An Intelligent Cloud-based Home Energy Management System Based on Machine to Machine Communications in Future Energy Environments

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***Abstract*— Recent advances in machine-to-machine communication technologies facilitate location/context-aware home energy management system that can provide predefined services. Such systems can establish the context model about the structural situations and the interrelations between dynamic events and services. These systems also can reason the adaptive services according to the policy construction and user requirements. However, due to their architectural limitations, the recent systems are not so flexible with respect to system scalability and availability. The important issues, such as the enhancement of the personalized service, the energy-aware service prediction of the multi situations, and the scalability of the various service domains, have not been adequately considered in the recent researches. Therefore, this paper proposes an intelligent cloud-based home energy management system (CHEMS), considering these issues. We employ cloud computing methods to deal with problems that the existing systems have. Cloud computing technologies can help the existing HEMS to deal with a large amount of computational and storage resources required to use enormous energy management data effectively. We implemented CHEMS in the test bed and conducted an experiment to verify the efficiency of the proposed system. The results show that the proposed system reduces the service response time up to 39.4 percent.**

Keywords-cloud computing; home energy management system; machine to machine communications; pattern learning

I. INTRODUCTION

Smart grid technologies have changed the electricity infrastructure more efficiently. These technologies help both electricity provider and consumer to improve energy efficiency and to reduce greenhouse gas emissions by optimizing power generation, transmission, distribution, and management. HEMS is composed of a wireless sensor network (WSN), a smart meter, a smart distribution panel, a integrated management server, and a smart actuator. They collect a variety of information and optimize energy efficiency [1]. The conventional HEMS systems have focused on standby power reduction and pattern analysis of power consumption.

Context awareness indicates the concept that computers can sense and react based on their environment. With the increasing demand for a personal environment service (PES), context-aware systems have been implemented in various places. In recent years, these systems have been gradually applied to HEMS to improve energy efficiency. These systems can offer context-aware services to users with regard to the analysis of information about the circumstances. However, the conventional systems spend excessive resource and long-term pattern analysis time, since they have to gather and store a lot of contexts and data for reasoning.

The widespread availability of embedded sensors (e.g. smart meters or monitoring sensors) for ubiquitous computing is increasingly supporting complex HEMS applications and services. Modern embedded sensors are especially well-suited to leverage information about a user's situations because they are often integrated with the mobile devices that facilitate obtaining detailed and meaningful descriptions of a user's situation. However, large-scale usage of embedded sensors will lead to the emergence of a complex organization system which requires huge computing resources. Furthermore, an increase in the embedded sensors will lead to the great rise of machine-to-machine (M2M) communications over wired and wireless links.

To deal with these problems, we propose a novel home energy management system (HEMS), i.e. intelligent cloud based home energy management system (CHEMS). Cloud computing is an emerging technology aimed to provide computing and storage services over a network [2]. Thus, cloud computing is widely applied to various applications and systems, such as a multimedia delivery service or other novel services that require high-performance processing capability [3]. Cloud computing technologies can help the existing HEMS to deal with a large amount of computational and storage resources required to use enormous energy management data effectively. Our design goals for CHEMS are:

1. Automated deployment and management of virtual infrastructure in the cloud: CHEMS employs cloud computing concept to provide home energy management services. CHEMS takes a dynamic description of a service, which encapsulates service's requirements. Thus, according to this dynamic description of a service, CHEMS can easily deploy and manage virtual infrastructure in the cloud.

2. Pattern-based learning for optimal control: Accurate reasoning based on user's living/power consumption patterns can reduce heavy event processing since it helps to find out the period when only devices are needed to be activated with respect to user's living/power consumption pattern. While dynamically generating the policies and service patterns with respect to the energy and service states, CHEMS can minimizes the energy and system resource consumption.

3. Light-weight middleware support: We present the light-weight middleware which supports the energy-aware services. The proposed light-weight middleware is based on

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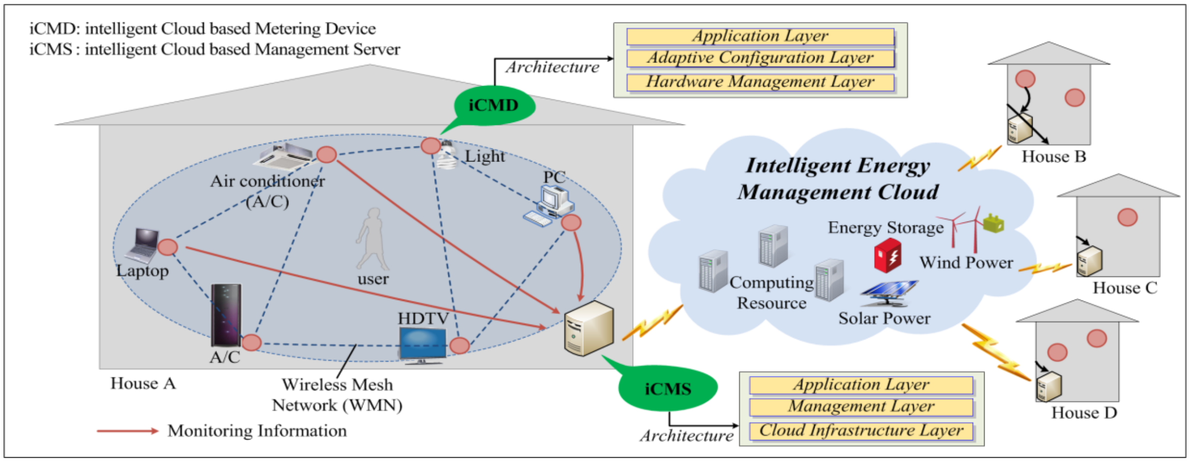

Fig. 1. Overview of intelligent Cloud-based Energy Management System (iCHEMS).

the learning mechanism which analyzes the schedule and activity of users, and also the power consumption state of devices. By grouping similar context models and pattern clustering based on user life styles, CHEMS facilitates the effective pattern learning. Then, it dynamically reconfigures the middleware on the devices that support load-balanced ubiquitous push services.

4. Extensibility and scalability: As new kinds of sensing devices, data sources, and new user activity patterns are continuously becoming available, the system is easily able to extend the service coverage to support more users. Moreover, the interface of the proposed system shouldn't be limited to a specific type of sensor connectivity. We developed a light-weight middleware and its self-configuration schemes which allow an embedded device to be reconfigured with respect to its new environment.

Furthermore, based on its pattern generation, distributed service reasoning and service prediction, it seamlessly offers the personalized and localized energy management services to residents with higher service satisfaction.

II. Related Work

A. Home Energy Management System

HEMS is an emerging technology which monitors, analyzes and controls devices such as heating, ventilating, and air conditioning (HVAC) system to reduce power consumption and CO2 emissions.

Many researchers proposed the ZigBee based HEMS systems [4]-[6]. These systems controls and monitors home appliances. In these papers, especially ZigBee (IEEE 802.15.4 standard) technology was used for implementation of HEMS, due to low-power and low-cost features of ZigBee technology. On the other hand, Son *et al* [7] presented HEMS based on power line communication (PLC). Zhao *et al* [8] presented a building energy management system (BEMS) by using a multi-agent decision-making control methodology. Nguyen *et al* [9] dealt with advanced load management strategies for BEMS. This paper suggested a real-time control using wireless sensor network. Wei *et al* [10] proposed an adaptive home/building energy management system (A-HEMS/BEMS) for managing power consumption by using the convergence of heterogeneous sensor/actuator networks. Mineno *et al* [11] proposed the system framework for building energy monitoring and analysis system based on the packet data network.

B. Electricity Smart Meter

A smart meter is an advanced metering device that can be used to measure energy consumption and can communicate this information to other devices. The smart meter is the most important component of advanced metering infrastructure (AMI) that connects HEMS and a smart grid that optimize the production, distribution, and consumption of electricity [12]. Kung *et al* [13] proposed a fuzzy-based adaptive approach to measure electric power, and also RMS (root mean square) voltage and current using a genetic algorithm (GA). Benzi *et al* [14] presented the definition of a local interface for power meters and the specific architectures for a proper consumer-oriented implementation of a smart meter network. Silva *et al* [15] proposed a data mining framework for the exploration and extraction of actionable knowledge from data generated by electric power meters. On the other hand, security is an important issue in the design of the smart meter. Kim *et al* [16] suggested a secure smart-metering protocol, considering several important aspects of security and authentication such as key management, secure transmission, and device authentication.

III. Intelligent Cloud-based Energy Management System

The current intelligent HEMS can provide smart services such as a user-centric service based on context-awareness, a power distribution service based on demand forecasting, or an autonomous energy management service based on the M2M communications. The provision of these intelligent HEMS will lead to the usage of enormous computational and storage resources as mentioned above. To deal with these problems, we propose a novel home energy management

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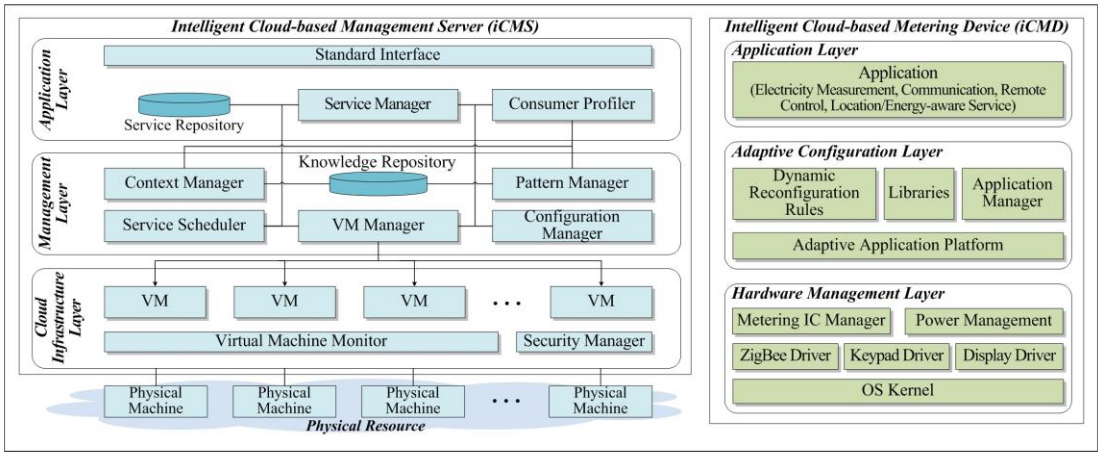

Fig. 2. Architecture of iCHEMS (iCMS and iCMD).

system i.e. CHEMS. In this section, we present the overall system architecture of CHEMS.

A. Overview of CHEMS

Fig. 1 shows an overview of CHEMS which consists of an intelligent cloud-based management server (iCMS) and an intelligent cloud-based metering device (iCMD). The main features of our system are as follows:

1) CHEMS uses cloud computing methods to process complex tasks that require enormous computational and storage resources.

2) CHEMS has the capability to manage local renewable energy.

3) CHEMS should consider energy reduction by the optimization of sensing, processing, and transmission of M2M nodes.

4) CHEMS provides users with user-friendly location- and situation-based push energy management services in order to enhance user interaction and energy efficiency.

B. Architecture

Fig. 2 illustrates the system architecture of iCMS. iCMS needs to be reconfigured to allocate additional or release unneeded resources and appropriately reorganize the deployed software, hardware, middleware components. iCMS consists of three architectural layers: application layer, management layer, and cloud infrastructure layer.

1) Application layer: This layer creates the instances of energy management service model. This layer plays a role in service analysis, service decision, service creation, service configuration, and service management. This layer includes all components related to applications which run in the cloud. This layer consists of a service manager, a consumer profiler, a service repository and a standard interface.

- Service manager analyzes requested services and interprets the service requirement of a consumer's request. When the service is requested, the service manager determines which system resources are suitable and how many system resources are needed.
- Consumer profiler gathers the information about the consumer (e.g. user or device). The information contains user's preference, location, energy consumption, etc.
- A user requests a service and the system provides a service through standard interface.

2) Management layer: This layer controls the process related to the provision of cloud and context-aware services. This layer consists of a context manager, a service scheduler, a VM manager and a configuration manager.

- Context manager gathers information about the circumstances and manages this information.
- Service scheduler determines resource entitlements for the allocated VMs. In other word, the service scheduler determines when VMs should be added or released to meet the service requirement.
- VM manager consists of an accounting manager and an energy monitor. The accounting manager checks the actual resource usage and accounts for the cost. The energy monitor analyzes energy consumption of VMs and physical resources. It enables iCMS to perform the energy-efficient resource allocation.
- Configuration manager controls all the essential parameters related to the system configuration. These parameters include the size of the virtual resources, the cloud infrastructure provider to use, or the software component.

3) Cloud infrastructure layer: This layer controls and manages the hardware/software resource in the physical level resource. This layer applies virtualization technology to hide the characteristics of the physical resources. This layer also should consider security issues caused by cloud computing. This layer consists of VMs, a virtual machine monitor, and a security manager.

- VMs dynamically run and stop on multiple physical resources.
- Security manager guarantees confidentiality, integrity and authentication. It provides strong isolation.

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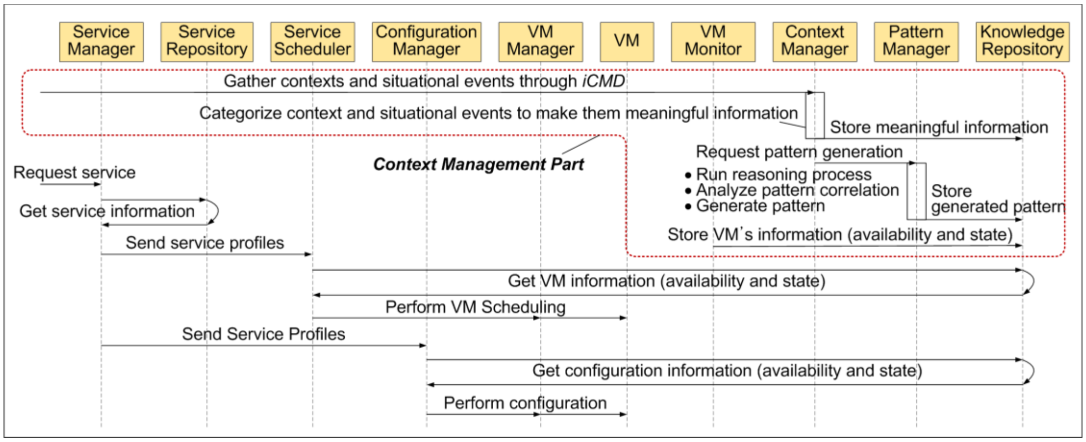

Fig. 3. Sequence diagram of provisioning cloud computing servcie.

- Virtual machine monitor observes the availability and state of VMs.

The physical resource is composed of the physical level resources such as computing, storage, power, and network resources.

On the other hand, iCMD consists of an application layer, an adaptive configuration manager, and a hardware management layer. The application layer is mainly used for service analysis, service decision, service creation, service configuration, and service management like the application layer of iCMS. The adaptive configuration manager controls and manages the rule-update process. The administrator modifies or updates the rules through the administrator mode of the iCMD. The hardware management layer has the role of managing the various hardware modules such as a metering IC, a ZigBee tranceiver, a display driver, etc.

C. *Cloud Service Based on Situation-Awareness*

Fig. 3 shows a sequence diagram for provisioning a cloud service according to the situational and environmental events in iCMS. The light-weight middleware operates the learning mechanism and predicts the personalized service with regard to the policy modification and the energy management. The sequence diagram divides into two independent parts that is context management part and cloud management part.

1) Context management part: The iCMS receives contexts about an environment and situations such as power consumption and a user's movement through the iCMD. The context manager then analyzes and categorizes the gathered contexts and situation event to make them meaningful information and stores them in the knowledge repository. On the other hand, the pattern manager performs reasoning task (through the inference engine), pattern correlation task (through the pattern correlator), and pattern generation task (through pattern generator). The pattern is generated based on the user's situations, the power consumption, and the service history. This pattern is used for the provision of energy management based on prediction to the local use. This generated pattern is stored on the knowledge repository.

2) Cloud management part: The cloud computing is an important property of this system. The user requests energy management service through a mobile device. The proposed platform interconnects the heterogeneous devices and networks for scalability and interoperability. When a user moves to another location, this middleware verifies the meaning events and predicts the pattern-based service. The intelligent device creates the passive events and offers active service, called push service, to user based on the interconnection. The procedure of the cloud management part is as follows.

First, the user sends requests for a service to iCMS. This request is passed to the service manager. The service manager requests the service repository to send the service profiles which include a service requirement (i.e. required virtual resources).

Second, the service manager transmits the service profiles to the service scheduler to perform the scheduling i.e. resource entitlements. The service profiles are passed to the service scheduler that employs this information to request the virtual infrastructure creation. The service scheduler requests the knowledge repository to send information about the VMs (e.g. availability and state of the VMs). When receiving this information, the service scheduler determines resource entitlements for the allocated VMs. That is, it determines when VMs should be added or released to meet the service requirement.

Third, the service manager transmits the service profiles to the configuration manager to perform the configuration according to the infrastructure's conditions. The configuration manager manages all the essential configuration parameters, such as the size of the virtual resources, the cloud infrastructure provider to use, or the software component parameters. The configuration is composed of three processes which are pre-configuration (VMs are configured before they are started), post-configuration (VMs are configured after they are started), and re-configuration (VMs are configured as a result of topological changes). To perform these configuration steps of a component, the configuration manager retrieves the

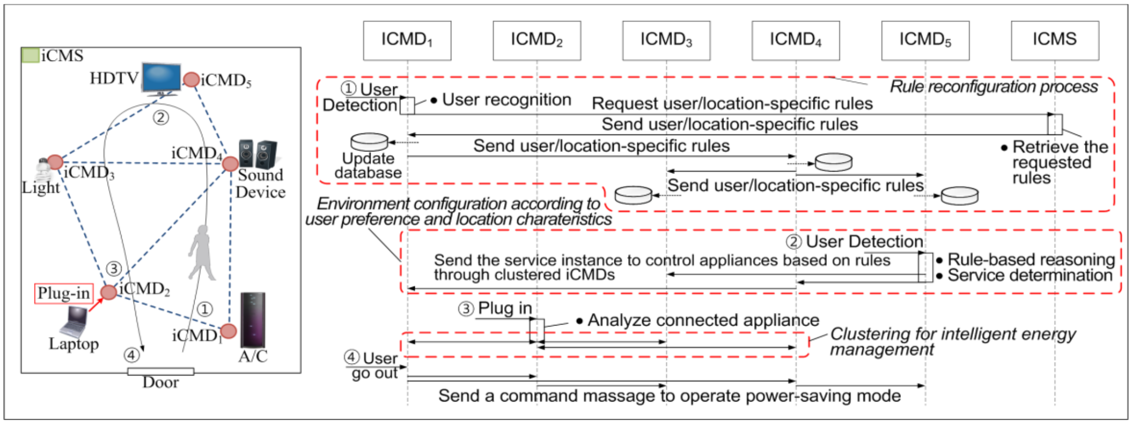

Fig. 4. Interoperation flow of a home energy management service scenario.

related configuration description from a knowledge repository, and performs the configuration.

In this section, we will show a simple service scenario to explain interoperation among both multi iCMDs and between iCMD and iCMS. Fig. 4 shows interoperation flow of a simple home energy management service scenario.

1) Rule reconfiguration: Alice enters the room. iCMD1 detects and recognizes Alice through interaction between iCMD1 and Alice's handheld ZigBee transceiver. iCMD1 then requests iCMS to transmit user/location-specific rules. When receiving the requests from iCMD1, iCMS retrieves the requested rules from the knowledge repository and sends the user/location-specific rules to iCMD1. iCMD1 then updates database and transmits these user/location-specific rules to adjacent iCMDs.

2) Environment configuration according to user preference and location characteristics: Alice walks towards HDTV in order to watch a movie and turns on the HDTV. iCMD5 performs rule-based reasoning and determines a

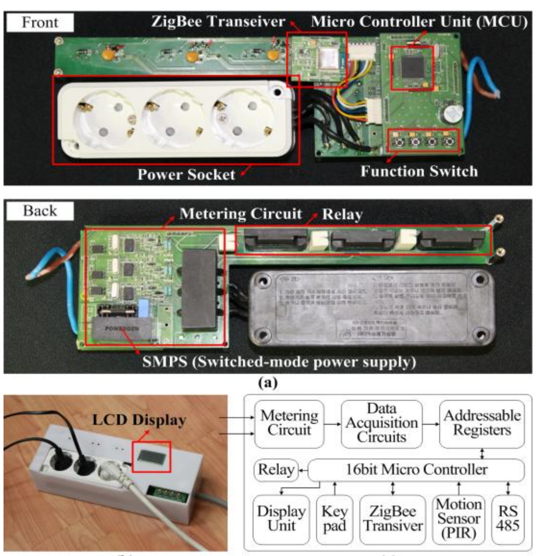

Fig. 5. Prototype of ICMD; (a) PCB layout, (b) prototype, and (c) hardware block diagram

service. It then creates a service instance.

3) Clustering for intelligent energy management: According to the location-aware clustering, iCMDs interconnects with iCMDs which are located in same location. When an iCMD detects the user movement or the energy consumption, the iCMD requests the cooperation of energy management service to clustered iCMDs.

4) operation in power-saving mode: If iCMD1 perceives that Alice goes out the room, the iCMD1 sends all the iCMDs a command message to operate in power-saving mode.

IV. IMPLEMENTATION

Fig. 5 shows a prototype and a hardware block diagram of iCMD. Same hardware components as reference [17] are used except for the micro controller unit (MCU). In this paper, the 8-bit MCU instead of the 16-bit MCU is used as the main processor, because of the reduction of the production cost. A 250 kbps/2.4 GHz ZigBee transceiver module is used for communication. The metering circuit is used for measurement of the power consumption and monitoring the power state. The power group consists of the SMPS and power regulation circuit. A variety of information such as power, voltage, and current as well as temperature and humidity is displayed through the LCD display unit. The relay plays a role in shutting off the standby power and remote control.

V. EXPERIMENT AND RESULTS

A. Test-bed

We deployed CHEMS in the real home service test bed to estimate its efficiency. We analyzed the proposed mechanism according to various scenarios at real homes and enhanced the correctness of the proposed system according to user activity patterns and service scenarios. The results presented in the following were collected from 1 month dynamic experiment, where 20 iCMDs and various appliances (TVs, VCRs, humidifiers, microwave ovens, air conditioners, PCs and etc.) in our test bed. We tested three

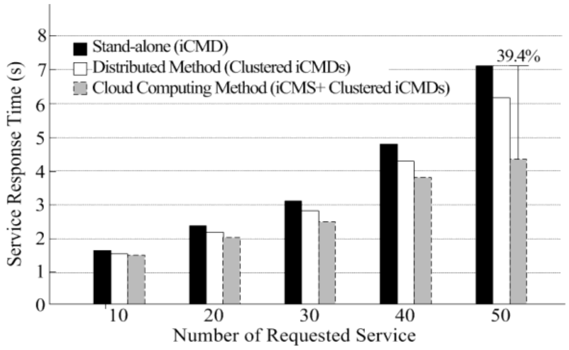

Fig. 6. Comparison of the service response time.

types of power control systems in the experiment environment.

B. Experiment and Results

Headings Fig. 6 shows the service response time by the number of requested service for home energy management. The results show that the proposed system reduces the service response time up to 39.4 percent. Even though the number of requested service increases, the proposed system maintains certain levels of delay of the home energy management due to resource allocation through iCMS. The proposed system gradually decreases the slope of the service response time according to the efficient management of metering data, and resource allocation and configuration. However, stand-alone iCMD rapidly increases the service response time due to the overhead from the increasing number of metering data and control messages.

VI. CONCLUSIONS AND FUTURE WORKS

We designed and implemented CHEMS considering new trends of HEMS which require interoperable user-centric services to the green home domains. We utilize a cloud computing concept to deal with various problems of the existing systems. We implemented and evaluated the proposed system in the real home test bed. The results show that the proposed system reduces the service response time up to 39.4 percent. We are planning to implement efficient authentication and authorization mechanisms for the reliable service domain interconnection and pattern generation.

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