Development of LED Smart Switch with Light-weight Middleware for Location-aware Services in Smart Home

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Abstract — *In recent years, the home network has focused on service diversity and the intelligent enhancement of devices for providing user-centric services. Recent studies dealing with home network systems aggregate the sensor data and manage various devices for reasoning the adaptive services. However, home network systems, especially intelligent devices, are difficult to implement due to the high setup cost and the problems with interconnection among other devices in a home domain. Therefore, we consider the intelligent implementation of light switch present in whole spaces. We propose a LED Smart switch with light-weight middleware which provides location-aware service and pattern-based service prediction. The proposed switch with an embedded sensor manages active and passive events according to the sensor data analysis and the service reasoning. Furthermore, the LED smart switch locates the user and interconnects among other switches over a network connection. The smart switch using a LED display provides simple information service, such as weather forecast, stock information, and the light status, using icons and digitalized voices. To evaluate the efficiency of our switch, we implemented testbed, in a home and an office. Our switch reduces the service response time by up to 12% for our experiment*[1].

Index Terms — smart switch, location-aware service, light-weight middleware, distributed scheme

I. INTRODUCTION

Recent concerns [1] into home networks are aimed at context aggregation, context analysis, as well as the service prediction. Current home network systems [2], [3] focus on the enhancement of the system and sensor intelligence for increasing the service accuracy and efficiency. The enhancement of the system intelligence provides for powerful service reasoning and management. However, these systems have the problems inherent to a centralized scheme, such as system overloads, event process bottlenecks, and the excessive use of system resources. Recent works [3], [4] on sensor network provide an increase of information accuracy (including the environmental context change, the unpredictability of device control, and the interrupt) and the monitoring of the user mobility. However, such systems do not offer service diversity but instead offer context management by deploying sensor networks without various device controls. Therefore, intelligent devices [5] with a distributed scheme in a home is necessary in order to reduce service configuration delays and enhance the location-aware service more effectively. The current intelligent devices have these problems as follow:

- Different network interfaces: The individual devices are not able to interconnect to the other types of devices due to the limited and specific support of network interfaces.
- Too heavy-weight or tiny-weight middleware: Most types of the existing intelligent devices with heavy middleware provides the web crawling services, the user-centric services and the device control services instead of the home server. In other hand, another type of the current devices offers the simple device control and the web crawling without the event analysis and the service reasoning.
- A separate structure from the sensor network: The existing intelligent devices deal with the service reasoning and the device control according to the contexts aggregated from sensor network. Therefore, the devices need to interoperate with the sensor network or the system.

We must consider how to make the devices more efficient in order to reduce the deployment cost and enhance the service configuration. According to the characteristics of the space, different devices and networks exist at each location. However, the light and the light switch exist in most spaces, especially in a home. When a user enters a location, he or she finds the light switch and controls the light, first of all. The current switches simply control the device (turn it on or off). Therefore, we propose a LED Smart Switch which has the following features:

1. ***Distributed scheme***: If the smart switch is installed in all spaces they then can control the location-specific contexts and services. Furthermore, the switches can interconnect among the other switches and transmit the device/service/environment status by network connections. They consume less system resources and provide faster service prediction than the centralized scheme due to the light rule-based reasoning and the distributed context/service/device management.
2. ***Network convergence***: In accordance with the various network connections, the LED smart switch provides device control and information services. The network connections among the switches facilitate seamless services and dynamic service reconstruction. Through the network convergence the LED smart switch enhances the efficiency and the scalability of the location-aware service.

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3. ***Location-aware service***: The switch is able to reason the adaptive services according to the characteristics of the spaces and the users. The specific location has the static patterns of the service request, the user mobility and the device control by the user requirements. For instance, an inhabitant usually turns the light on and sits for a long time in the study. Thus, the location-aware system can generate more efficient patterns and event analysis. When a user goes to work, the switch located by the front door shows and speaks the weather information to a user. Furthermore, the switch confirms the whole device status and autonomously controls the devices to provide energy-saving service.
4. ***Energy-aware service***: The switch with an embedded sensor collects the sensor data, the user movements and the illuminance. The LED smart switch controls the devices, turning them on/off and adjusting the brightness. When a user moves to another location, the switch controls the devices and confirms the service status for an energy QoS guarantee. Furthermore, the switch uses a LED display with an event-driven sleep-awake mode.
5. ***Active/passive event with the embedded sensor***: With regards to the event (service request, motion detection, illumination change, interrupt and touch motion), the switch analyzes the contexts as well as generates the service patterns. The switch has the roles of a sensor, an intelligent system and a device controller.
6. ***Light-weight middleware design***: The device and switch with small-scale system resource and memory have difficulty in effectively managing excessive contexts and services. In the home, due to the lesser frequency of collisions and the sudden situation changes, the light-weight middleware provides an efficient service configuration.

Our proposed LED smart switch based on network convergence provides remote device control, location-aware service and efficient service prediction according to the distributed context/service/device management. The LED smart switch has a low deployment cost and interoperates with the current system, infrastructure and networks. Our switch with light-weight middleware generates service rules and patterns according to the analysis of the location-aware contexts without a huge consumption of system resources. According to the light-weight middleware and the rule-based service prediction based on the service history, the switch can decrease the pattern generation delay and the service reasoning time. In addition, we designed the LED display to use the touch motion detection and show the preference information by icons. The switch with the embedded sensor does a more efficient context analysis than the separate system (sensor networks and appliances with switches) in the home.

In the rest of this paper, we first discuss the related works about the home network systems and switches in the home domain. We subsequently propose a LED smart switch with light-weight middleware. We then present the LED smart switch implementation. We subsequently evaluate the performance in the testbed. Finally, we present our conclusions and our ideas for future works.

II. Related Works

A. Centralized Home Network System

The current home network systems [6], [7] manage the tremendous amounts of contexts, policies, and rules for providing the best service. Thus the system consumes a lot of system resources due to the need to analyze the contexts. Many research works focus on the service reasoning, the event analysis and the sensor deployment for providing the intelligent services in the home. Centralized systems are categorized into three types based on their architecture and purpose.

First, the context-aware system [8] focuses on the context aggregation and modeling based on the sensor network. The current system considers how the contexts are effectively represented and how the undefined events decrease. Most of the previous systems provide an inefficient service configuration and have excessive context management. The efficiency and quality of service (QoS) guarantee of a system depends on the number and performance of their devices. Therefore, the role of the devices is more important than the role of the sensors for enhancing the QoS guarantee.

Second, the main goal of the agent-based system [9], [10] is its powerful reasoning mechanism. The agent analyzes the situations and then determines the service according to huge rules, policies and conflict solutions. However, in the home which has the less conflicts and services, the system must consider the tradeoff of the service accuracy and the service efficiency.

Last, the location-aware system [11], [12] continuously gathers and manages the sensor data for offering seamless service by user detection. This system stores and analyzes the whole contexts, patterns, events and interrupts in the home. However, the excessive event processes may lead to an increase in the resource consumption and frequent unnecessary policy modifications. To adequately support efficient services the system needs to construct the distributed environments.

B. Remote Controller and Switch

According to the appliance characteristics, various remote controllers and switches exist in the home. Recent works on the remote controller and switch provide various device controls, called the multi-in-1 controller/switch. In [13] and [14] the remote controller manages various appliances by using the Zigbee protocol. However, these systems focus on the device control and the network connection without the consideration of the service prediction using context management. On the other hand, this specific remote controller[15] offers context aggregation and device management. Though it has the context management, this controller does not consider the service prediction and the device interconnection.

Inhabitants want to use the remote control service and the autonomously seamless service created by the device interoperability. Therefore, we select not the specific device and controller but the light switch for providing the location-aware service and the enhancement of the service efficiency. The smart switch with the light-weight middleware controls the lights as well as the networked appliances. The smart switch with the embedded sensor aggregates the events and maintains the services. The switch in a distributed manner manages the location-aware contexts, services and rules. Furthermore, the smart switch increases the efficiency of the system according to the generation of simple patterns and rules using the limited contexts.

III. System Architecture

The LED smart switch with the light-weight middleware enhances the efficiency and scalability of the system. The switch, using the network interconnections along with other switches, can offer various device controls, including the light control, in multiple locations and a seamless the location-aware preference information service.

The system architecture of the LED smart switch has three characteristics, as follows:

1. ***Service and user living pattern generation with sensor data aggregation***: The smart switch uses a simplified learning mechanism based on the Hidden Markov Model. The switch generates the location-aware patterns with regard to the space characteristics, user movement, illuminance, time and service requests. When the switch detects the event (device control, service reconfiguration, environmental context change, etc.), it reconstructs the service patterns and rules.

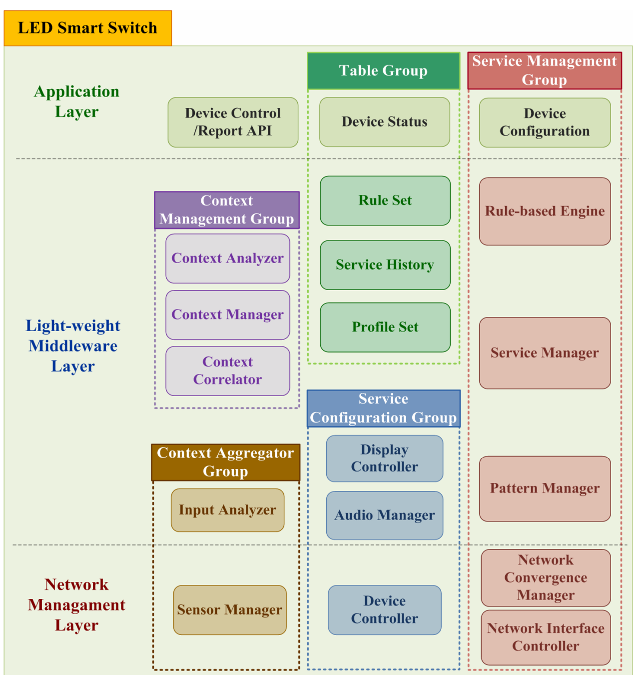

Figure 1. Architecture of the LED smart switch with the light-weight middleware

2. ***Adaptive device control with rules***: The smart switch provides the device control and the service configuration according to simplified service rules without the definition of complex correlations and collision management. The system [12] excessively consumes the system resource which control the lights according to the analysis of the user movement monitoring and the prediction of the user activity. With regard to the user movement detection and the service rule the proposed switch offers device control (e.g. turn on/off, and brightness adjustment) and information services.

3. ***Service policy based on space characteristics***: The inhabitants have different usage purposes and movement patterns in every location. The users prefer different brightness and have different movement frequencies according the space characteristics. Our system provides location-aware services to the users by using service rules for increasing the service efficiency.

A. Light-weight Middleware

Fig. 1 shows the LED smart switch with the light-weight middleware in a smart home. Our system does not provides the whole service reasoning, including the service management, but a simplified service prediction, including an event analysis for the deployment of the switch using low system resources. Our middleware consists of five groups.

- ***Context Aggregator Group (CAG)***: This group collects the contexts (events, interrupts, sensor data, manual inputs, service requests, etc.) or the information. This group classifies the input data and the event according to the input type. Sensor Manager gathers the sensor data and manages the sensor status, sleep-awake modes, according to the service patterns. Input Analyzer analyzes the meaning of the touch motion and service request. Input Analyzer also receives the sensor data from Sensor Manager and transmits the events to Context Management Group.
- ***Context Management Group (CMG)***: This group analyzes the contexts, including the input data and the events. It then determines whether the switch providers the service configuration, or not. Moreover, this group stores the contexts to Table Group and monitors the contexts (service history, profiles, rules, policies, service/device status and events). Context Analyzer classifies the contexts and analyzes the environmental changes. Context Manager transmits the contexts, the service status and the environmental status to Table Group. Context Correlator imbues the raw data with signification of correlation and then manages the correlation among the contexts.
- ***Table Group (TG)***: This group stores the contexts by their classification, such as the rules, service history, profiles and status. In addition, this group transmits the contexts including the correlations to Service Management Group and receives the new contexts containing the

generated patterns, rules and service status. This group also stores the device status and manages the service patterns with device control messages. Rule Set manages the service rules (e.g. a long-term touch is emergency call, etc.) and the system rules (e.g. interrupt processes, reasoning procedures, pattern modifications, etc.). Service History stores the service and device status used for generating the service patterns. Profile Set manages the registered characteristics of spaces, users and devices. Profile Set classifies the types of space and sets up the correlation with the service rules.

- ***Service Management Group (SMG)***: This group has the main function of service prediction and determination using the network connections. This group reasons the service by the service rules, events and patterns. Furthermore, this group maintains the service status and reconfigures the services by the interrupts while the service is offered. According to the new events, this group determines whether the service and device status changes, or not. For providing seamless service and a QoS guarantee, this group connects to other smart switches/devices/systems using network convergence. Rule-based Engine predicts and reasons the adaptive services by the service rules and policies. This engine validates the correlation between the event and the service pattern received from TG. Service Manager manages the service status and the environmental contexts. If CAG receives a illuminance change, the service manager will cooperate with the rule-based engine and control the light. When a user moves to another location, this manager determines the transmission of the service status. Pattern Manager generates the service patterns, the living patterns and the service rules. With regard to the service and event history received from TG, this manager connects the service patterns with the rules/policies/correlations. Network Convergence Manager controls th heterogeneous status of the switches, networks and services in a scalable fashion. This manager verifies the network status and selects the adaptive topology for maintaining the network connection. Network Interface Controller selects the adaptive network interface and maintains the network status.
- ***Service Configuration Group (SCG)***: This group configures the services and devices according to the device controls. Device control provides the vibration, voice, display as well as the information query. This group transmits the control message to an adaptive device or interface by the service reasoning and determination. Display Controller manages the display (such as turn on/off, color change, brightness change and the icon information service). This module interconnects with a Web crawler and matches the icon up with the contexts collecting the preference information. Audio Manager converts the preference information to a voice file and transmits it to the users through the speaker. Device Controller transmits the control message to the adaptive device using Network Convergence Manager and Network interface Controller.

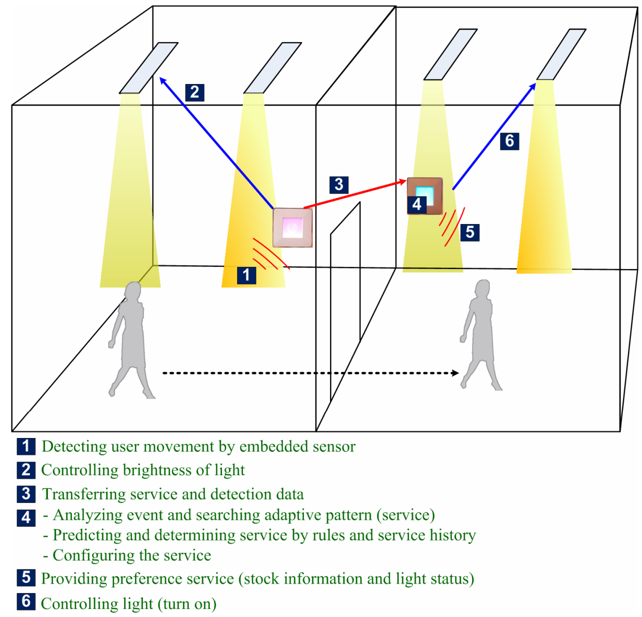

Figure 2. The LED smart switch interconnection and service configuration

The LED smart switch using the light-weight middleware controls the devices and maintains the services by its self-configuration rules and patterns. Our proposed switch has a more efficient service configuration and a faster service response time due to the distributed scheme, pattern-based service prediction and location-aware service management.

B. System Interconnection Flow

The LED smart switch dynamically configures the service according to the network connections among the other switches and the rule-based service prediction. Fig. 2 and 3 show the service reconstruction done by the user movement detection. In Fig. 2, the switch detects the user movement and then monitors the service status. When a user moves to another location, the switch adjusts the brightness of lights and transmits the service status to another location's switch by the network connection. If a user enters to the location, the switch will verify the service status and previous location's contexts. The switch then controls the lights and provides the preference service (e.g. stock, news, weather information, etc.) to the user. To provide seamless and location-aware service, the LED smart switch predicts the pattern-based service with regards to the user movement detection, environmental context change, space characteristics and the service status. If a new event is a repetitive one, the smart switch provides the service, including various device controls, faster and more efficiently than the first event analysis.

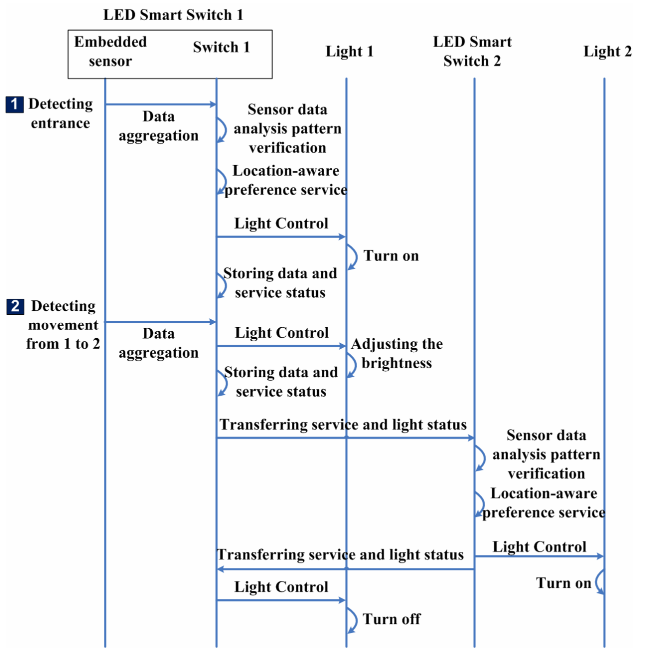

Figure 3. Device control flow by the detection

As shown in Fig. 3, the LED smart switch with the embedded sensor aggregates the location-aware detection events and analyzes the environmental and situation contexts. For matching the correlations and generating the patterns, our proposed switch, using the simplified rule-based engine, continuously stores the service/movement/event history and manages the service.

Fig. 4 shows the two types of user requests, the switch touch and the service request using the handheld device. With regard to the user request, the LED smart switch reasons the service and determines whether the service collides with other devices and services, or not. The service request is able to control the devices, receive the preference information and

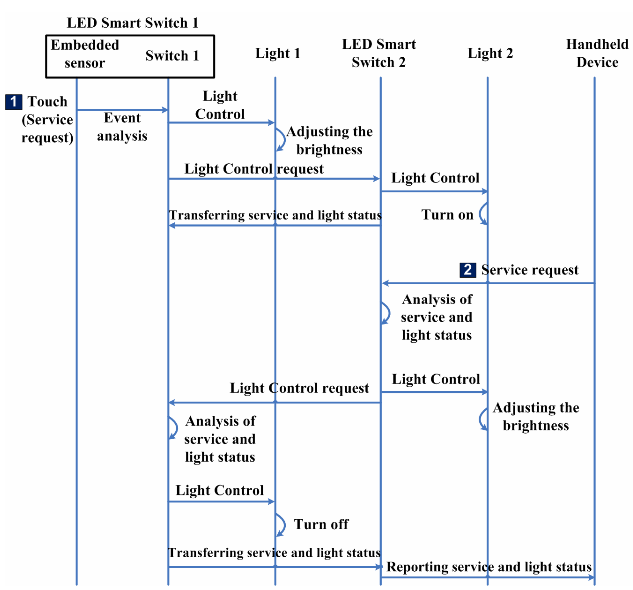

Figure 4. Device control flow by the service request

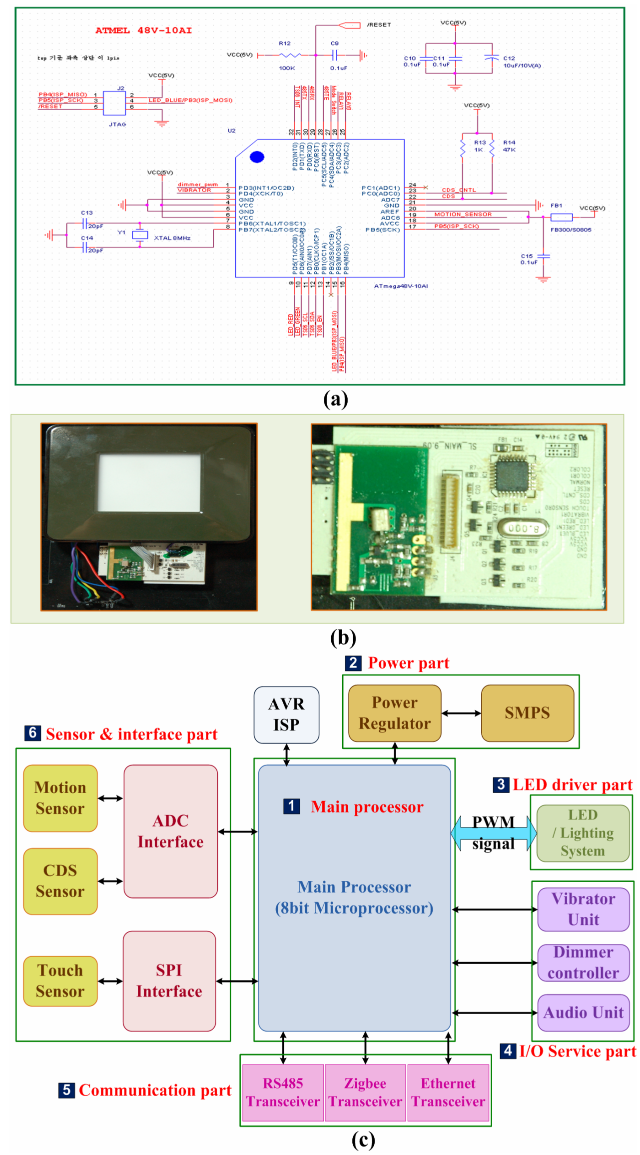

Figure 5. LED smart switch (a) main processor (b) hardware structure and (c) block diagram of hardware

offer a specific service, such as an emergency call. According to the touch status containing the time, direction and location, the smart switch or dimmer switch, provides different services. If a user wants to command using the remote control, he/she will use one's handheld device using the network convergence. In the case of a remote control command, the smart switch verifies the service status and confirms the service contexts to the user.

IV. System Implementation

A. Smart Switch Implementation

Fig. 5(a) shows a main processor circuit diagram of the LED smart switch. The hardware structure of the LED smart switch is shown in Fig. 5(b). The LED smart switch was implemented as an intelligent device (switch) with 128Kbytes of Flash, 4KBytes of SRAM and a 4KBytes of EEPROM. We also implemented the light-weight middleware based on OSGi platform and the rule-engine using the OSGi bundle.

Fig. 5 (c) shows the LED smart switch structure which includes five parts: the main processor, the power part, the LED driver part, the I/O service part and the communication part. The block diagram of the hardware structure of the LED smart switch is as follows.

- The main processor controls the other parts of the smart switch and uses an 8bit microprocessor. They are made up of various ports that include the Dimmer control, the vibration sensor, the LEDs for the backlight (red, green, blue), the touch control, the ISP connection, the motion sensor and the illumination sensor, etc.
- The power part has a power regulator and a SMPS that is flexible for the deployment of various LED arrays. The LED driver, containing the constant current controller chipsets drives the LEDs and the lighting system according to the generation of the LED's characteristics.
- The I/O service part consists of the vibration sensor, the dimmer controller that uses the touch motion, and the audio unit. Our switch enhances the QoS and increases the service diversity according to these various I/O units.
- For interconnections among other devices (like a LED smart switch in another space, mobile, status, etc.), the communication parts is composed of RS485, ZigBee and Ethernet modules.
- The sensor & interface part needs to organize the motion sensor (detection of user movement) using a radio frequency (RF) sensor, an illumination sensor (for the energy saving efficiency), a CDS sensor and a touch sensor for enhancing the QoS.

Table I shows the detailed specifications of the LED smart switch.

B. LED-based and Location-aware Services

As Fig. 6 shows, the LED smart switch provides location-aware service through the LED display, vibrator and speaker. Fig. 6 (a) shows the differential service according to the user movement detection and the illuminance. For instance, when the user enters into a dark space that has a low illuminance, the smart switch turns on the LED display and the light with high illuminance. Our proposed switch uses the LED display and provides the energy-aware service by a light rule-based service prediction and LED control.

TABLE I THE LED SMART SWITCH SPECIFICATIONS

Parameter	LED Smart Switch
Memory	128Kbytes Flash, 4KBytes SRAM, 4KBytes EEPROM
Communication	RS 485 Multi-drop, Zigbee, Ethernet
OS	uCOS-II 2.76
Middleware Platform	OSGi R3(Prosyst mbs 5.2)
Rule Engine	Light-weight rule engine (OSGi Bundle)
Database	MemoryDB
Sensor	CDS sensor, Motion sensor, Touch sensor (QT160)

(c)

Figure 6. Implementation of the LED smart switch (a) light control service (b) preference service (e.g. weather) and (c) installing the LED smart switch in the testbed

Fig. 6(b) illustrates the weather information icon. When a user goes out, the smart switch confirms the weather information to the user. Moreover, when a user touches the display using a predefined motion, the switch provides emergency calls, the energy-saving service, or an alarm service by the shape of the icon. The user touches the smart switch and receives the vibration and voice services.

V. PERFORMANCE EVALUATION

A. Testbed and Experimental Environments

For the efficiency estimation we implemented our device to a real home and office. The LED smart switch is connected to the network through the Ethernet and the Zigbee. We also

TABLE II THE CENTRALIZED HOME SYSTEM SPECIFICATIONS

Parameter	Centralized Server
Memory	2GB memory
Communication	PLC, WLAN, Zigbee, Ethernet
OS	Window XP
Middleware Platform	OSGi R3(Prosyst mbs 5.2)
Inference Engine	Reasoning and Rule-based Engine (OSGi Bundle)
Sensor	CDS sensor, Motion sensor, Touch sensor, Camera sensor

analyzed the proposed switch according to various situations. We applied real patterns of user movement and service requests to the testbed. Our proposed switch detects the illuminance, touch motion and user movement. We tested 2 types of home systems in the experiment's environment.

We also implemented a home server [16] with a centralized scheme. Table II shows the specifications of the centralized server. In the experiment, we verify the efficiency of our scheme in comparison with the centralized scheme.

B. Evaluation Results

Fig. 7 shows the service response time of the two types; the centralized scheme and the distributed scheme. Fig. 7 (a) illustrates the average delay from the event creation to the service configuration in each element. Our proposed switch has a significant difference in comparison with the centralized system in the event detection, the service prediction and network interconnection delay. With regard to the distributed scheme which manages the individual contexts, events and services, our switch with the light-weight middleware is more efficient in the

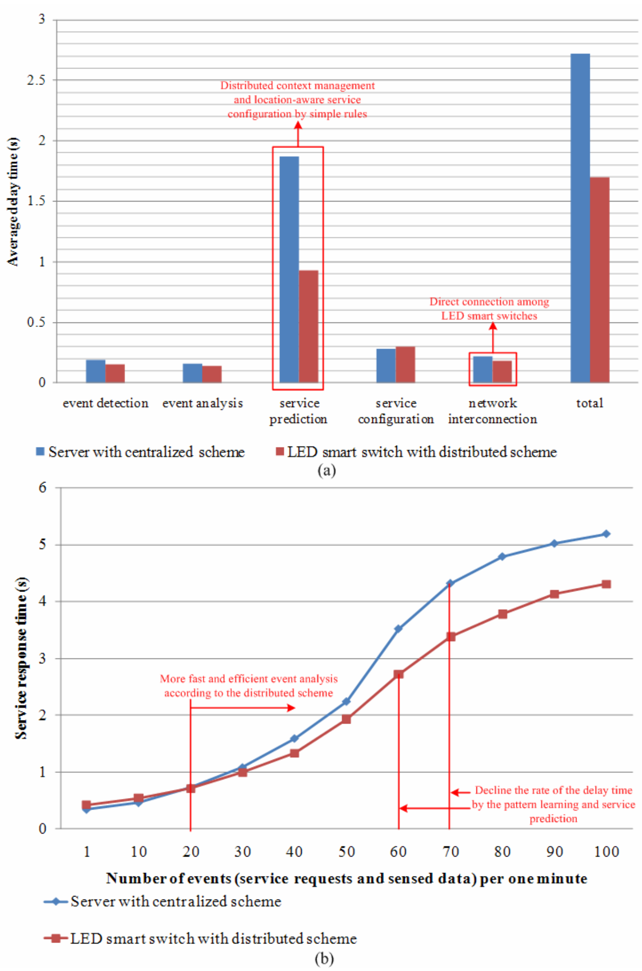

Figure 7. Service response time with and without LED smart switch (a) average delay time (b) service response time

context management used for generating the patterns. Furthermore, due to the lesser amount of event management and the simplified rule-based service configuration, our system is faster for service prediction than the home server.

Fig. 7 (b) shows the service response time according to the number of events. Even though the user movements and the sensor data increased, the proposed system has a lower increase rate of the service response time. With regard to the efficient event analysis and service prediction, our switch is slowly increased. It is easy to see that under the conditions (up to 20 users) our switch is able to guarantee the adaptive services with a shorter delay than with the centralized system. The experimental results illustrates that the service response time can be reduced by up to 18%. Moreover, when the number of events increase, our system is more efficient than the centralized system. Therefore, we can apply our switch with light-weight middleware to a home as well as to large-scale spaces.

VI. Conclusions and Future Works

In the last decade, the business models for the home network are evolving from a total system with a centralized server, into various consumer electronics. For enhancing the QoS guarantee, we do not consider the service diversity but the number of devices. Therefore, new trend is tending from how much information the system manages to how many devices the system controls, which leads to the design of intelligent devices with a distributed scheme.

In this paper, we propose an LED smart switch with light-weight middleware to manage the location-aware service more efficiently. Our proposed switch predicts the adaptive services with regard to the user movement detection, illuminance monitoring and the location-aware service pattern using network interconnection. Furthermore, the switch provides a seamless service and an energy-saving service according to the cooperation among other switches and an efficient event analysis. The light-weight middleware reduces the excessive consumption of system resource, the processing delay and the event analysis. We implemented the LED smart switch in a real testbed and evaluated the experimental results. The service response time of our switch with the distributed scheme is reduced up to 18% compared to current home systems with a centralized scheme.

We are currently working on the tradeoff between the efficiency and the QoS guarantee for enhancing user satisfaction. Moreover, we are studying the conflict and authentication management in order to apply the smart switch to large-scale spaces. We are developing various intelligent devices and switches, to be used as new consumer electronics.

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