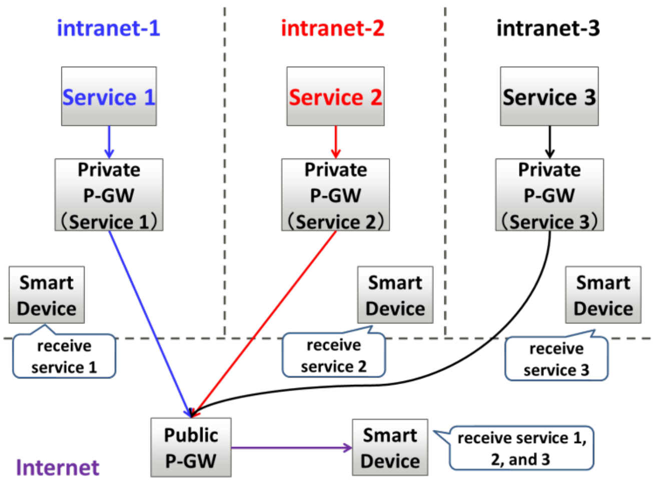

Figure 6: Example of multi-tenant push services

The public P-GW treats push notifications from all services to the smart device by the direction of each private P-GW. The smart device can receive all services on the

Internet and each service on each intranet. The smart device connects to the public P-GW and can receive all services on the Internet.

7 CONCLUSION

We proposed an architecture of seamless application push and implemented a system using an Android smartphone. We then confirmed that it could achieve seamless push notifications by which the smartphone could receive push notifications regardless of whether it was connected to the Internet or intranet and it could download applications from the application server. The smart device automatically could establish a VPN connection in conjunction with receiving a push notification. Usability was improved and the security of the smart device was maintained with our architecture because user interaction regarding the input of VPN passwords was unnecessary. In addition, we measured the delivery time for push notifications and the time we measured on the Internet was 157.4 [msec]. Our approximate requirements were within a second and the results were reasonably low. Future work would be to find ways to resume and continue downloading even a device has moved to a different network while downloading applications.

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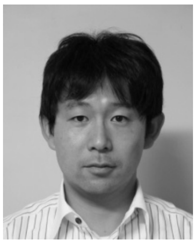

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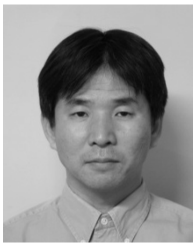

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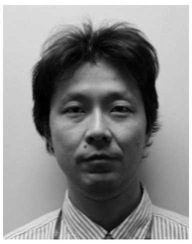

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The proposal of a phased expansion plan for smart meters and home network

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Abstract - In this paper we have carried out research and development for the implementation of a home network and to cut consumption during electric power peak periods. As a result, we propose technological innovations for a home network and a gradual expansion plan for a smart meter and home network. More specifically, the proposal describes #1 a system to create a home network which includes a smart meter in a two-layer configuration with existing networks, #2 implementation of an electric power peak cut system which considers safety, and #3 the installation of a high performance communication system with a "mutual complementary wireless and wired network" into the home network.

Keywords: smart meter, home network, energy saving, energy management, regional safety, DSM, Mutually complementary network, wireless and wired ;

1 NEED FOR A HOME NETWORK

Since the Great Tohoku Earthquake ended operations of a nuclear power plant, the need for a home network to reduce electric power consumption during maximum power demand, in other words, implement an electric power peak cut in a home has been increasingly discussed. Along this line, and based on the smart grid initiative, researchers have been extensively working on regional energy management technology, building control energy systems and home energy management systems (or HEMS) [1]. Prompted by the Great Hanshin Earthquake on January 17, 1994 and the tsunami which struck Indonesian Sumatra on December 26, 2004, a home network is considered essential for safety and energy saving of a home. Believing that a home network should not be impossible given the current technological level, we have been studying its implementation [2]. Functioning as a sensor for the region, each individual home collects information on nature and man-made disasters. This eventually leads to home and regional safety, energy saving and convenience [3].

Although researchers have been proclaiming the necessity for a home network since the 1980's under the banner of home automation, this has not been achieved due to three issues. The first issue is the concern regarding integration of a home network for the entire home although there are already existing individual networks. Integration of two different network systems is extremely difficult. The second is the lack of research on the convenience that could be obtained by connecting home appliances, computer peripheral devices and sensors to the network because the home network terminals (nodes) are expensive and have not been standardized. And last is that installation of a home network and adjustment requires work by an engineer, which translates into high prices.

To address the first issue regarding integration of a home network and existing individual network systems, one solution is to configure a two-layer network which can combine both systems. To resolve the second issue of home network terminals being very expensive, a mutual complementary communications system using wireless and wired applications can be realized by a single chip using present semiconductor technologies to reduce costs [4].

By establishing high communications performance which eliminates installation and adjustment, the third issue regarding the high costs of engineering work can be handled [5]. This is the mutual complementary communications system mentioned above, which can provide stable, consistent communication performance at ordinary homes [6]. This communications system is called a "mutual complementary network by wireless and wired communication."

2 STRUCTURE OF TWO-LAYER HOME NETWORK

A typical home today has several individual networks, including a hot water heater, an interphone system, a home security system, Internet and a telephone line. Since it is difficult to create a home network that covers the entire home by combining all these existing individual network systems, one solution is to form a two-layer network structure. In this particular structure, as shown in Fig.1, a gateway connects the home network covering the entire home with the existing individual network systems. Various electric and electronic devices, such as home appliances including air conditioners and refrigerators, and computer peripherals including printers, hard disc drives, and lightings, are all hooked up to the home network covering the entire home.

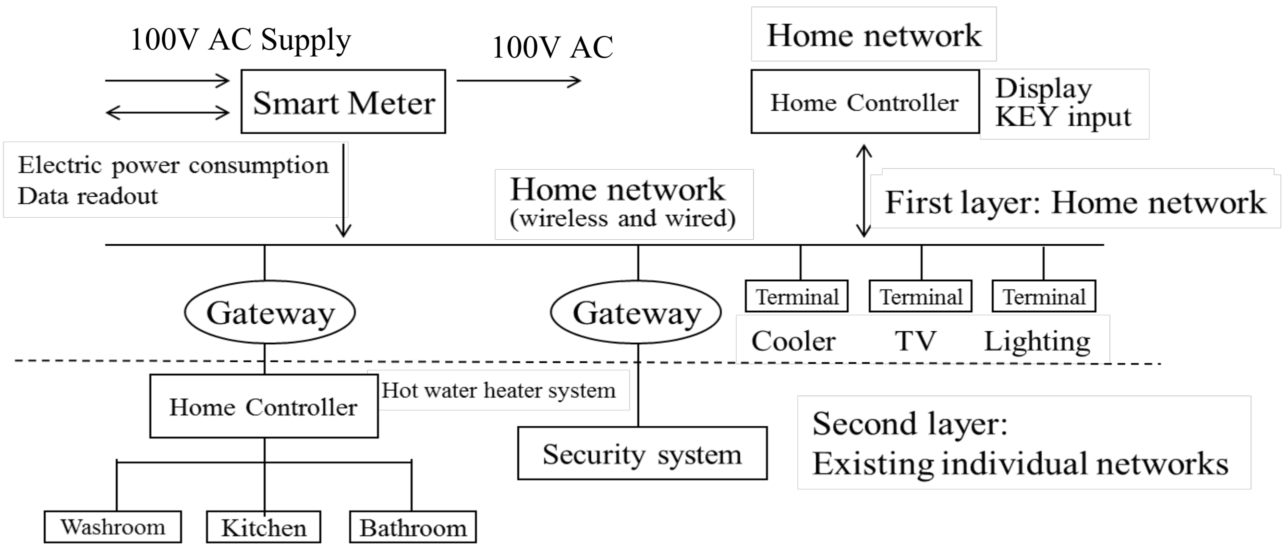

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Figure 1: Structure of a two-layer home network (Patent; similar gateway)

Viewed from either one of the layers, the gateway is a terminal within the network. This gateway chooses the path of least load to the network. In other words, it is an arrangement where the interior conditions are presented, and the information can be used by the other side (or specifications) when helpful. And of course there are no restrictions regarding development and growth between the two layers of network. This particular system of a home network works smoothly with the existing network systems to provide information to avoid various dangerous conditions and contributes to improved convenience. The authors refer to the connection (gating) of these two network systems as “light gating”.

3 PROPOSAL FOR ELECTRIC POWER PEAK CUT WHICH CONSIDERS SAFETY

One measure to address concerns regarding an insufficient electric power supply is the “electric power peak cut” concept. In the future, the electric power company may directly control home devices such as an air conditioner through a smart meter [7]. However, such a system still requires careful attention as such control may involve risk to human life or cause accidents. In Japan, 30% of the total electric power generated is consumed by households [8]. Attempts have been made to make energy usage “visible” in order to promote an individual sense of economy, thus reducing electric power consumption. Such attempts, however, have limitations. Hence a more advanced idea of “demand side management (DSM)” is proposed at this time.

Our proposal to reduce home electric power demand utilizes demand side management as its core structure, where the appliances in the home are reset with a control mode in the home network controller, based on a “peak cut control table,” prepared in advance. Table 1 shows “peak cut control table”. The table defines the values which dictate the control mode of each home appliance starting with the level at the time of peak cut. Compared with the normal consumption conditions, the home owner sets up the controller so that Level 1 peak cut reduces consumption to 67%, Level 2 to 50% and Level 3 to 33%. The authors plan to incorporate two features into this control. One readily shows the amount of energy cutback and associated electric power fee by simulation, and another introduces a game which takes advantage of edutainment (educational entertainment) [9].

In the two-layer home network structure shown in Fig.1, electric power of 100vAC is supplied through the smart meter. The smart meter measures, and reports electric power consumption to the electric company while receiving and maintaining electric power during peak cut. The electricity rates in Table 2 are simulation examples to explain this system. The table shows three levels of electricity rates and when they are to be applied. The application time is arbitrarily set at 10:00-16:00.

As shown in Case 1 in Table 2, the electric power consumption is cut back to maintain a constant electricity bill for a home. Within this peak cut time frame, since the electricity fee rate is 300% at Level 3, the usage rate is reduced to 33%, which translates to an 83% overall reduction. If peak cut is implemented for three months for all six hours, the annual total electric power consumption rate becomes 96%. While this is only a 4% reduction, 83% of the total demand, as discussed above, may be sufficient in reducing peak demand supply.

Case 2 in Table 2 is a simulated electric power bill where the electric power consumption remains unchanged at a home even during the peak cut time. At Level 3, the fee rate during the peak cut time period is 300% and the average for one day is 150%. The electricity bill for one month of peak cut time is 104% and 113% for three months. Assuming that half the homes adhere to this cost increase, there is a 92% load reduction. This suggests that simply increasing the electricity bill may not be sufficient. It is necessary that the home controller simulates the electricity bill based on the individual peak cut control table while accumulating the data of actual consumption.

Table 1: Peak Cut Control Table (Patent; Similar).

	Normal time		Peak cut time		
Home appliances	Level 1	Level 2	Level 1	Level 2	Level3
Air conditioner (inverter)1	F	low	off	off	off
Air conditioner (inverter)2	F	low	low	off	off
Air conditioner (inverter)3	F	F	low	off	off
Air conditioner (inverter)4	F	F	F	low	off
Air conditioner (inverter)5	F	F	F	F	low
Floor heating 1	F	low	off	off	off
Floor heating 2	F	F	low	off	off
Floor heating 3	F	F	F	F	low
Refrigerator	F	F	low	off	off
Washing machine	F	F	low	off	off
Rice cooker	F	F	low	off	off
Hot water system(Gas)	F	F	F	F	low
Hot water system (electric/ Heat storage)	F	F	low	off	off
Lighting 1	F	F	off	off	off
Lighting 2	F	F	off	off	off
Lighting 3	F	F	low	off	off
Lighting 4	F	F	low	low	off
Lighting 5	F	F	F	F	low
Desktop PC	F	F	F	off	off
Display	F	F	F	off	off
HDD	F	F	F	off	off
Printer	F	F	F	off	off
Existing network					
Hot water system(Gas)	F	F	F	F	F
Hot water system (electric)	F	F	off	off	off
Hot water system (electric/Heat storage)	F	F	F	off	off
Door intercom system	F	F	F	F	F
Security system	F	F	F	F	F

F : Free setting by resident (assumed to be 100% in load calculation)

Low , off : Selected setting by resident

Table 2: Peak Cut Time Electric Power Rates (Unit%).
Peak cut June - August, 10:00 to 16:00 (4 electricity rate settings: Normal, Level 1, Level 2, Level 3)

Electricity rate setting	Normal	Level 1	Level 2	Level 3
Electric power rate ratio (yen/KWt)	100	150	200	300
Case 1: Electric power consumption ratio (#1)	100	67	50	33
Case 1: Electric power consumption ratio (#2)	100	92	88	83
Case 1: Electric power consumption ratio (#3)	100	98	97	96
Case 2: Electric power rate ratio (one day)	100	113	125	150
Case 2: Electric power rate ratio (one month out of 12 months)	100	101	102	104
Case 2: Electric power rate ratio (three months out of 12 months)	100	103	106	113

In case 1, electric power consumption is regulated to maintain the same electric power fee.
In case 2, electric power consumption is not regulated.
#1: Percentage of electricity within the time frame when peak cut is implemented(%)
#2: Percentage of total electric power consumption within the time frame when peak cut is implemented(%)
#3: Percentage of total electric power consumption for one year when peak cut is implemented(%)

4 PROPOSAL OF A MUTUAL COMPLEMENTRY NETWORK BY WIRELESS AND WIRED COMMUNICATIONS

Propose a "mutual complementary network by wireless and wired communications", which leads to high performance, be applied to the home network. The mutual complementary network is a communication system that simultaneously employs two or more different methods to improve the communication performance [5]. As "two or more different methods", this study uses wired and wireless communications. Specifically, the PLC (Power Line Communication) [10] is used for wired communication and Zigbee [11] for wireless.

As shown in Fig.2, when transmitting data from point A to point B, the data is simultaneously sent by wired and wireless methods. In this case, communication is successful if the data communication can be completed by either method. In a three story, 200 square-meter reinforced concrete houses, communication performance by wireless alone is 82% as shown in Fig.3, while wired is 70%. Considering theoretical communication inability for both wireless and wired to be 5.4%, this translates to 94.6% of the communication performance. In fact, however, an even better communication performance of 100% was achieved [6].

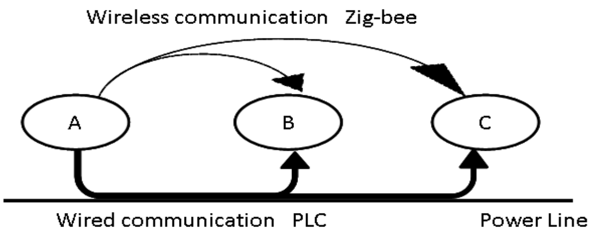

Figure 2: Mutual complementary network by wireless and wired communication

In practical application, using a simpler routing three times reduces the rate of unsuccessful communication to as low as 0.02%. Evaluation of an actual system to determine whether this is sufficient or not, is desired. In a "simpler routing" system, if communication is unable to go through one route, another route is used.

This routing system is completely independent from the previous communication performance while minimizing the software load [12].

		Wireless Communication	
		Able 82%	Unable 18%
Wired communication	Able 70%	Able 57.4%	Able/Unable → Able 12.6%
	Unable 30%	Unable/Able → Able 24.6%	Unable 5.4%

Figure 3: Communication performance of a mutual complementary network (by wireless and wired communications)

5 STEP-BY-STEP ACHIEVEMENT OF HOME NETWORK EQUATIONS

A smart meter and home network cannot be constructed overnight. As mentioned above, the home network has not been realized even though researchers have advocated its necessity and effectiveness since the 1980's. Looking back, one reason was that necessity was not as high as expected, and there were technological problems, such as cost. Today, this is no longer the case. The necessity is supported by a more urgent call for energy saving and home safety, while a "mutual complementary network by wireless and wired communications" solves technological and cost issues. One remaining obstacle is the lack of enthusiasm and action to create a home network under one set of standards by concerned parties. The home network definitely needs a common set of standards to connect home appliances.

Figure 4 shows a proposed plan to reduce home electric power consumption based on a step-by-step plan to expand the smart meter and home network. The first step is regarding an electric power supply and electric power consumption meter at a current general home

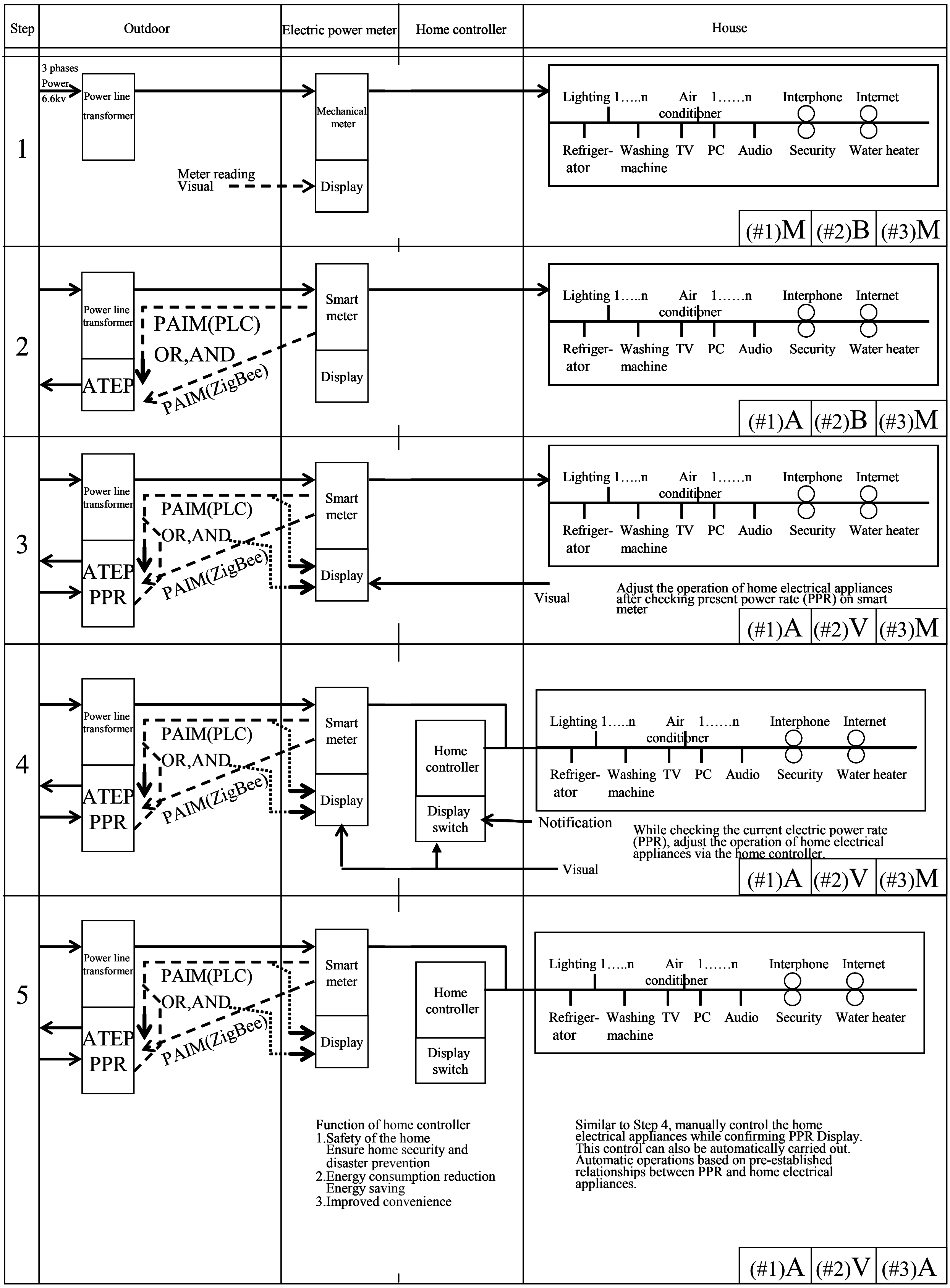

Figure 4: Steps to reduce home energy consumption using a smart meter and home controller,

Definition: PAIM : electric Power Automatic Inspection of a Meter, ATEP: the Amount Total of used Electric Power, PPR: the Present Power Rates

#1: Meter Reading-A-Automatic,-M-Manual, #2: Visualize of Electric Power-B-Blind, -V-Visual, #3: Reduction Easiness of Electric Power-A-Automatic,-M-Manual

The electric power consumption is visually measured to generate the electricity bill. In the second step, the electric power company uses an electronically operated electric power meter to collect and calculate the electric power consumption from each home through wired and/or wireless communication. Such an electronic meter is called a smart meter. In the third step, the smart meter indicates the consumption status of electricity for the month so the resident can directly control the home electric appliances. The fourth step connects the smart meter to the home controller via the network. In turn, the home controller is connected to various home appliances through the network. To implement peak cut, the home resident uses the home controller to read the peak cut level from the smart meter and implements energy saving measures according to the level.

The fifth step requires setting a "peak cut control table" to control the energy saving measures to a specified level during peak cut. The smart meter posts the electric bill level at the time of peak cut so the home controller can regulate the home appliances. At times other than peak cut, simulation and control functions of the home controller can be used to identify other energy saving opportunities and further improve disaster mitigation, security and convenience in each individual home.

6 CONCLUSION

This paper proposes a step by step plan to introduce a smart meter and home network in order to reduce electric power consumption. Three major technologies are discussed: " a two-layer home network", "a system to implement electric power peak cut while considering safety" and "a mutual complementary network by wireless and wired communications" which support the proposed plan. The proposed plan can only be implemented when people at various homes are mutually and socially influenced. Specifically, the following four ways were discussed above.

1) Influence home economics by increasing the electric power rate during peak cut time.
2) Promote the control of the electric power demand by introducing edutainment.
3) The home network is also effective in areas other than energy and energy saving.
   Ensure security and disaster prevention and improve convenience.
4) Raise social issues regarding carbon dioxide emissions and nuclear power plants so that individuals can consider their responsibility as a member of society.

It is also important that electrical appliance manufactures equip their products with terminals so they can be connected to the home network. Once the effectiveness of the home network is recognized, information gained by institutes and organizations regarding the electric power crisis will become a driving force to promote proposed implementations.

The home network is essential in times of electric power crisis. In other words, technology can save mankind. If we are really advanced persons who no longer need nuclear power generation, cutting back on electricity to this degree is only natural. To reduce home electric power consumption more is required than just targeting peak cut. It does not mean to only use electric power when you need it, it means cutting back even outside the peak cut time. It does not simply mean not wasting it. It is that you cut back on the energy or don't use it all. The author et al., will continue to study the subject in order to realize a home network which contributes to home safety, security and energy saving and convenience.

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Toward the operation guidelines for municipal social media account: From the analysis of user's behavior on Twitter in the Great East Japan Earthquake

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Abstract – More and more municipal organizations have been using Twitter for information distribution or interactive information exchange. Such official information sources are supposed to be relied upon by citizens when a disaster breaks out, but how such information on social media should be operated is not known.

This research investigated the user behavior around the Twitter accounts of municipal organizations in the Great East Japan Earthquake. Through the close investigation, the operation guidelines for a municipal Twitter account were obtained.

Keywords: Social media, Twitter, Information behavior, the Great East Japan Earthquake, Guideline

1 INTRODUCTION

Together with the rising popularity of social networking services, a micro blogging service Twitter had been used extensively when the Great East Japan Earthquake happened on March 11, 2011.

There were a few types of Twitter use; information broadcasting to public, information receiving from public, and information exchange among closed members. They were useful when other media disclosed their own weaknesses. The mass media worked well for nation-wide broadcasting but not so much for regional broadcasting. The phone line was overloaded to connect [1][2]. People were anxious about what was happening, what would be going on, and wanted the information. Twitter matched to fulfill these needs.

As for the Twitter use by municipal organizations, it was still in the beginning stage of big growth at that time. Some accounts were relatively new while some other already had a number of followers. Soon after the disaster, we gained increasing momentum to use such social media. More numbers of municipal organizations officially started to use social media, especially Twitter. Recently the government officially encouraged municipal organizations to use social media for their information broadcasting [3].

However, we do not know exactly how municipal Twitter account worked, and thus we do not know how municipal social media account could be operated effectively so that the account is useful to the public, especially in emergency. To answer this question, we investigate the user's behavior on Twitter in the Great East Japan Earthquake, and draw the operation guidelines for municipal social media account.

2 RELATED WORKS

2.1 Twitter

Twitter is an online microblogging service. It provides almost real-time online short text communication. It can be used from various internet devices including a personal computer, a smart phone, and other mobile phones. A short text message called a "tweet" can be viewed from the world if it is not sent from the specially closed account. This normal tweet can be searched by keywords, tags, and accounts. Subscribing an account called "following" is a feature of Twitter. By this, a subscriber called a "follower" can view the tweets of the "following" account without any operation. Thus an account that sends useful information regularly to the receiver, or that "tweets" useful information regularly, is likely to be followed. When a receiver of a tweet thinks to distribute the tweet, he/she can tweet that tweet. This action is called "retweet."

2.2 Twitter Use in Disaster

Mendoza et al. studied the behavior of Twitter users in the 2010 Chilean earthquake in the hours and days following this disaster [4]. They performed a preliminary study of the dissemination of false rumors and confirmed news. They analyzed how this information propagated through the Twitter network to assess its reliability as an information source under extreme circumstances, and showed that the propagation of rumors differed from that of news because rumors tended to be questioned more than news by the Twitter community.

Longueville et al. studied how Twitter could be used as a reliable source of spatio-temporal information by focusing on the 2009 French forest fire, aiming to demonstrate its possible role to support emergency planning, risk assessment and damage assessment activities [5]. They studied the temporal dynamics of the tweets, how location names were cited, who published the tweets, what type of domains were cited as URLs.

Vieweg et al. analyzed the tweets generated during two concurrent emergency events in North America 2009, the Oklahoma Grassfires of April and the Red River Floods in March and April [6]. They focused on communications broadcast by people on the ground, investigated the tweets in terms of location information and update with their dissemination. They then identified information that might contribute to enhancing situational awareness during emergencies.

Qu et al. studied the messages in a microblogging site Sina-Weibo that is very similar with Twitter and is popular in China in the 2010 Yushu Earthquake [7]. They investigated the content of the messages, the trend of different topics, and the information spreading process.

Miyabe et al. studied the tweets in the Great East Japan Earthquake in terms of their locations [8]. They concluded how people used Twitter was different from the locations depending on the damages.

Umejima et al. studied the false rumors and their corrections in a disaster, and indicated that a false rumor is easier to disseminate [9].

These studies analyzed the Twitter uses by people at large in emergency cases, where this study focuses on the use of municipal accounts in emergency cases.

2.3 Twitter Use by Public Institutions

Alam et al. studied six governmental Twitter accounts in Australia [10]. They analyzed the content of the tweets as well as the responses from the citizens.

Kavanaugh et al. studied the local governmental use of social media including Twitter [11]. They conducted a survey to local governmental institutions, the analysis of the followers of governmental Twitter accounts, and the analysis of the messages in Facebook accounts.

These studies analyzed the use of Twitter by public institutions in normal circumstances, while our study focuses on the Twitter use in emergency.

3 DATA AND ANALYSIS

3.1 Data

The analyzed data were from the Twitter accounts that were registered in "Govtter," the link site of official municipal Twitter accounts [12]. Govtter only lists the Twitter accounts that were confirmed as those operated by governmental institutions. A total of 363 accounts were listed as of January 2012 including the municipal accounts, the governmental accounts, and other public institutions. Among those accounts, 149 accounts were older than March 11th of 2011, before the earthquake.

In Twitter, a tweet is stored with the links to the date and time of the tweet, the identifier number called Status ID, and the account information. These tweets could be acquired from the latest tweet to as far back as 3200 tweets by Twitter API in the official site (in 2011 when the data was collected) [13]. However the number of follows and the number of followers in the account information were those at the time of getting the tweet data, which meant chronological change of those values could not be obtained by this method.

Thus we used Twilog service to obtain the change of the number of followers [14]. In Twilog, the number of follows and the number of followers are recorded along with the tweet itself for the registered Twitter accounts. We used all the data of the municipal accounts that were listed in Govtter and registered to Twilog before March 11th of 2011, which counted to 34 accounts.

The data were obtained from February 1 to April 30 in 2011. The total number of the tweets was 42825.

3.2 Analysis

The data was analyzed in the following way.

First the outline of the data was obtained. It was about the tweet and follower in this study. The basic structure of information behavior is sending information and receiving information. Information is sent by a tweet. Thus the number of tweet was used for analysis. If a person wants to receive the information from an account, the person follows the account. This action is reflected as the number of followers across time, the increasing rate of followers in other words. Thus the increasing rate of followers was used for analysis.

After getting the outline of the number of tweets and the number of followers for all the accounts, the accounts were categorized into four groups in quantitative viewpoint according to the number of the tweets and the number of followers across time. The average values of these metrics were used as the borderlines of the groups, which is common in explorative data analysis. Each group was investigated accordingly.

Furthermore, the content of the tweets were investigated. They were categorized in five in qualitative viewpoint. The relation between the groups and the content categories were also discussed.

4 RESULT

4.1 Change of the Number of Tweets and Followers

The change of the number of tweets for all the 34 accounts is shown in Fig. 1. The account names in the legend are simply in alphabetical order. Because a tweet bot "Obsekuri" which was an extremely frequent tweeter than other accounts is included in Fig. 1, it is difficult to see the data of other accounts. To get the general outline of the change of the number of tweets, the account was removed from the graph and Fig. 2 is shown.

The Change of the number of followers for all the accounts is shown in Fig. 3. Figure 4 shows the change of the number of followers of the accounts that had increasing rate of the followers more than the average.

As for the change of the number of tweets, we naturally can see the peak right after the day 3/11, but the patterns seem to vary for the other parts. As for the change of the number of the followers, some accounts have increasing number of followers while other accounts do not have such rapid increasing number of followers. There seems to be that the accounts that already had many followers before the day 3/11 were likely to have more increasing rate of the followers after the day 3/11.

4.2 Quantitative Categorization of the Accounts

To better understand what was going on after the general view in 4.1, we categorized all the accounts into four groups in terms of

1) the number of tweet per day, and

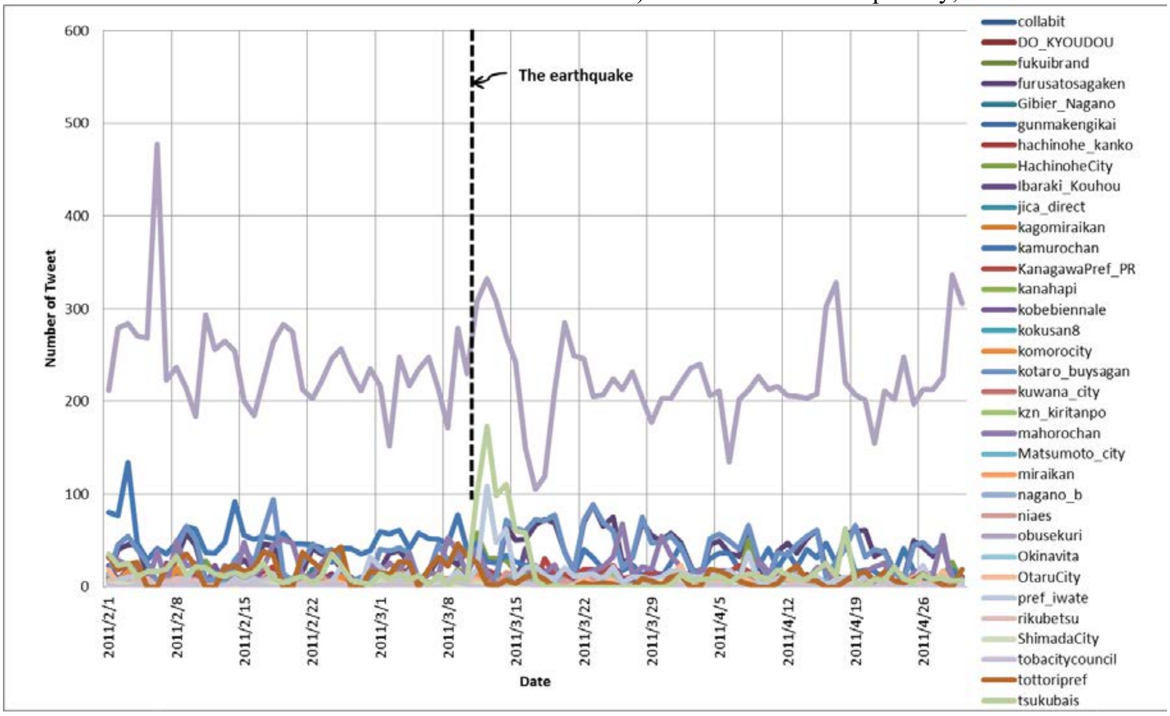

Figure 1: Change of the number of tweets for all the accounts

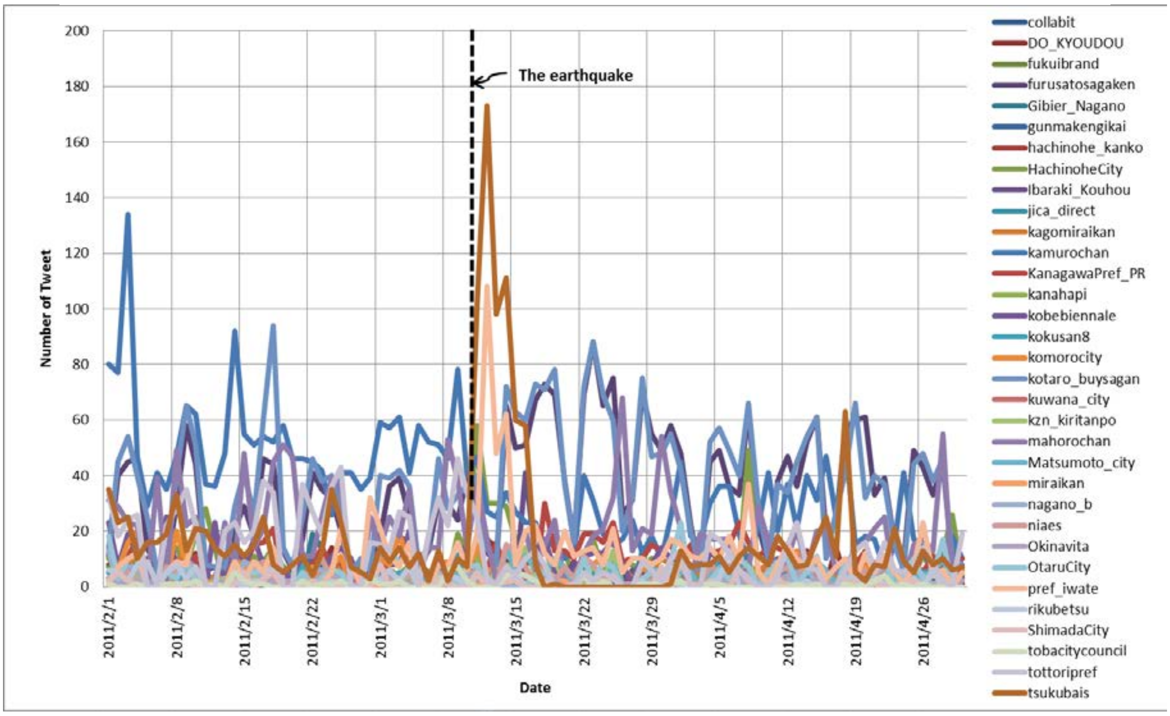

Figure 2: Change of the number of tweets for the 33 accounts

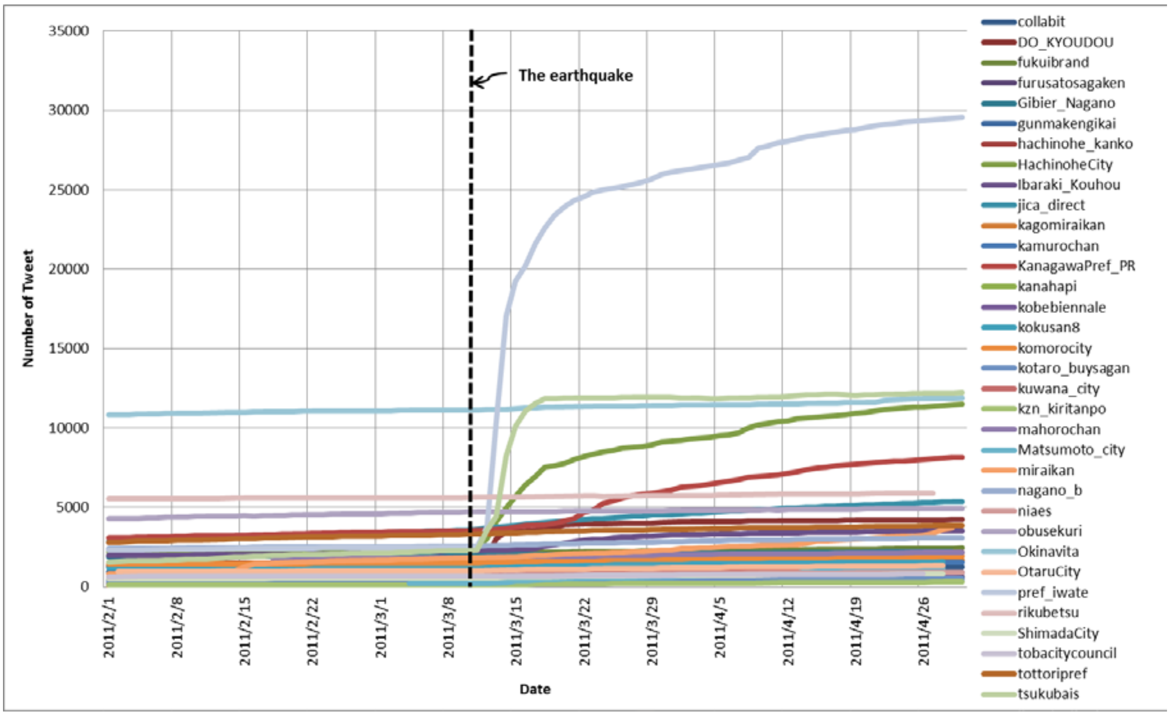

Figure 3: Change of the number of followers for all the accounts

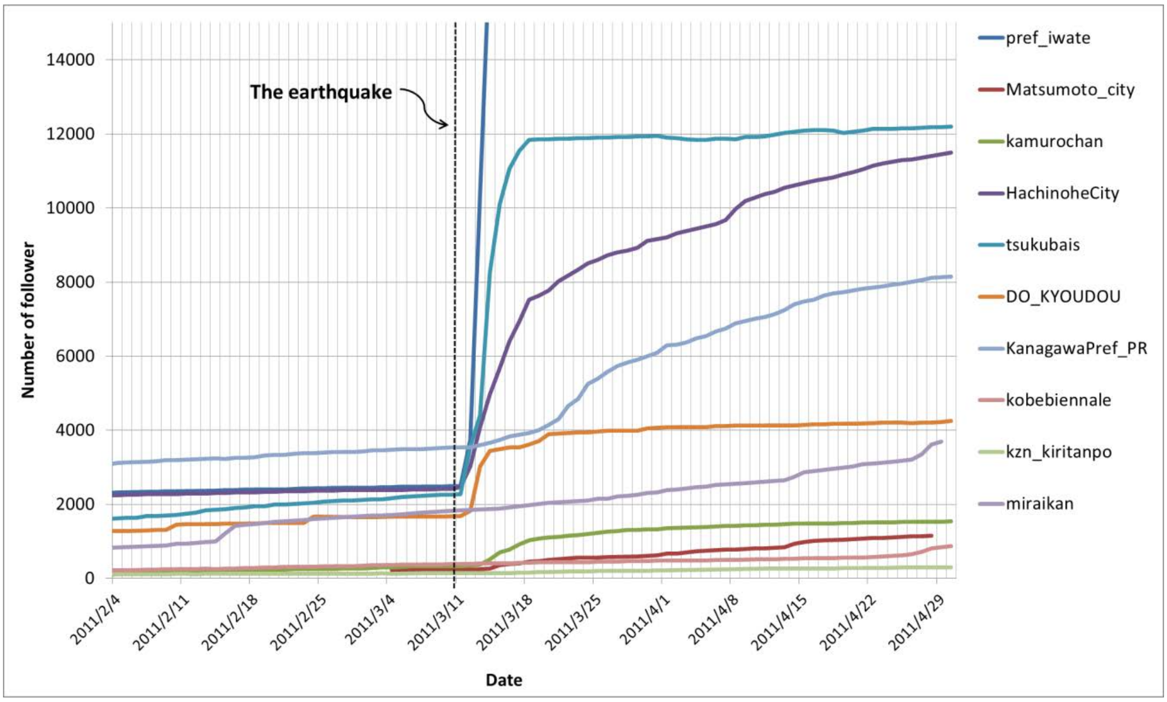

Figure 4: Change of the number of followers for the accounts that were above the average in increasing rate of followers

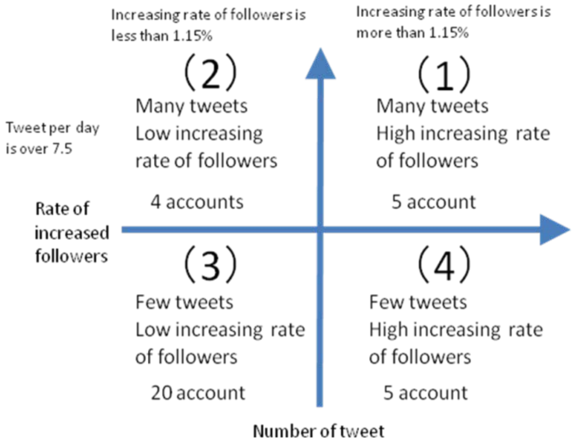

Figure 5: Four groups according to quantitative categorization of the accounts

2) the increasing rate of the number of follower per day after the date of the earthquake.

The average number of tweet per day was 7.5 and the average increasing rate of the number of follower per day was 1.15%. Thus the account could be divided whether it was more than 7.5 tweets or not, and whether it had more than 1.15% increasing rate or not. As shown in Fig. 5, we numbered each group from (1) to (4) that was same with the quadrant.

Figure 6 shows the graphs of the group (1) with many tweets and high increasing rate of followers. Five accounts belonged to this group. We see additional graphs besides the number of tweets and the number of the followers in the figure. Those are the number of tweets per content category. EQ-Communication, EQ-Citation, EQ-Announcement, EQ-Primary Info and Non-EQ in the legend are the content categories where EQ means earthquake. They are explained later in this paper. Figures 7 and 8 also have the same graphs and legends. This group (1) gained rapid increasing number of followers after the day 3/11.

Figure 7 shows the graphs of the group (2) with many tweets and low increasing rate of followers. Four accounts belonged to this group. Although this group had many tweets but the change of the number of tweets was not very noticeable.

The group (3) is one with few tweets and low increasing rate of followers. Twenty accounts belonged to this group. Although most number of the accounts belonged to this group, the group appears to be of inactive accounts. Thus this group is not focused in this paper hereafter. Figure 8 shows the graphs of the group (4) with few tweets and high increasing rate of followers. Five accounts belonged to this group.

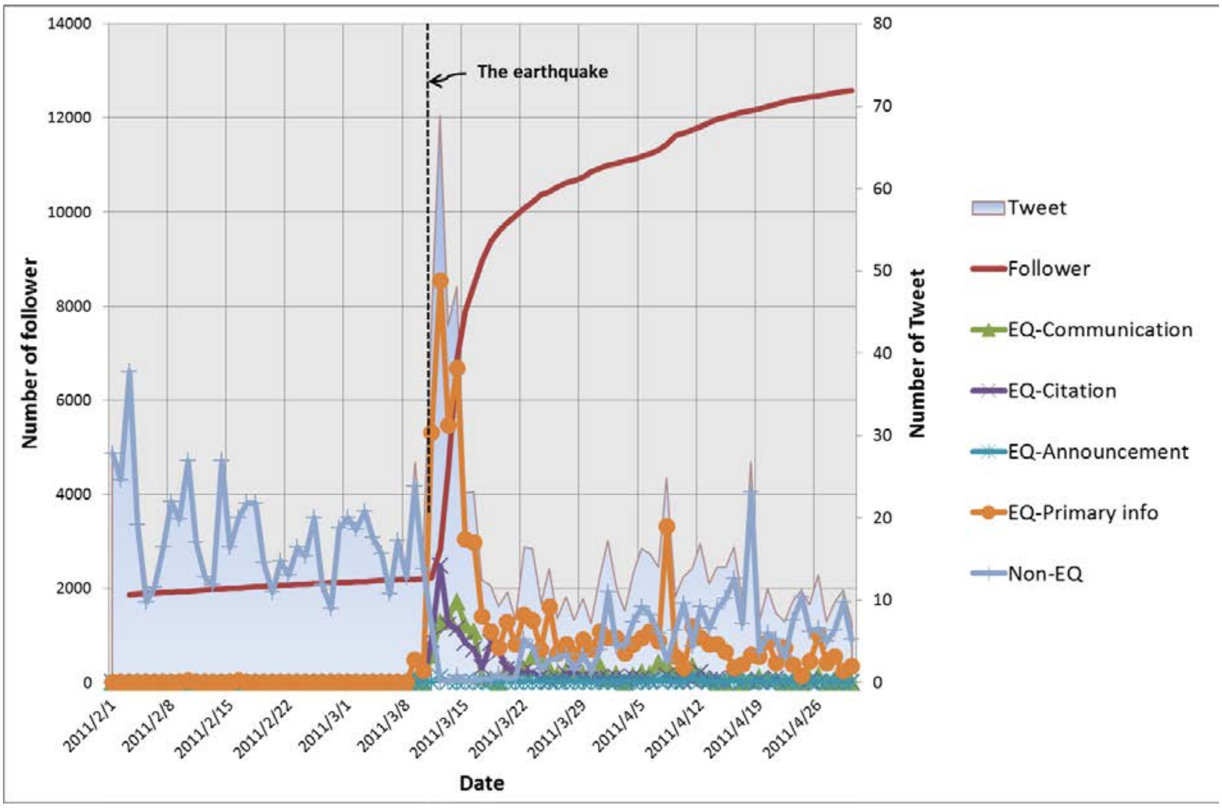

Figure 6: Group (1) with many tweets and high increasing rate of followers

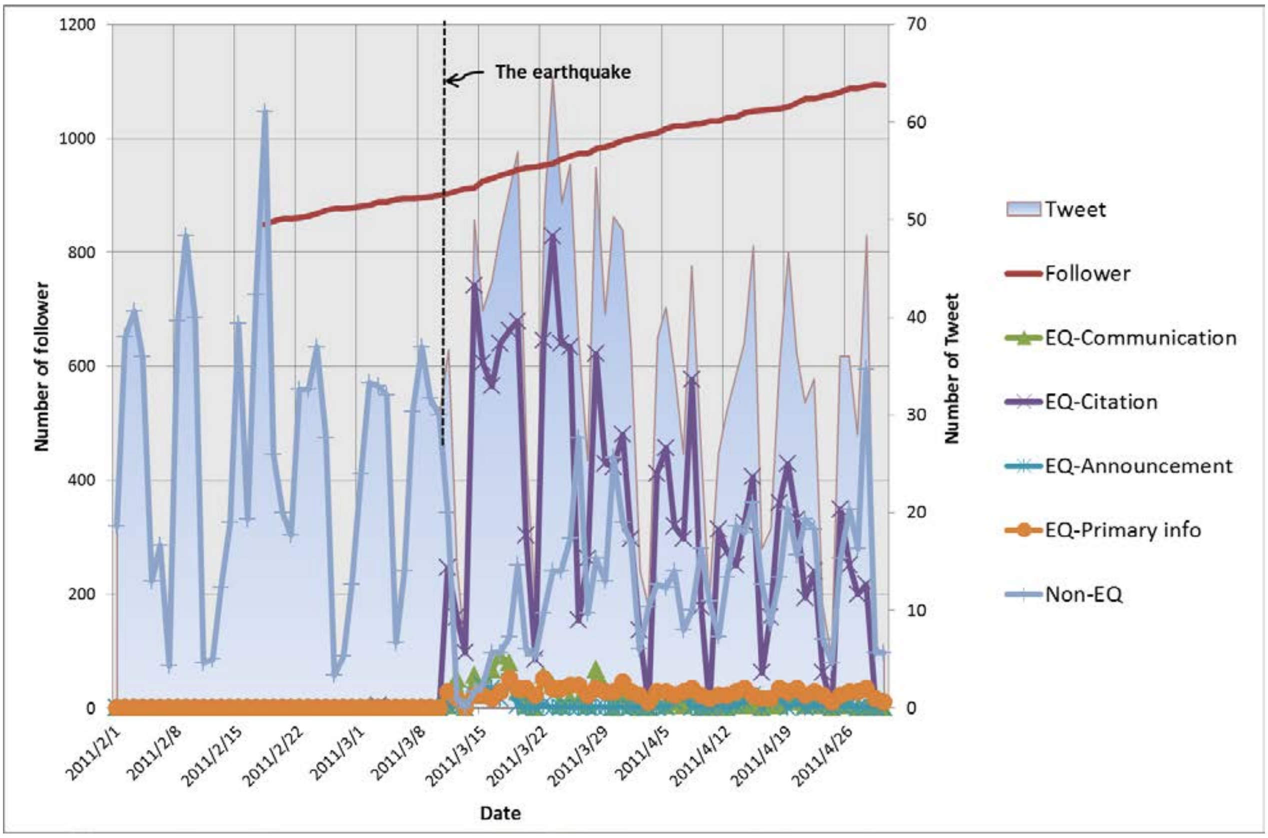

Figure 7: Group (2) with many tweets and low increasing rate of followers

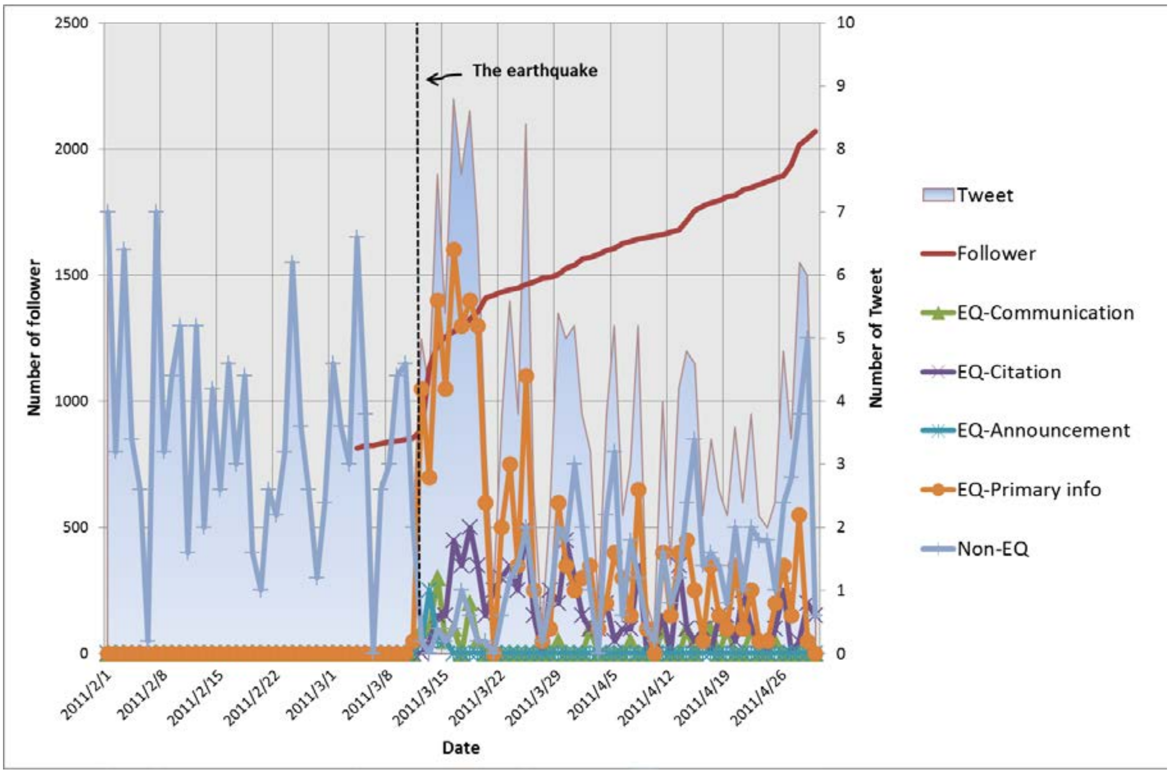

Figure 8: Group (4) with few tweets and high increasing rate of followers

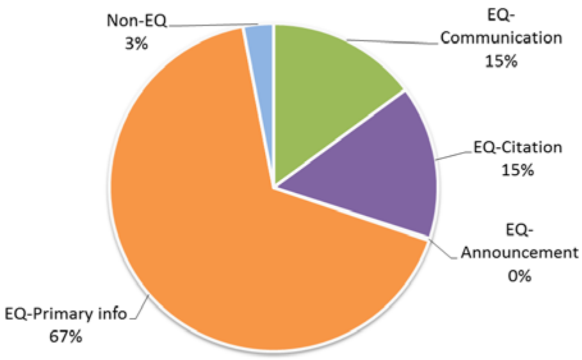

Figure 9: Tweet content of Group (1)

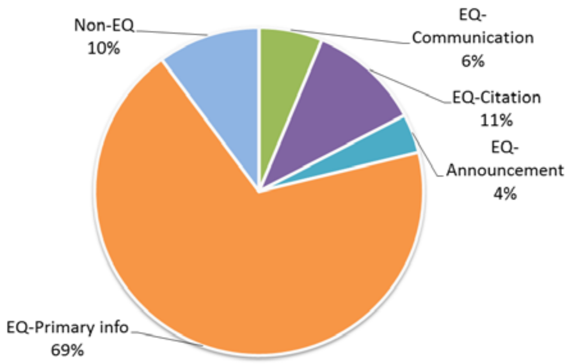

Figure 10: Tweet content of Group (4)

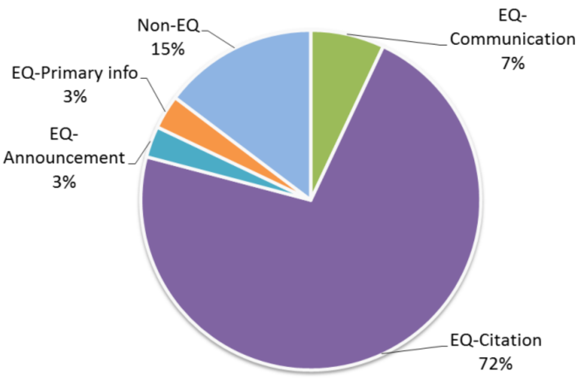

Figure 11: Tweet content of Group (2)

We might expect that many tweets draw many followers. This was not true however. Certainly it seemed to be true that few tweets usually did not draw much attention, as seen in the group (3). We also saw the cases where many tweets drew much attention as seen in the group (1). However at the same time we saw the cases where many tweets did not draw much attention as in the group (2), and the cases where few tweets drew much attention as in the group (4).

Through this quantitative categorization, we could see interesting outline patterns of tweets and followers in the graphs. But this is not enough to explain what causes high increasing rate of followers.

4.3 Content of the Tweets

The content of the tweets were then investigated. The tweets were categorized in the following five types.

a-1) Earthquake related: Communication with other account (EQ-Communication).

This includes the reply using @ to communicate with other accounts about the earthquake. The reply to other accounts is in this category even if "RT" (this means retweet) was used. The tweet that used RT to make the information or the information exchange itself open can be in this category. Even if the tweet included new information, it is in this category if its main purpose is for communication.

a-2) Earthquake related: Citing existing information (EQ-Citation)

This includes the tweet that cites existing information related to the earthquake. The retweet, and the tweet of a link to the related news are included in this category. The tweet that includes cited information and appended new information can be in this category or in a-4) category depending on the weight of both parts.

a-3) Earthquake related: Announcing to people (EQ-Announcement)

This includes the tweet that is related to the earthquake and that can be taken as the announcement to the unspecified followers. Difference from a-4) category is that this does not include new information, and often includes a call or request for action. A tweet of general caution for blackout is an example.

a-4) Earthquake related: Announcing primary information (EQ-Primary info)

This includes the tweet that provides the information where the tweeter is the primary source, new information in other words. The examples are the tweet of primary information when the official Web site is not running, and the tweet of notifying the official Web update related to the earthquake.

b) Earthquake non-related (Non-EQ)

This includes the tweet whose content is not related to the earthquake. For example, all the tweets before the earthquake belong to this category.

The process to determine these content categories was as follows:

1) Two persons, a collaborator and the author, were involved with the process.
2) The tentative categories and their criteria were decided through the discussion over the collected tweet data.
3) One account was selected from each of the four groups in Fig. 5 randomly as the sample accounts. The tweets of those accounts from 3/11 to 3/17, immediately after the earthquake when Twitter users took rapid following actions, were categorized according to the tentative categories and the criteria. The categorization was independently conducted by the two persons.

4) To check the two person's agreement on categorization, Cohen's Kappa coefficient was calculated.
   Cohen's Kappa = 0.861 for 1016 tweet items
5) After being confirmed that the Kappa was high enough, the categories and their criteria were determined without change.
6) The rest of the tweets were categorized according to the criteria by the collaborator.

4.4 Account Groups and Their Content

The content categories of the tweets in each account group are also shown in Figs. 6-8. Clear contrast between the groups was found. Many tweets in the group (1) and (4), which had high increasing rate of followers, seemed to be in a-4). Whereas many tweets in the group (2), which had low increasing rate of followers, seemed to be in a-2).

To analyze the relation between the account groups and the content categories more, the tweet content from 3/11 to 3/17, a week since the earthquake, was investigated in each of the three groups. The contents of the group (1), (4), and (2) are shown in Figs. 9, 10, and 11 respectively.

What is common in the group (1) and the group (4) is that the most numbers, nearly 70%, of tweets were in a-4). In contrast the most numbers of tweets in the group (2) were in a-2).

From this analysis, we see that the accounts that tweeted primary information were followed by many people.

5 OPERATION GUIDELINES

From the result of the previous section, we can draw operation guidelines for a municipal Twitter account in emergency.

(1) First and foremost, provide primary information. People want it.

Accounts with high increasing rate of followers mainly provided a-4) category tweets regardless of the number of tweet.

(2) Immediate tweet is helpful.

This can be observed from Figures 6 and 8. The content changed, and the number of tweets also changed after the earthquake in the group (1) and (4). The group (1) accounts that had been relatively active before the earthquake responded more immediately than other accounts, and were followed by much more people.

(3) Communication can also be helpful.

The group (1) accounts were most followed. This can be considered they were most useful or they drew most attention. What is different from other groups and is even different from the group (4) is that they tweeted a-1) more often.

(4) Citation can be tweeted, but not so many.

All accounts tweeted citation to some degree, but the group (2) which tweeted citation mainly did not get high increasing rate of followers in spite of many tweets.

(5) Daily activity to have followers is significant.

The group that gained the most number of followers, and the group that gained the most increasing rate of followers was the group (1). Another difference of the group (1) from other groups is that it held the most number of followers before the earthquake. Having more followers means having stronger dissemination ability, and this could result to draw more people.

6 CONCLUDING REMARKS

In this paper, the use of Twitter accounts by municipal organizations was focused. The user's behavior on Twitter in the Great East Japan Earthquake was analyzed from both quantitative and qualitative viewpoints in terms of the number of tweets and the tweeted content. Motivated reason is because it is not clear how such social media accounts can be used effectively in the emergency, although such social media, Twitter especially, are encouraged to use by the Japanese government.

Through this research, it was revealed that there were types of behaviors of the municipal accounts and some were useful and were followed by many people. Then the results obtained by close investigation were organized as the operation guidelines for a municipal Twitter account in emergency.

Although the research achieved this clear contribution, there are issues to consider in the future. This analysis only focused on the tweet itself. Other factors could affect the user's behavior. Examples are geographical factor and organization factor. The account closer to the disaster areas could be more followed. The account of the organization whose activity is more related to the disaster could be more followed. Those factors could be related to the number of primary information. Thus analysis from different viewpoints can be conducted.

Another issue is credibility of tweet. Twitter among other social networking services suffers from identity verification and fact verification. False rumor has been regarded as a problem. It is possible that the user's behavior reflected self-protection from false rumors. The credibility of municipal accounts is high, and this could push the number of followers. The same behavior might partially explain why primary information was evaluated higher than citation. With this consideration, information from municipal account is important, and primary information from municipal account is even more important. Designing more credible social medium can also be another direction from this research.

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Verification of Safety Properties of a Program for Line Tracing Robot using a Timed Automaton Model

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Abstract - Ensuring the reliability of embedded systems has become very important. Reliability may be ensured by a number of formal verification techniques including model checking. We study one such verification technique through a physical example of an embedded system, a line tracing robot. This paper describes how to model the behavior of a line tracing robot program as a network of timed automata and we also present experimental results for this verification by the UPPAAL model checker. The line tracer was built using LEGO Mindstorms and this paper also describes the implementation using LeJOS, a Java development environment for LEGO Mindstorms.

Keywords: Embedded System, Real-time System, Formal Verification, Timed Automaton

1 INTRODUCTION

Embedded systems have become ubiquitous in our society touching many aspects of our daily life. Ensuring the safety properties of these embedded systems has become crucially important. Model checking techniques are often used in order to ensure these properties. Most model checking techniques are based on the finite state machine model. The behavior of the target system is modeled as a tuple of automata. Usually, program variables, such as integer variables, are translated into corresponding state variables. For example, a general 32-bit integer variable might be translated into an 8-bit integer as long as the target program does not use constants with values lying outside the -128 – 127 range available. Even with these constraints such modeling can detect important faults during the design phase. Some embedded systems, however, require time properties in their specification. Several models have been proposed to deal with such real-time systems. One such model is the timed automaton, proposed by Alur and Dill [1]. The most interesting point of the timed automaton model is that it uses clock variables which range over real numbers. Locations and transitions within the timed automaton model have a limited form of syntax for applying constraints on clocks. Timed automaton models can, therefore, naturally represent the behavior of real-time systems. The most popular verifier for the timed automaton model is UPPAAL [2], developed by Wang-Yi's research group. The timed automaton used in UPPAAL is a strong extension of the original timed automaton. It can deal with bounded integer variables and guard expressions on transitions can express constraints on such variables. Several successful applications of UPPAAL have been reported, these include verification of audio-video protocols [3], a gear controller [4], and timeliness properties of multimedia systems [5].

Embedded systems sometimes control continuous systems. For example, a water level controller may observe the level in a certain tank and control the inflow and outflow valves associated with that tank. Note that the water level and the valve flow are usually continuous values. Hybrid automaton models have been proposed in order to deal with such systems consisting of discrete and continuous sub-systems. Several studies have proposed simulators for hybrid systems.

The question at the core of our research is how can we formally verify the behavior of such hybrid systems [6]? Our first step is to find what properties can be verified using conventional verifiers such as UPPAAL by working on a real application. We use a line tracer as our application for the following reasons.

- It contains time properties as design specification;
- We can implement a real system with reasonable costs using LEGO Mindstorms kit [7];
- We can freely describe the control program in Java using LeJOS [8].

A line tracer is an autonomous robot which traces a line painted in black on white background sheet according to values read by color sensors.

Through experiments, we have succeeded in the verification of safety properties of a line tracer, using timed automaton model and UPPAAL. The main contributions of this study are; i) the translation of a control program and its operating environment into a formal model, and ii) to show applicability of model checking for verifying embedded systems. Our study is still in its preliminary stage because we set limitations such as no disturbance and handling only straight lines. However, we believe that this study leads to verification of real embedded systems using model checking.

The rest of the paper is organized as follows. Sec. 2 outlines the foundations of our work. Sec. 3 and Sec. 4 describe the model and implementation of our line tracer. Sec. 5 presents preliminary but promising experimental results and Sec. 6 offers some discussion of these results. Finally, Sec. 7 provides a concluding summary and outlines future plans for our work.

2 PRELIMINARIES

Here, we will briefly outline the background to our work and introduce definitions and notions used in this paper.

2.1 Timed Automata

A timed automaton is an extension of the conventional automaton with clock variables and constraints for expressing real-time dynamics. These are widely used in the modeling and analysis of real-time systems.

Definition 1 (constraints) *We use the following constraints on clocks.*

1. *C represents a finite set of clocks.*
2. *Constraints $c(C)$ over clocks C are expressed as inequalities in the following BNF (Bacchus Naur Form).*

$$E ::= x \sim a \mid x - y \sim b \mid E_1 \wedge E_2,$$

where $x, y \in C, \sim \in \{\leq, \geq, <, >, =\}$, and $a, b \in \mathbb{R}_{\geq 0}$, in which $\mathbb{R}_{\geq 0}$, is a set of all non-negative real numbers.

Time constraints are used to mark edges and nodes of the timed automata and for describing the guards and invariants.

Definition 2 (timed automaton) *A timed automaton $\mathscr{A}$ is a 6-tuple (A, L, l_0, C, T, I), where*

- *A: a finite set of actions;*
- *L: a finite set of locations;*
- *$l_0 \in L$: an initial location;*
- *C: a finite set of clocks;*
- *$T \subseteq L \times c(C) \times A \times 2^C \times L$ is a set of transitions. The second and fourth items are called a guard and clock resets, respectively; and*
- *$I : L \to c(C)$ is a mapping from location to clock constraints, called a location invariant.*

A transition $t = (l_1, g, a, r, l_2) \in T$ is denoted by $l_1 \overset{a,g,r}{\to} l_2$.

A map $v : C \to \mathbb{R}_{\geq 0}$, is called a clock assignment (or clock valuation). We define $(v + d)(x) = v(x) + d$ for $d \in \mathbb{R}_{\geq 0}$ and some $x \in C$.

For guards, resets and location invariants, we introduce some notation for clock valuations. For each guard $g \in c(C)$, a function $g(v)$ stands for the valuation of the guard expression g with the clock valuation v. For each reset r, where $r \in 2^C$, we introduce a function denoted by $r(v)$, and let $r(v) = v[x \mapsto 0], x \in r$. For each location invariant I, we shall introduce a function denoted by $I(l)(v)$, which stands for the valuation of the location invariant $I(l)$ of location l with the clock valuation v.

The dynamics of a timed automaton may be expressed via a set of states and their evaluations. Changes from one state to a new state may be as a result of either the firing of an action or an elapsed time.

Definition 3 (state of timed automaton) *For a given timed automaton $\mathscr{A} = (A, L, l_0, C, T, I)$, let $S = L \times \mathbb{R}^C_{\geq 0}$ be the complete set of states of $\mathscr{A}$, where $\mathbb{R}^C_{\geq 0}$ is a complete set of clock evaluations on C.*

The initial state of $\mathscr{A}$ can be given as $(l_0, 0^C) \in S$. For a transition $l_1 \overset{a,g,r}{\to} l_2$, the following two transitions are semantically defined. The first one is called an action transition, while the latter one is called a delay transition.

$$\frac{l_1 \overset{a,g,r}{\to} l_2, g(v), I(l_2)(r(v))}{(l_1, v) \overset{a}{\Rightarrow} (l_2, r(v))}, \qquad \frac{\forall d' \leq d \quad I(l_1)(v + d')}{(l_1, v) \overset{d}{\Rightarrow} (l_1, v + d)}$$

The semantics of a timed automaton can be interpreted as a labeled transition system.

Definition 4 (semantics of a timed automaton) *For a timed automaton $\mathscr{A} = (A, L, l_0, C, T, I)$, an infinite transition system is defined according to the semantics of $\mathscr{A}$, where the model begins with the initial state. By $\mathscr{T}(\mathscr{A}) = (S, s_0, \overset{\alpha}{\Rightarrow})$, the semantic model of $\mathscr{A}$ is denoted, where $\alpha \in A \cup \mathbb{R}_{\geq 0}$.*

Definition 5 (run of a timed automaton) *For a timed automaton $\mathscr{A}$, a run σ is finite or infinite sequence of transitions of $\mathscr{T}(\mathscr{A})$.*

$\sigma = (l_0, \nu_0) \overset{\alpha_1}{\Rightarrow} (l_1, \nu_1) \overset{\alpha_2}{\Rightarrow} (l_2, \nu_2) \overset{\alpha_3}{\Rightarrow} \cdots$

2.2 Computation Tree Logic

In model checking, specifications are written as logical formulas. Computation Tree Logic (CTL) [9] is a temporal logic suited to dealing with such formulas. Using CTL we are able to describe specifications relating to behaviors of a program for a line tracer robot.

Let AP be a set of atomic propositions. The syntax of CTL is defined as follows:

$$\begin{aligned}\varphi ::= \; & \bot \mid \top \mid p \mid \neg\varphi \mid \varphi \vee \varphi \mid \varphi \wedge \varphi \mid \varphi \to \varphi \\ & \mid \mathsf{AX}\varphi \mid \mathsf{EX}\varphi \mid \mathsf{A}\Diamond\varphi \mid \mathsf{E}\Diamond\varphi \mid \mathsf{A}\Box\varphi \mid \mathsf{E}\Box\varphi \\ & \mid \mathsf{A}[\varphi \;\mathsf{U}\; \varphi] \mid \mathsf{E}[\varphi \;\mathsf{U}\; \varphi],\end{aligned}$$

where p is an atomic proposition in AP. The symbols $\bot$, $\top$, $\neg$, $\vee$, $\wedge$ and $\to$ have their usual meanings. The symbols X (“next”), $\Diamond$ (“eventually”), $\Box$ (“globally”), and U (“until”) are temporal operators. The symbols A (“always”) and E (“exists”) are path quantifiers. Intuitively, temporal operators represent statements of a path, and path quantifiers represent statements on one or more paths which are branching forwards from a state. In a CTL formula, temporal operators are preceded by a path quantifier. Due to space limitation, we omit semantics. Please refer to Emerson [9] for details of the semantics of CTL.

For example, a safety property that “variable x is less than 10 for all paths” is written as a CTL formula $\mathsf{A}\Box(x < 10)$.

2.3 UPPAAL

UPPAAL, Wang-Yi et al. [2], is a popular model checker for extended timed automata. It supports model checking for both conventional and timed automata. UPPAAL allows verification of expressions described in an extended version of CTL. In addition, it supports local and global integers and primitive operations on integers, such as addition, subtract and multiplication with constants. Such expressions are also allowed on the guards of transitions. System models can be created from multiple timed automata which are synchronized via a CCS (Common-Channel Signaling)-like synchronization mechanisms.

An important point is that, with the exception of clocks, the extended timed automaton used in UPPAAL cannot deal with real valued variables. We, therefore, have to round real values to integer values when we model the target systems.

3 MODEL

A "line tracer" is a vehicle which traces a course, assumed to be painted in black on white background using a line of constant width. The line tracer's starting point may or may not be on the course. For example, an oval course (the same as the track used in an athletic field) is frequently used.

A model for a line tracer consists of the following three models:

- Controller Behavior;
- State Transition of Environment;
- Disturbance.

Controller behavior can be modeled using a state machine. Usually, controller programs change the values of some state variables depending on the values of other state variables.

For example, the state variables of a line tracer may be the location of the tracer, the locations of the right and left sensors, the output values of the right and left sensors, direction of the line tracer and the rotation speed of left and right wheels.

The output values of the right and left sensors are used as inputs to the controller. The rotation speed of left and right wheels are set by outputs from the controller.

State transitions in the environment are usually represented by differential equations on state variables. In a hybrid system, such equations are used, while in a finite state model, differential-difference equations are used as an approximation.

For a line tracer, the principle state variables are summarized in Table 1.

We need some additional constants to complete the model, more specifically, these describe the physical dimensions of the line tracer. These are listed in table 2, los, ros are a tuple of (l, a), where l and a are distance and angle relative to the center of the vehicle. Figure 1 illustrates the relationships between state variables and constants.

Let us assume that a line tracer turns at speed directly related to that of the left and right wheels, h_s and l_s. Then its equation of motion can be written as follows.

$$\frac{d\theta}{dt} = \frac{h_s - l_s}{w} \quad (1)$$

$$\frac{dx}{dt} = -r_c \cdot \sin\theta \cdot \frac{d\theta}{dt} \quad (2)$$

$$\frac{dy}{dt} = r_c \cdot \cos\theta \cdot \frac{d\theta}{dt} \quad (3)$$

Table 1: State Variables of a Line Tracer

variable	description
x:	x-coordinate of the center of a line tracer
y:	y-coordinate of the center of a line tracer
θ:	direction of a line tracer
slx:	x-coordinate of the left sensor of a line tracer
sly:	y-coordinate of the left sensor of a line tracer
srx:	x-coordinate of the right sensor of a line tracer
sry:	y-coordinate of the right sensor of a line tracer
wl:	revolution speed of the left wheel of a line tracer
wr:	revolution speed of the right wheel of a line tracer
sl:	the sensed value of left sensor
sr:	the sensed value of right sensor

Table 2: Constants

constant	description
w :	width between left and right wheels of the line tracer
los:	offset to the left sensor from the vehicle center
ros:	offset to the right sensor from the vehicle center

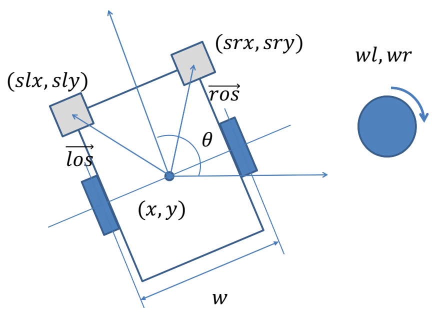

Figure 1: Constants and State Variables

Table 3: Conversion Table for Sine Function

domain of x (degree)	round of $100\times$ sin(x)
$[0, 10)$	8
$[10, 20)$	26
$[20, 30)$	42
$[30, 40)$	57
$[40, 50)$	71
$[50, 60)$	82
$[60, 70)$	91
$[70, 80)$	96
$\vdots$	$\vdots$
$[350, 360)$	-9

$$r_c = \frac{w}{2} \cdot \frac{h_s + l_s}{h_s - l_s} \tag{4}$$

Disturbances can be modeled as an uncertainty error for each of the observed variables. For example, the line tracer's sensor output value, s, may change with an uncertainty value given by the following equation: $s_o = s_r + \varepsilon(s)$, where s_o, s_r, and $\varepsilon(s)$ represent the observed value, ideal value and error in observation, respectively.

3.1 Quantization

The timed automaton used in UPPAAL can model the behavior of our controller. As we have noted above, however, UPPAAL uses integer variables only. Most of the state variables in our model have real values, therefore, we must approximate these as integer variables.

Most of our state variables use trigonometric functions (for example, equations (2) and (3)). Thus, we have to approximate these functions by rounding to integer values as long as we use finite models. The values of trigonometric functions range in [-1,1], this is clearly not suited to integer representation which would give only three values -1, 0, and 1. Therefore, we assume that trigonometric functions range in [-100, 100]. Also we adopt degree as unit for angle. Table 3 shows an approximation conversion table for the sine function.

3.2 Sampling

Another problem is that we cannot deal with functions on time. Usually state variables can be represented as a function on time, however, UPPAAL does not provide suitable functions. Therefore, we have to regard state variables as discrete signals.

Sampling is a useful method for reducing a continuous signal into a discrete signal. For a discrete signal, we can then model its change in time as a timed automaton with update functions.

Let us consider the state variables x, y, θ, slx, sly, srx, sry, wl, wr, sl, and sr. Values for slx and sly are calculated using x and y with the constants listed in Table 2. Values for sl and sr are determined from the values of x, y, los and ros, and a course model, which consists of some parameters and the equations of the course. The values of wl and wr are determined by the controller.

Table 4: Logic for Color Sensors

		RightSensor	
		black	white
LeftSensor	black	go straight	turn left
	white	turn right	go straight

Therefore, we need calculate the current value of x, y and θ using equations (1) $\sim$ (4).

Using sampling and update functions, we can construct a model where the values of variables are updated at a fixed time interval using small deltas. We will describe update expressions in detail in Sec. 5.

4 IMPLEMENTATION

LEGO Mindstorms NXT [10] is a kit for assembling robots and machines with various actuators and sensors. These robots and machines can be programmed with user defined behaviors. The actuators include stepping motors which allow accurate control of rotation angles. There is a range of sensors which include color sensors, touch sensors, and sound sensors. Various programming languages are available for programming the NXT kit. The most popular languages are NXC (Not eXactly C) [11] and LeJOS which is a Java development environment. NXC and LeJOS have program classes for NXT sensors and actuators.

This research uses LeJOS for developing the control program for a line tracer. Our line tracer has two color sensors located left front and right front of the tracing car.

Table 4 shows the controller logic associated with these sensors. If, for example, LeftSensor and RightSensor sense white and black respectively, then the controller issues a "turn right" command to the motors.

The output of these sensors is a bounded integer value. If the value is greater than some threshold level then the controller treats it as white. Wheel motors react independently to turn commands. For example, "turn left" makes left and right wheel motors speed up and slow down, respectively.

Figure 2 shows the controller in LeJOS. Figure 3 shows the physical implementation as a line tracer robot.

5 EXPERIMENTS

Here, we consider an ideal model and we ignore disturbances. In this experiment we use a simple controller program, where the rotation speed of the wheels has only two values, h_s and l_s. Also, we assume that sensors discriminate only between white and black in the robot's operating environment. In other words, the values of sl and sr are dependent on the position of the line tracer. We explicitly model the delays in sensors and actuators. We do this by setting parameters d_s, d_a, and d_t for delay between the time when the program senses color and the time when the sensors obtain the values of colors, delay between the time when the program issues a command and the time when the motor reacts, and sleeping time before next sense-act loop, respectively.

```
import lejos.nxt.Button;
import lejos.nxt.ColorSensor;
import lejos.nxt.SensorPort;
import lejos.nxt.ColorSensor.Color;
import lejos.nxt.LCD;
import lejos.nxt.Motor;
public class Controller {
  public static void main(String[] args)
     throws Exception {
   int rid,lid;
   final int HS = 420, LS = 120, BLACK = 7,
   MS = 360, HSEC = 500;
   Color colorR ,colorL;
   ColorSensor sensorR =
     new ColorSensor(SensorPort.S3);
     // 1(S3):right
   ColorSensor sensorL =
     new ColorSensor(SensorPort.S4);
     // 2(S4):left
   Motor motor = new Motor();
   motor.B.setSpeed(MS);
   motor.C.setSpeed(MS);
   Thread.sleep(HSEC);
     // wait for devices to be stable
   motor.B.forward();
   motor.C.forward();
   while(true) {
     rid = sensorR.getColorID();
     lid = sensorL.getColorID();
     if (rid == BLACK)
       motor.B.setSpeed(LS);
     else      motor.B.setSpeed(HS);
     if (lid == BLACK)
       motor.C.setSpeed(LS);
     else
       motor.C.setSpeed(HS);
     if (Button.readButtons()
       == Button.ENTER.getId())
       break;
   }
  }
}
```

Figure 2: Controller in LeJOS

Figure 3: The Implemented Line Tracer

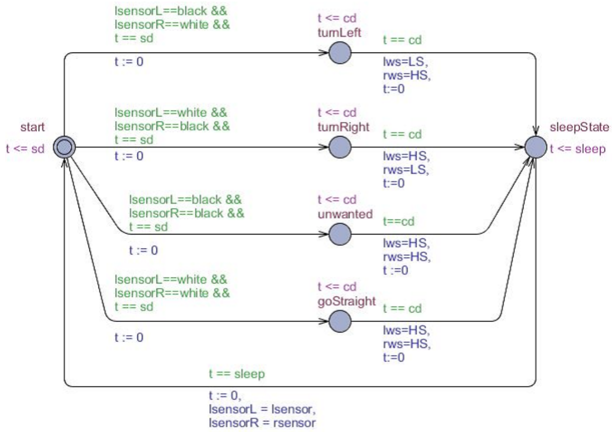

Figure 4: Timed Automaton Representing the Controller

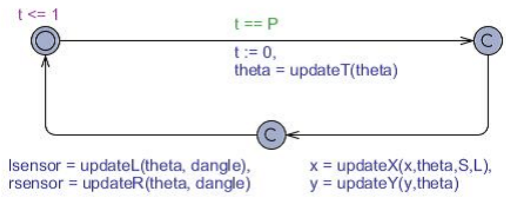

Figure 5: Timed Automaton Representing Update

For modeling and verifying the behavior of a line tracer, it is necessary to model not only the controller program but also position updates depending on the course that the robot is tracing. We therefore use the two models shown in Figs. 4 and 5, which correspond to the controller and updating processes, respectively.

The control behavior model shown in Fig. 4 corresponds to the LeJOS program `Controller` described in Fig. 2. As described in Section 4, the `Controller` decides motor speeds according to the four possible combinations of read values from the color sensors. This timed automaton represents the control program. From the initial location, represented by double circle, one can see that there are four transition each of which corresponds to a pair of sensor values.

Figure 5 shows the timed automaton which updates state variables at regular, discrete time intervals. The automaton periodically calls functions updateX, updateY, updateT, updateL, and updateR which update state variables x, y, θ, sl, and sr, respectively. The automaton deals with these in sequence first updating the value of θ, and then the values of x and y. It then updates the values of sl and sr based on the new values of x, y, and θ. The following equations for θ, x, and y are used by the update functions.

$$\theta' = \theta + \alpha \quad (5)$$

$$x' = x + \frac{wl + wr}{2} \cos\theta \quad (6)$$

$$y' = y + \frac{wl + wr}{2} \sin\theta \quad (7)$$

$$\alpha = 90 \cdot \frac{wr - wl}{w \cdot \pi} \quad (8)$$

If we assume that the time increment between samples is small then the distance moved by the vehicle can be approximated to $(h_s + l_s)/2$. The above equations use this fact. Note that here we are using the pseudo sin $/100$ defined in Table 3 and not the standard $\sin$ function. Also we let the values of the parameter p range in $[0, 359]$ by using an expression $(p + 360)\%360$.

To allow the updating of parameters including positions it is necessary to include the course in model. We assume that the course is a straight line along with x-axis. We also assume that if the value of x becomes greater than 1000 then it is reset to 50. This device let a line tracer run infinitely in the finite state model. The automaton shown in Fig. 5 incorporates information on the straight course.

We obtain a model representing the line tracer by combining the above-mentioned automata. We then checked the correctness of the line tracer program by verifying the following queries

1. $\mathsf{E}\Diamond(900 < x)$.
2. $\mathsf{E}\Diamond(\mathtt{C.turnRight})$.
3. $\mathsf{E}\Diamond(\mathtt{C.turnLeft})$.
4. $\mathsf{E}\Diamond(\mathtt{C.unwanted})$.
5. $\mathsf{A}\Box\neg(\mathtt{C.unwanted})$.
6. $\mathsf{E}\Diamond(\mathtt{C.goStraight})$.
7. $\mathsf{A}\Box((x > 280) \rightarrow (-100 < y < 100))$.
8. $\mathsf{A}\Box((x > 280) \rightarrow (\theta < 10 \vee 350 < \theta))$.
9. $\mathsf{E}\Diamond((x > 280) \rightarrow \mathtt{C.turnRight})$.
10. $\mathsf{E}\Diamond((x > 280) \rightarrow \mathtt{C.turnLeft})$.

The first of these, query (1), means that the line tracer will reach the area $x > 900$. Queries (2) and (3) mean that the controller eventually reaches state C.turnRight and C.turnLeft. Queries (4) and (5) mean that the controller eventually reaches state C.unwanted and that the controller never reaches state C.unwanted, respectively, where both of sensors detect black color. Note that queries (4) and (5) contradict each other, i.e., query (5) is negation of query (4). Query (6) means that the controller eventually reaches state C.goStraight.

Queries (7), (8), (9) and (10) use the assumption that the line tracer is in stable state. Note that we consider that the tracer is in a stable state after the point $x = 280$. This can be observed in traces of the simulation. The traces are obtained from the UPPAAL using the simulation mode view. Queries (7) and (8), respectively, mean that the line tracer roughly keeps on track and moves in the appropriate direction when it is in its stable state. The last two queries mean that the line tracer eventually turns left or right even if the tracer is in stable state.

Each of these queries (except for query (4)) was verified successfully using the parameters in Table 5. Verifications were performed within one second using UPPAAL ver. 4.0.13 on Windows 7 64 bit OS, Intel Core i7 960 3.20GHz, with 12 GB memory. Figure 6 shows verification process using UPPAAL.

Table 5: Parameters used for Verification

params	value	description
wc:	100	width of the track line
w:	120	width between left and right wheels of the line tracer
los:	(180, 30°)	offset to the left sensor from the vehicle center
ros:	(180, -30°)	offset to the right sensor from the vehicle center
h_s:	12	high speed
l_s:	6	low speed
x_0:	-200	initial value of x-coordinate of the center of the vehicle
y_0:	200	initial value of y-coordinate of the center of the vehicle
θ_0:	340°	initial value of direction of the vehicle
d_s:	1	time delay of sensors
d_a:	1	time delay of actuators
d_s:	2	periodical sleeping time

Every query, except for query (4), represents a specification that the line tracer has to satisfy. Ideally, conjunction of all queries should be verified. Unfortunately, UPPAAL does not allow nesting of path quantifiers in a formula so we verified the queries one by one. However, when we consider all the queries together, they describe necessary conditions to check the behavior of the line tracer.

Let us consider the effect of changing parameters. Query (4) is verified if we change the parameters los and ros to (170, 30°) and (170, -30°). As an obvious consequence of this Query (5) is no longer verified. This is because changing the positions of the two sensors, los and ros, reduces the distance between them. If the width of line is unchanged then the possibility of both sensors detecting black becomes higher. Verification of query (4) means that state C.unwanted is eventually reached.

6 DISCUSSION

Here we discuss our experiments and consider related work in the field of control engineering.

6.1 Discussions on the Experiments

These experimental results are not enough to convince us that the line tracer runs safely. They do, however, show that from the theoretical point of view, our approach of using a verifier for timed automata, will work.

The parameters used in verification are not the same as the those used in the implementation. For example, the width ws between the left sensor and the right sensor is 180. This value of ws is greater than 120, the width of the line tracer. This might lessen the validity of the model. The parameters are, however, acceptable because the value ws is greater than 100, the width of the track, which allows the control logic to work.

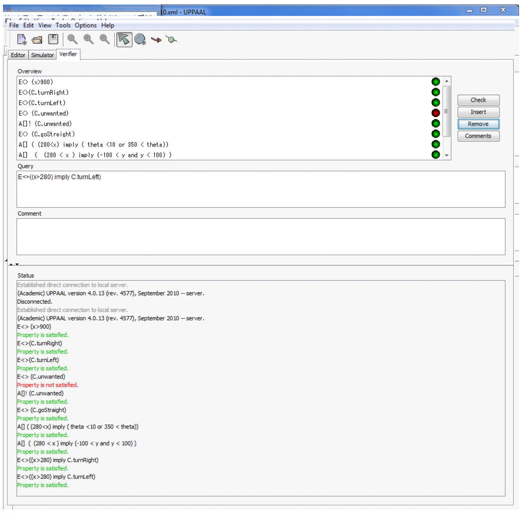

Figure 6: Verification using UPPAAL

Also the wheel speed 6 or 12 is acceptable given the size of the line tracer.

The workload involved in modeling the system was considerable (it took over 2 man-months) due to our limited knowledge of modeling, especially that of dealing with with continuous models. Some of parameters in Table 5 are very sensitive to variation, if these values are different by only a small amount then the behavior of the whole system changes and, consequently, verification will fail. For example, if we change the value of d_s to 4, then the verification fails.

One might think that low wheel speed increases the possibility of successful verification. In other words, the slower a line tracer moves, the more successively it keeps on track. However, due to quantization, a low wheel speed causes the delta values per unit of time to be 0 in our model. Therefore, we cannot use a value smaller than 6 as the low speed for the model's wheels. This problem can be resolved by increasing the physical sizes in the model. However, such a revision causes a so-called state explosion which means that model checker either cannot respond in a reasonable time or it exhausts its available memory.

Nevertheless, this still shows the importance of design analysis and verification in the early stages of development.

During the modeling, we would have liked to have had an automated generation tool which translated from an abstract parameter model to a concrete UPPAAL model, as well as a simple tool to analyze counter-examples and simulation results obtained from UPPAAL. Such tools would have been very useful in refining the model.

6.2 Related Work

It is important to assure reliability in the field of control engineering and other fields. In this section, we briefly describe related work on formal verification of applications in control engineering.

One of major approaches to verification of control systems is conversion from continuous into discrete systems using various techniques such as abstraction and reduction. This approach allows verification using ordinary model checking. For example, T. K. Iversen et al. reported on the verification of a real-time control programs using UPPAAL [12]. In their paper, the authors constructed a brick sorter system using LEGO RCX and wrote control programs in Not Quite C (NQC). The paper also describes the verification of safety and liveness properties by automatic translation from the control programs. The brick sorter system has similar characteristics to our research at the point that writing programs to simulate real-time systems. However, the brick sorter system is essentially a discrete system even though it contains time dependencies.

In verification of robotics, Sharygina et al. carried out a survey of model checking of the control system of NASA robotics systems [13]. In this survey, the authors summarize various techniques for verification and show verification of a robot control system. Safety and liveness properties are verified but these properties were not related to continuous dynamics. Even though survey does not cover the handling of continuous dynamics, it is a good resource. As a similar area, the verification of a real vehicle is described by Proetzsch et al.[14]. Even though our aim is the verification of continuous systems, our approach in reflects those above, i.e., conversion to timed automaton using quantization and sampling techniques.

There are alternative approaches to handling control systems. For the analysis of real models, such as cyber-physical systems, hybrid systems [15] seem to promise models which reflect the target systems more precisely. This is because a hybrid system is one in which continuous and discrete dynamics are mixed with time progression. Several approaches have been proposed to deal with hybrid systems. One of these approaches is hybrid automaton [16] which is a formal model for describing mixed discrete-continuous systems. HyTech [17] is a model checker for linear hybrid automata. Another approach is hybrid constraint languages such as Hybrid CC [18] and HydLa [19]. These languages are declarative and provide the power to write programs with logical formulas. Execution environments for these languages are available, Hybrid CC interpreter and Hyrose, respectively.

As with many control systems, a line tracers can be considered as a hybrid system by describing their movements using differential equations and their control programs in discrete time. It is generally accepted that real embedded systems are too big to fully verify. Therefore, it is usual to focus on important behaviors. As an example of hybrid approaches, Fehnker et al. [20] described the verification of the behaviors of a line tracer by constructing a model using hybrid I/O automata and correctness proofs. In that paper, the authors presented verification of safety property, that is, a line tracer should move along a straight line and never run off. However, the authors noted that some time details, such as time delay between two motors, were not considered .

7 CONCLUSION

We have modeled the controller of a line tracer as a timed automata. We have also verified the model so as to ensure that the line tracer keeps on track by using the UPPAAL model checker. In this paper, we dealt with simplified conditions such as there being no disturbance and the course being straight. However, we believe that our study shows the applicability of model checking for verifying real embedded systems.

Future plans for this research involve exploring other control algorithms, hybrid modeling and detailed analysis of delays in the model. We would like to introduce a PID controller (proportional-integral-derivative controller), which is a widely used feedback control system. PID control is widely used in control systems in control engineering. When PID control is applied to a line tracer, it enables smooth motion. However, PID control requires the maintenance of some historical records of state variables, and also requires complicated calculation. This approach seems to be better suited to hybrid modeling. We intend to use hybrid model, as well as verifiers and simulators to determine suitable parameters for PID control. Finding suitable parameters for tuning PID controllers to deal with particular problems is difficult and we believe that our approach may prove viable.

Another research direction is timing analysis of motor delays. From preliminary experiments, we have found that motor delay cannot be ignored in the design of a controller program if we wish to obtain a high quality controller.

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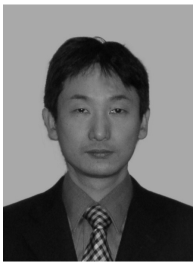

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