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Design of An Agent-oriented Middleware for Smart Home

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Abstract - In smart home environment, different kinds of system components including hardware elements, software components, network connections, and sensors are required to cooperate with each other to reduce environmental burden by energy management and to support human's life allow for a comfortable lifestyle. This paper proposes a concept of an agent-oriented middleware for smart home that consists of various home electric appliances and various sensors related to smart grid or micro grid. The agents acquire variety of information, data, etc. from the smart home environment and store/manage them in a methodical manner. Then agents configure and provide the home energy management service, life-support service, multimedia service etc. based on the information and user requests. In this paper, we describe the concept, design and initial implementation based on our agent-oriented middleware. We implemented initial applications related to multimedia and energy management to confirm the effectiveness and feasibility of our middleware to apply for smart home.

Keywords: Multi-agent, Middleware, Smart home, Ubiquitous computing, Life-support system

1 INTRODUCTION

Recently, several challenging works have investigated smart home and service provision on the smart home environment. There are two mainstreams in researches on smart home; one is research on energy management system to reduce environmental burden, and the other is for life-support service construction scheme using various sensor information. In energy management system, researches proposal advanced methods for controlling energy and promoting energy saving to reduce environmental burden [1]–[3]. Additionally, we need to consider the planned blackouts in the area after the Great East Japan Earthquake. On the other hand, in researches on life-support service construction, superior frameworks and schemes

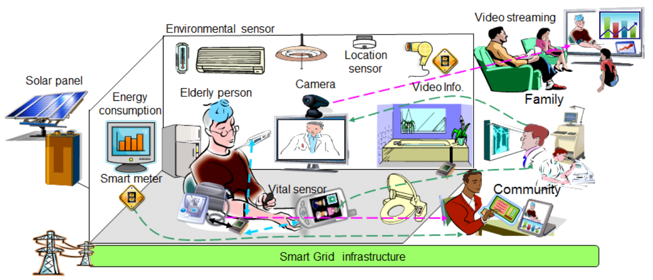

Figure 1: An application of coordination of home electric appliances and various sensors in smart home environment.

are actively challenged for dynamic cooperation among many kinds of system components, i.e., entities in smart home environments and ubiquitous computing environments, to provide user-oriented services [4]–[9].

The discussions on actual applications in smart home have been mainly focused on energy control of home electronics appliances and provision of life-support service, multimedia service, etc. In the future, these services control energy and appliances in user's house, and provide user depending on the situation based on various sensor information and user preference. In other words, we need to utilize various kinds of information to provide life-support service, multimedia service, etc. based on the infrastructure such as Home Energy Management System (HEMS).

We are promoting research and development on fundamental technologies aiming at smart home environment. In smart home environment, the home appliances and various sensors provide in a coordinated manner energy management service, life-support service, and multimedia service. We are targeting at the services such as home care support for elderly people who live alone including watching over, healthcare, safety confirmation, etc. from coordination of home appliances and sensor information as shown in Fig. 1. We are also considering multimedia services such as video streaming or videoconferencing constructed from coordination of computers, home appliances, and smartphone considering Quality of Service (QoS), Quality of Experience (QoE), energy consumption, etc.

As for QoS and QoE, the system needs to satisfy user requirement in smart home environment. To address this, the system has to consider not only selection of the devices (appliances) from user location, but also resource situation of network, software, and hardware including electrical power consumption. This is because resource availability tends to be poor and unstable depending on the device and status of use.

In this research, we are aiming to realize various service construction schemes in smart home in order to provide QoE-aware and energy-aware services against changes of resource status and user's situation. We have proposed an effective handling of multiple contexts including user context and resource contexts [10], [11]. To accomplish the objective, we apply agent-oriented middleware approach.

The overview of this approach is agentification of each entity in overall smart home environment. Basically, agent has context management ability and cooperation ability for conflict resolution on multiple contexts. Agent also has maintenance mechanism for long-term context to accumulate and

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reuse history and experiences of past cooperation among agents. Agents would make the energy-aware and QoE-aware service provision possible by the individual behavior and the cooperative behavior. As a first step, we described concept of the middleware, and energy-aware and QoE-aware service provision [12]. However we had not confirmed the feasibility and effectiveness in terms of energy-aware.

In this paper, we propose an agent-oriented middleware for smart home environment. Moreover, we describe design of the middleware focusing on the service construction scheme for QoE-aware and energy-aware service provision considering the multiple contexts. We evaluate our proposal from results of simulation experiments. We also introduce the initial implementation of multimedia communication application and home energy management application based on our middleware to confirm the feasibility and effectiveness.

The rest of this paper is organized as follows. In Section 2 we present related work and problem. In Section 3 we describe the motivation and concept of our middleware. The service construction scheme is described in Section 4. The simulation results are presented in Section 5. Moreover some initial applications are illustrated in Section 6. Finally we conclude this paper in Section 7.

2 RELATED WORK AND PROBLEM

2.1 Related work

Many studies have been done on addressing and analyzing the reduction of energy consumption and environmental burden with ICT [13]–[17]. And there are many middleware related to smart home and ubiquitous computing. The existing middlewares, frameworks, and service construction schemes are actively challenged for dynamic cooperation among many kinds of system components. CARMAN [18] considers Mobile News Service (MNS) for mobile users. It provides service based on user mobility, device's performance and user's preference. When the service is provided by a single mobile device, performance of the device is most important for the service. Therefore there are various kinds of works for providing high quality of web service within the limits of device's performance [19], [20]. These works are focusing on provision individual user-centric service using a single mobile device. To provide multimedia service by utilizing the available resources, we found it will be more efficient if multiple devices around the user can be used at the same time, instead of using only a single device.

In other similar works, service is provided by coordination with any devices around user [7], [9]. These frameworks construct the service based on service template which is requested by user. It means they search appropriate function to the requests and cooperation between various devices. Ja-Net [4] also aims to construct emergent service based on user preference.

These works' objective is same as our basic concept in terms of providing the service by coordination with heterogeneous entities. Moreover these works are providing superior mechanism of useful naming system, service description language, service emergence, power management, and sensor system.

We suppose existing service construction schemes are based only on user context and functional components, and they are concentrating on guaranty of coordination and operation or standardization of the specifications. It is important for smart home environment to satisfy a particular requirement and limitation including network resource, computer resource, and energy consumption. In case of rich service provision such as multimedia services in smart home environment, we suppose it is much more important to consider QoE. For instance, there are ever-changing situations like user mobility, device's performance around user, resource condition, and demand response based on energy management system. Therefore, there would be a possibility that devices which are physically very close to the user cannot provide the service due to lack of the resources, even if the devices potentially have good performance. Moreover it's necessary to provide the service in consideration of cooperation problem of unexpected devices, softwares, and network in addition to energy consumption problem.

We concluded that it's required to achieve service construction scheme which considers not only user request but also other situation (context) including user location, environmental information, devices, software, network, and energy consumption in effective and integrated manners.

2.2 Problems

We need to address some technical problems to provide QoE-aware and energy-aware services on smart home environment that consists of computers, audio-visual home electric appliances, and sensors.

Management of resource context

We define "context" as situation of target entity at time t and temporal changes of the situation after/before time t. The situation is represented as internal representation model of the entity. Existing works have been mainly focusing on user context acquisition scheme such as users' locating information. However, in terms of resource of entity, it was treated as only a value of the target resource parameter at time t, not as "context". In smart home environment that consists of many kinds of entities in different level of functionality and performance, it is important to consider resource context efficiently as well for proper QoE control and energy management.

Multiple context coordination

In smart home environment on which heterogeneous entities coexist, QoE and energy consumption should be maintained in the range from entity level to overall system level. Therefore, we have to consider not only functional specification of the entity, but also multiple context coordination including resource context and user context.

Non-deterministic property of service construction

There are mutual dependencies and interoperability among entities that are not resolved deterministically from analysis of static specifications. Each entity is basically designed to work by itself, not designed to work with unknown entities cooperatively. Thus, services constructed from the entities would not work whether entities consistent with applicable specifications.

Effective acquisition of various and amount of information related to smart home

Many wired/wireless sensor devices detect environmental data and vital data in the smart home. For example, there are electrical power consumption, location, vital sign, and brightness in real time. As for home care support service, the information has limitations for obtaining an accurate estimation because the information is obtained by the vital sign limited piece of information on certain individuals. It would be possible to perceive the health condition of elderly person with greater accuracy using physical location of the person, environmental information such as ambient temperature, room brightness, energy consumption, and video information, as well as the vital sign. However, it is difficult to acquire all the information because of the limitation of computational resources and network resources include wireless sensor's battery. Consequently, we need to consider the effective way of information acquisition.

Service provision based on various kinds of information

After acquisition of various kinds of information, effective information and service provision using the information would be a challenge. The data and information including energy consumption, vital sign, location information, environmental information, multimedia data, etc. contain significant diverse aspects in both quantitative and qualitative. Therefore, we need to construct the service provision mechanism include provision of required data and information, and control devices based on data and information.

3 OVERVIEW OF AN AGENT-ORIENTED MIDDLEWARE

3.1 An agent-oriented middleware

In this section, we describe the following three approaches to solve technical problems.

Agentification of each entity

We define "Agentification" as a process making a target entity workable as an agent by adding knowledge processing mechanism. We also add context management ability, cooperation ability to resolve context conflict to the agents, and adaptive communication ability [21]. Moreover, we embed long-term-context maintenance ability to the agents to accumulate cooperation history and experiences.

Multi-context-based Service Construction scheme

To realize QoE-aware and energy-aware service construction considering multiple context, we propose contract-based service construction scheme of agents. Agents make organization based on Contract Net Protocol (CNP) [22]. Moreover, we model heuristics and dependency information on cooperation history in past among agents as long-term context among agents. This kind of context is also managed by the agent. By using this context, agents organize the entities to construct more advanced services employing lessons learned.

Control scheme of demand response based on user policy

To control energy consumption in smart home, we propose the control scheme of home appliances based on user policy and user's situation considering QoE, QoS, energy consumption, and CO_2 reduction.

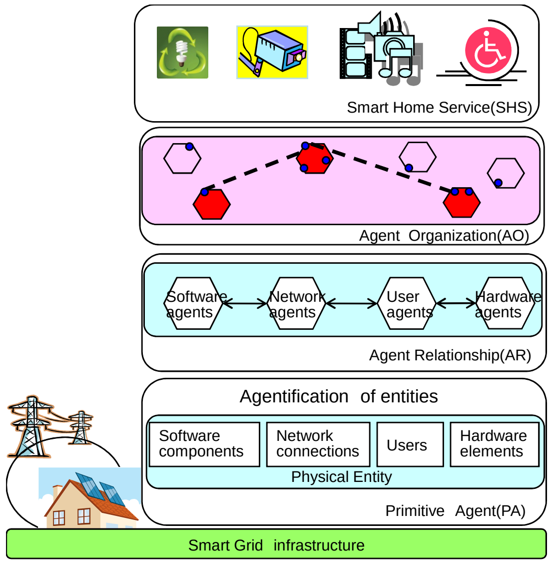

Figure 2: Agent-oriented middleware

The fundamental framework of our middleware is shown in Fig. 2. Our middleware consists of four layers, i.e., Primitive Agent layer (PA), Agent Relationship layer (AR), Agent Organization layer (AO), and Smart Home Service layer (SHS). PA makes physical entities to agents. For instance, the agents have ability to manage context, control sink node of sensor network, selection of communication protocol based on kinds of data and resource situation, etc. in this layer. In AR, inter-agent relationship based on long-term context among agents is created and maintained. In AO, agent's organization is constructed based on the context in PA and AR when user requirement or situation to specific service is issued. On the top layer SHS, actual service is provided to users.

3.2 Process of service provision

Fundamental process to provide service consists of the following steps.

(1) Agentification

Agent's designer adds each entity to domain oriented knowledge representation model that is suitable for classification of the entity.

(2) Updating of IAR

We define long-term context among agents as Inter-Agent Relationship (IAR). Each agent has different IARs to all other agents with which it has cooperated in past time. Each agent updates their IAR after its service provision by itself or by cooperation with other agents.

(3) Self-directive user requirement acquisition

Agent considers and acquires user requirement autonomously. Agent analyzes the requirement from user's profile, location information, behavior, and sensing data in the smart home environment. Agent has to choose in the most suitable manner to get the requirement because useful input devices may not be available in everywhere.

(4) Service construction and service provision

To provide service, agents construct its organization based on CNP. We apply hierarchical CNP, i.e., task announcement is propagated in order of hardware agents, software agents, and network agents. The agent organization is created based on context managed by each agent including sensor devices. The actual service is constructed and provided with combination of entities controlled by agents.

(5) User evaluation

The agent organization receives user's feedback concerning the quality of provided service when the service provision is finished. We introduce us-effectivity (E) based on [4]. In our middleware, when E value changes, each agent informs the update to all other agents that have relationship to it. Therefore, the result of evaluation is propagated to all related agents. It effects to reconstruction of various service and behavior of agent.

4 SERVICE CONSTRUCTION SCHEME

4.1 Basic Inter-Agent Relationship

Basic IAR consists of Tight Relationship, Group Relationship, Competing Relationship, and Positional Relationship like shown in Fig. 3.

(1) Tight-Relationship

Agents create Tight-Relationship (TR) when agents provide some services by constructing organization. It is possible for the agent to have past cases of successes and failures in cooperation by using TR.

(2) Group-Relationship

Group-Relationship (GR) is given to group of agents that have some potential dependencies. For example, there is GR among hardware entities such as sink node and source node of wireless sensor network, smart meter and appliance, desktop PC, speakers, and PC displays, etc. Agent can inform changes in their states frequently to the agents within the group by using GR.

(3) Competing-Relationship

Competing-Relationship (CR) is formed among agents that have same function. The reason we add this relationship is that there are agent's function in direct competition with agent which has same function when task announcement of the function is issued. The competing agents routinely inform their status to each other, and they can make good organization effectively when CNP-based negotiation runs by using CR. Moreover CR has the effect of reduction of messages because agents which have CR send message considering other agents situation.

(4) Positional-Relationship

Positional-Relationship (PR) is formed among agents that have same positional information. For example, there is PR among hardware entities such as smartphone and TV, and network entities such as network location including wireless network, Bluetooth. It is possible for the agents to select the device to provide the service around user.

4.2 CNP-based service construction with IAR

Our scheme which is based on CNP builds agent organization using IAR. CNP is a mechanism to make contract relationship among agents by exchanging messages such as task announcement, bid, and award, shown in Fig. 4. In this subsection, we briefly explain features of service construction scheme based on TR, GR, and CR.

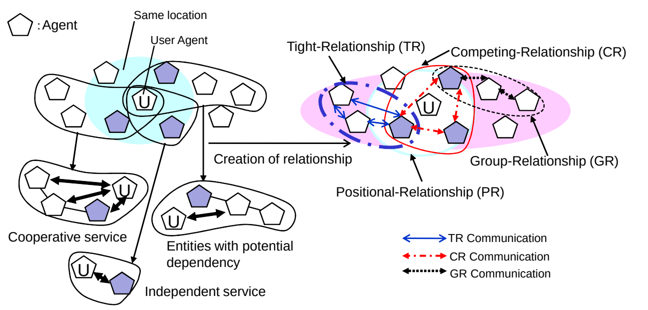

Figure 3: Class of Inter-Agent Relationship

(1) Case of TR

In Fig. 4(1), we assume that agent A has a `TR` with both agent B and agent C whereas no IAR exists between B and C. `TR` between A and B indicates that trouble was occurred when they had cooperation in the past, and `TR` between A and C indicates no trouble in the past. They refer to each IAR when B and C receive the task announcement from A. B does not send bid because `TR` against A is bad. That means the trouble in cooperation would occur this time too. On the other hand, C sends bid because C judges from `TR` that it would contribute to the task announced. It is possible to reduce trouble in cooperation by agent considering coordinated relationship in the past.

(2) Case of GR

We assume that agent A has no IAR with both agent B and agent C whereas relationship of type GR exists between B and C as shown in Fig. 4(2). C recognizes that `GR` against B exists when C judges the task announcement from A. Then C sends bid if C judges that B can provide service by referring to `state` in IAR. On the other hand, C ignores the task announcement if B cannot provide service. It is possible to reduce the trouble in cooperation by agent considering dependency of the agents.

(3) Case of CR

In Fig. 4(3), we assume that IAR of type CR exists between agent B and agent C whereas agent A has no IAR with both B and C. B and C receive the task announcement. Each agent checks IAR of type CR if it can process the task. When agent has `CR`, it refers to state of the `CR`. For example, B sends bid in case that B judged the value of `us-effectivity` on this task is higher than that of C. By contrast C ignores the task announcement in case that it judged `us-effectivity` of B is higher than C. In fact, it is possible to efficient construction of service by consideration of state of same function agent.

4.3 Concept of policy-based home energy management

In general, demand response is a control scheme of power consumption of consumers on the electric power provider side. The scheme controls operational status of home electric appliances. We propose a policy-based home energy manage-

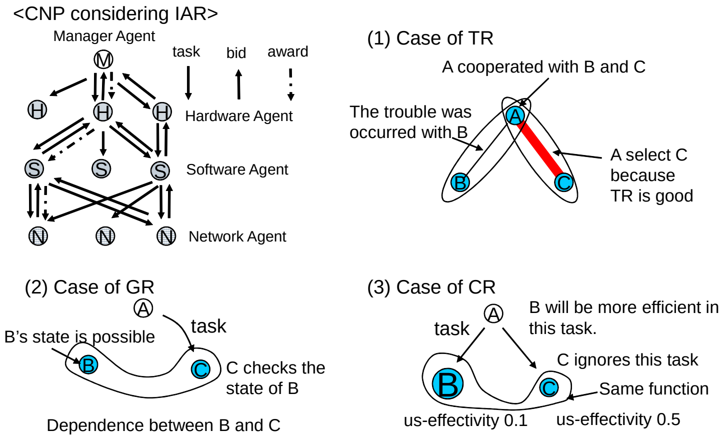

Figure 4: Service Construction based on CNP considering IAR

ment depending on demand response as shown in Fig. 5. The policy of this scheme means user's preference and priorities depending on situation of blackout or load sharing related to demand response. For example, our proposal method controls the air conditioner about the preset temperatures during periods of peak demand for electricity, or turns off air conditioners instead of switching on a fan cut electric power consumption by agents. Additionally our method controls electric pot, microwave, illumination etc. to reduce wasted electricity depending on user's preference and situation.

On the other hand, when the power goes down due to a disaster such as earthquakes, our method controls the illumination, radio, television etc. at a minimum power consumption considering the context such as time, room brightness and the rechargeable batteries. Additionally, when there is no possibility of demand response, our method provides multimedia service using a wide-screen TV and audio equipment based on user's preferences. In fact, each agent calculates the power consumption and CO_2, and agents control appliances based on IAR and user's policy.

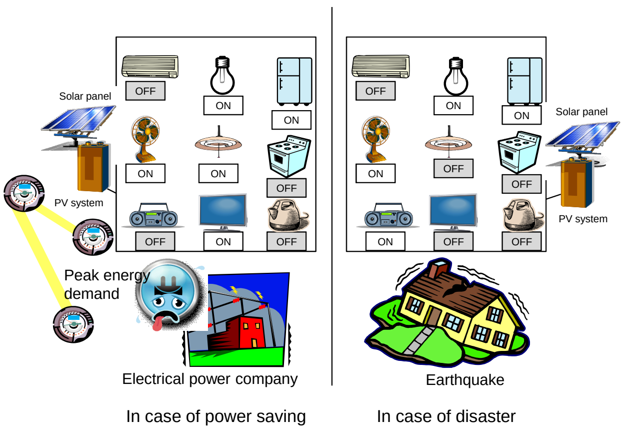

Figure 5: Overview of policy-based home energy management

5 SIMULATIONS

5.1 Implementation

To perform simulation, we implemented agents based on our middleware. We employed agent-based programming environment DASH [23]. We also performed simulation by IDEA [24]. IDEA is interactive design environment for Agent system. We used DASH because agent which is developed for simulation can easily be reused when we build application systems.

5.2 Evaluation method

In this simulation, QoE awareness of the system is measured and we investigate how much the QoE awareness is improved by introducing our middleware. To measure the QoE awareness, we apply User Request Achievement (URA) level. We can measure how much the user requirement is fulfilled by the system. Details of URA are described later.

Figure 6 shows the behavioral situation representation of the system. Here, three entities including a hardware entity, a software entity, and a network entity are making organization and providing service to a User. The user issues "User Request QoE" and the system provides service with "Provided QoE". Hardware Agent (HA) monitors CPU resource context and Network Agent (NA) monitors bandwidth resource context. On the other hand, Software Agent (SA) has knowledge concerning mapping from resource availability onto actual user level QoE.

The QoE evaluation of service is based on URA. URA is calculated by comparison between User Request QoE (RU) and Provided QoE (SV). In this simulation, we defined the range of URA is from -1 to 1. Here, ru_i is an element of RU and it represents User Request QoE on service element i. Also sv_i is an element of SV and it represents Provided QoE on service element i. The value of ru_i and sv_i is from 1 to 10. Here, URA on service element i, i.e. URA_i is represented as follows:

- $SV = \{sv_1, sv_2, ...\}$

- $RU = \{ru_1, ru_2, ...\}$
- $URA_i = (sv_i - ru_i)/10$

If URA_i is above zero, the user requirement is fulfilled. If it is below zero, the requirement is not satisfied. In this evaluation, the number of service elements is assumed to be two ($i = 1, 2$) and URA indicates the total URA, that is, a mean value of URA_1 and URA_2 for simplification.

We performed simulation for 500 times. The agent constructs CR immediately after simulation beginning. When SA constructs service, it refers to NA's bid and IAR. If SA judges that other agent is suitable, it disregards the task even if the task is acceptable. And if agent receives bid by two or more agents that can fulfill user requirement, agent sends award to agent with the highest value of E of IAR after referring to the value of E. The simulation receives an assumed user evaluation each time of service construction. The user evaluation is reflected to E. User evaluation is assumed good if sv_i is within from 120 % to 100 % when ru_i is regarded as 100 %. In this case value E is set to 1. It is assumed bad in case that sv_i exceeds 120 % or is below 80 %, and the value is set to -1. Otherwise it is regarded as usual, and the value is set to 0.

We compare three patterns of agent behaviors, i.e., our proposal (IAR-based approach), the case considering only user context (User-request approach), and the case considering only the maximum QoE value of agent for QoE without consideration of resource context (Maximum approach). Resources of HA and NA are assigned random values in every service construction. We also give tendencies of user request in four patterns, which is high quality (7∼10), middle quality (4∼7), low quality (1∼4), and random quality (1∼10).

5.3 Simulation results and evaluation

Figure 7 - 10 shows the frequency distribution concerning URA. Figure 7 is a comparison for case that RU is always in high, Fig. 8 is a comparison for case that RU is always in middle, Fig. 9 is a comparison in case that RU is always in low, and Fig. 10 is a comparison in case that RU is always in random numbers.

From analysis of Fig. 7 in case that RU is always in high, our approach could achieve the user requirement with higher frequency than User-request approaches. In case that user requirement is higher than the service environment, it can be understood that the requirement cannot be fulfilled even if

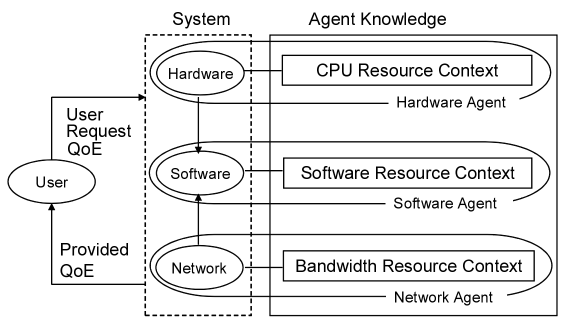

Figure 6: Behavioral situation representation of the system

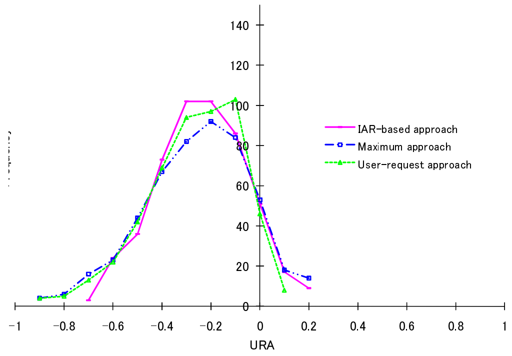

Figure 7: Results of comparison in case that RU is always in high

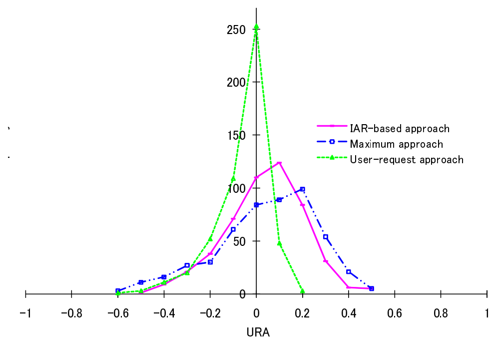

Figure 8: Results of comparison in case that RU is always in middle

only user context is considered. Moreover, in case that agent considers only the user request and the maximum value that can be selected, URA generally is lower than our approach, when user requirement is not fulfilled. It is understood that some conflict on resource context is occurred. Our approach also decreases bad service construction by considering IAR. This is because that IAR decreases the conflict of resource context. From these results our approach is rather effective in this kind of case.

From analysis of Fig. 8 in case that RU is always in middle, URA of User-request approach often closes to zero much more times than other approaches. On the other hand, compare to the User-request approach, IAR-based approach could fulfill the user requirement frequently. Moreover the case that URA of our approach is higher than that of Maximum approach is a little. From this result, if resources are available, our approach can provide a slightly better service than the original user requirement. We can find our approach considerably reduce bad service construction than other approaches such as in Fig. 7.

By analyzing Fig. 9 where RU is always in low, URA of User-request approach often extremely close to zero more frequently than other approaches. In our approach and Maximum approach, the case that URA closes to zero is not frequent. But, our approach closes to zero much more times than Maximum approach. Moreover User-request approach

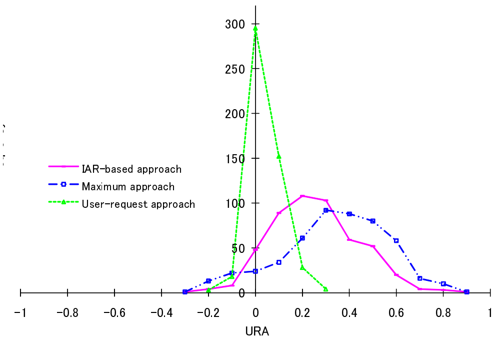

Figure 9: Results of comparison in case that RU is always in low

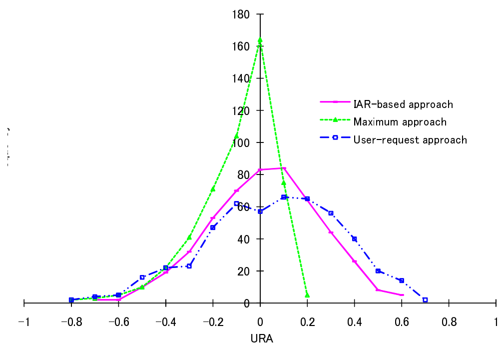

Figure 10: Results of comparison in case that RU is always in random numbers

and our approach reach much closer to zero than Maximum approach. We can find that the agents construct organization considering user requirement and IAR effectively. However, our approach is thought to be meddlesome service for user who does not want excessive quality.

By analyzing Fig. 10 where RU is always in random numbers, URA of User-request approach extremely close to zero more frequently than other approaches. In our approach, URA closes to zero and 0.2. Our approach also closes to zero much more times than Maximum approach. In negative side of URA, User-request approach generally is lower than our approach. Moreover, in Maximum approach, the case that URA closes to zero is not frequent. We can find that our approach that the agents try to construct organization to fulfill user requirement while avoiding low URA possible.

From these simulation results, it is understood that our approach is most effective under unstable environment with high-level user requirement. Additionally, it should be considered whether user requirement or relationship between agents which has the higher priority, when agents construct service. User requirement can be fulfilled by mainly considering IAR rather than user requirement in the environment with high user requirement and unstable resources. However, in the environment with suitable user requirement and stable resource, user requirement should be mainly considered rather than IAR. Therefore, we suppose that it is necessary to consider top priority between user requirement and IAR so that it matches to the situation when service is constructed in smart home environment.

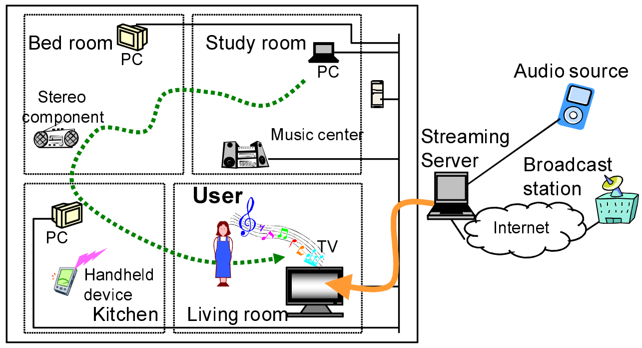

Figure 11: Overview of music distribution service

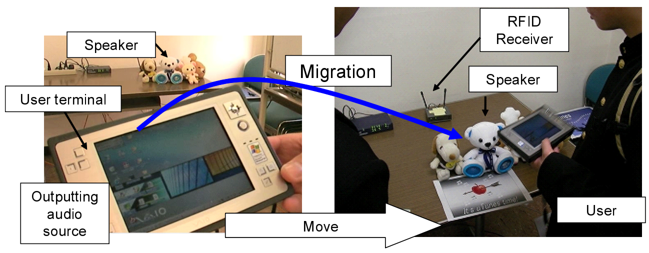

Figure 12: Snapshot of music distribution service

6 APPLICATIONS

6.1 Entertainment Application

We developed four applications based on our middleware to confirm that the middleware can apply to a broad range of smart home services. One is contents services. These applications are in the entertainment application domain. The other is an initial home energy management service.

The first example is a music distribution service as shown in Fig. 11. This service plays music through various speakers, by following the user's movement. As for hardware configurations, we used an active-type RFID system for sensing user's location. We equipped RFID receivers behind each speaker.

In Fig. 12, a user is carrying a user terminal with a tag of RFID. At this time the user is playing music on the user terminal. When the user approaches to the speaker on the table, the music migrates from the user terminal to the nearest speaker. Speaker agents provided the service considering CR of IAR and user location.

The second example is a jam session service as shown in Fig. 13. It is an entertaining and tangible application that can be enjoyable for the people in the range from the children to the elderly. A user selects some paper cups on which RFID tag attaches. On the cup, a picture that represents an instrument is shown. When the user closes the cups to the speakers, the speaker plays instrumental audio sources corresponding to the paper cup's instrument picture, such as dram, piano,

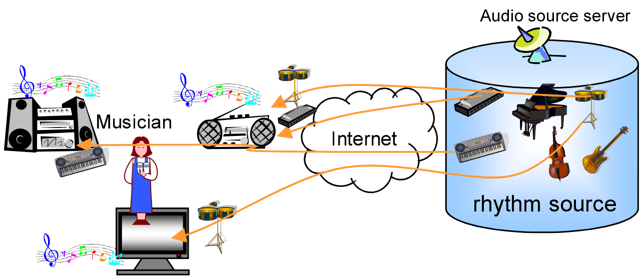

Figure 13: Overview of jam session service

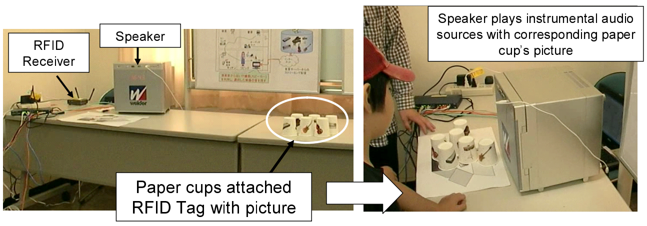

Figure 14: Snapshot of Jam session service

guitar, harmonica, and synthesizer, via the Internet as shown in Fig. 14. If the user moves the paper cups away from the speaker, the speaker stops playing instrumental audio sources corresponding to the paper cup's instrumental picture. Therefore, the user can play instruments by combining some paper cups. The agent's organization of this system was constructed by RFID agents, Comp. agents, AudioPlayer agents, Speaker agents, etc. In fact, we used two speakers, two RFID readers, and six RFID tags. This service was tried by more than 90 visitors at our laboratory's open house. This system could continue to provide service without experiencing any problems.

The third example is a multi-contents service as shown in Fig. 15. This application plays multi-contents by combing various contents from each server. Basically, we reused agents and function of music distribution service and jam session service to this system. And we added video streaming function. For example, when agent plays a slide show content on the display, the display agent call a music player agent. Then a music player agent plays a music content. We feel a single application running. In fact, agents combine a single content with another single content at the same time.

Figure 16 shows a snap shot of multi-contents service. When a child put a paper cup on the display stand, the system plays a music content and a slide show content on the display in Fig. 16 (Case 1). If the child moves the paper cup away from the display, the system stops to play the slide show contents and the music contents.

In Fig. 16 (Case 2), the users put three paper cups. The system plays two slide show contents, live video streaming and two music contents. When the users move three paper cups away from display, the system stops to play all contents. Additionally, this service was tried by more than 110 visitors at our laboratory's open house. This service could continue to work without experiencing any problems.

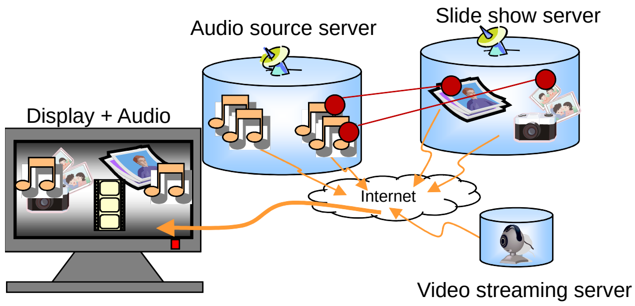

Figure 15: Overview of multi-contents service

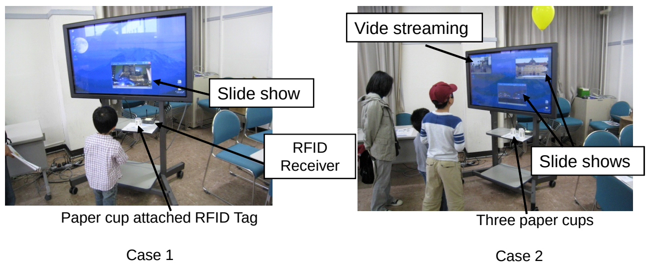

Figure 16: Snapshot of multi-contents service

From this multi-contents service, we confirmed that our middleware can treat various contents in parallel using smart home devices. We confirmed feasibility and effectiveness of our middleware based on IAR through three applications.

6.2 Home Energy Management Application

For initial experimental analysis and performance evaluation of energy management, we developed an energy management application using humidifier and environmental sensors. This energy management application controls electric power of the humidifier depending on degree of humidity and illuminance level. Figure 17 shows the experimental environment.

This application consists of humidifier, humidity sensor, light sensor, smart tap, solid state relay (SSR), and PCs. This humidifier is simple-function device. Therefore the humidifier does not have automatic adjusting function depending on the degree of humidity. We used e!NODE [25] developed in Mineno laboratory, Shizuoka University, Japan as the smart tap and SSR module. We also employed Phidgets sensor Kit [26] as the light sensor.

We performed this experiment in our laboratory. We used illuminance level of the light sensor to judge whether someone is in this room. When someone is in this room, we set the humidity operates. This will help to reduce waste of power consumption. In this experimental scenario, the application will start only if the value of degree of humidity is below 50% and the illuminance level of the light sensor exceeds 550. On the other hand, the application will stop if the value of degree of humidity is exceeds 50 % or the illuminance level of light sensor is below 200.

Figure 18 shows the experimental result. The horizontal axis is measured time, and the vertical axis shows electric

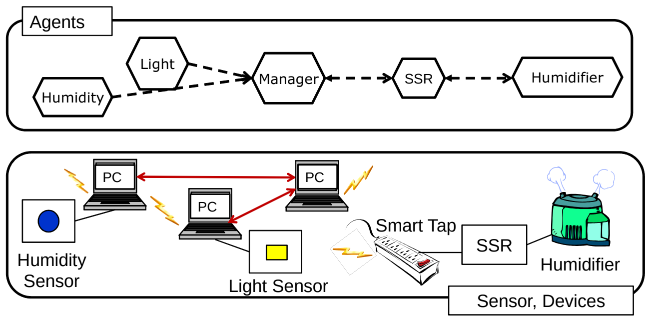

Figure 17: Experimental environment of energy management

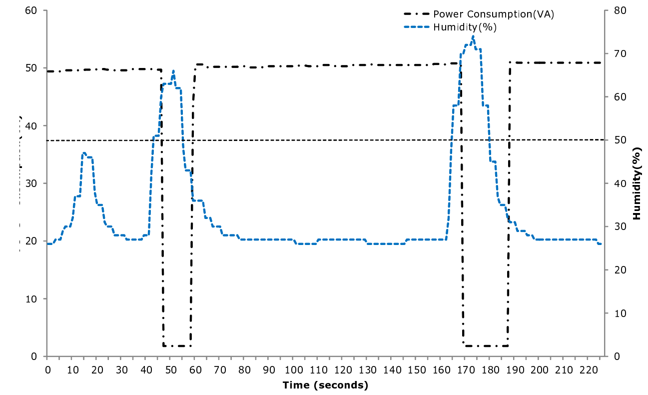

Figure 18: Power consumption and degree of humidity

power consumption and humidity. Electric power consumption decreased to around 0 VA when humidity increased after around 45 seconds and 170 seconds. It seems that this is caused by the reason that manager agent recognized humidity exceeded 50 % and turned off the SSR module to stop the humidifier. On the other hand, Electric power consumption increased to around 50 VA when humidity decreased after around 60 seconds and 190 seconds. Because the manager agent recognized humidity was below 50 % and turned on the SSR to start the humidifier.

It seems that this was caused by the reason that manager agent recognized humidity fell below 50 % and turned on the SSR module to start the humidifier. The execution time for the electric power control was about 3 seconds, thus it was proved that the response time was in acceptable range for practical use.

From this initial experimental analysis and performance evaluation of energy management, we confirmed that our middleware can apply home energy management service using home electric appliance and various sensors.

7 CONCLUSION

In this paper, we described the concept of an agent-oriented middleware for smart home environment. We designed our middleware focusing on the service construction scheme for QoE-aware and energy-aware service provision considering the multiple contexts. We also evaluated our scheme with some simulation experiments and confirmed its usefulness in smart home environment, particularly for multimedia services. Moreover we implemented entertainment application and home energy management application as a first step towards practical use of our middleware. And we performed some empirical studies with prototype system concentrating on evaluation of the effectiveness and performance evaluation of energy management.

In future, we would like to design detail method and algorithm of policy-based energy management according to various situation. We are also planning to consider data fusion mechanism and evaluate prototype system using a number of smart taps and environmental sensors.

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