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RESTful Design and Implementation of Smart Appliances for Smart Home

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***Abstract*—The world is changing and we are moving towards the day when everything will be network accessible, named 'Internet of Things (IoT)'. The growing popularity of IoT leads various services such as healthcare, connected car, smart education and smart home services. Among these services, smart home becomes commercialized most rapidly. We developed the Smart Home Protocol (SHP) to enable connectivity between various our smart home devices including smart appliances, LED bulbs, IP cameras, etc. In this paper, we present an overview of the SHP based on RESTful architecture, followed by a detailed description of architecture and application profile for smart home devices. We also introduce our smart home services and describe the implementation of smart home protocol in smart appliances. To our understanding, this study is important, since it is a basis for enabling connectivity between our smart home products as well as those from other device and appliance manufacturers. We believe this work plays an important role for designing and implementing smart home devices such as smart appliances.**

Keywords- smart home; smart appliance; restful architecture

I. INTRODUCTION

The world is changing and we are moving towards the day when everything will be network accessible, named 'Internet of Things (IoT)'. The growing popularity of IoT leads various services such as healthcare, connected car, smart education and smart home service. Among these services, smart home becomes commercialized most rapidly.

Smart Home is to make the home environment comfortable and fully automated by connecting home appliances, and other electronic devices and sensors through specific wired/wireless connectivity technologies. Smart home devices include TV sets, air conditioners, refrigerators, washers, door locks, IP cameras, LED light bulbs, ovens, and smart home sensors include those that monitor the indoor environment such as smoke detectors, temperature, humidity, etc. Through a total smart home solution that encompasses all smart home devices, customers will be provided with a convenient, ease-of-use, harmonized user experience.

Once connected, these devices and sensors can be monitored and controlled by home occupants through ubiquitous client devices such as smart phones and tablet computers. Once such an interconnected ecosystem of devices and sensors is in place, it would then be possible to offer home occupants value-added services such as home energy management, home security and safety, remote monitoring and control, etc. In the future, a smart home device ecosystem might include wearable sensors to monitor the physiological parameters of home occupants such as heart rate, blood pressure, etc.

In response to the growing interest of customers about smart home, Apple and Google, which are the leaders in mobile OS platform, recently introduced smart home platform. This smart home platform will allow customer easily to control various connected products using devices that run on their mobile OS platform. Some service providers such as AT&T and Verizon have begun offering home automation and home security solutions that lease networked systems of devices in a subscription model instead of selling individual solutions.

In this paper, we present our smart home protocol (SHP) to enable connectivity between various our smart home devices. SHP defines new open APIs for smart home devices with IP connectivity. SHP follows RESTful API design principles, meaning that SHP uses standard HTTP methods to retrieve and manipulate resources of devices.

The objective of this paper is to introduce our SHP API. So, we first present an overview of the SHP and then focus on the design principles of API for our smart appliances among various functional components of SHP. We also present detailed description and examples of RESTful API. We believe this work plays an important role for designing and implementing smart home devices such as smart appliances.

The rest of this paper is organized as follows: In Section II, we first provide an overview of existing home automation protocols, and then we categorize and summarize recent activities of major players in the field of smart home and IoT. In Section III, we provide an overview of our smart home protocol, followed by a detailed description of RESTful application profile for smart appliances. In Section IV, we introduce our smart home services and describe implementation of RESTful API developed in smart home applications and smart appliances for smart home services. We conclude this paper in Section V.

II. RELATED WORK

Several home automation protocols have been developed to control home appliances, lighting and home energy systems. In recent years, smart home automation technologies have been moving into the mainstream and garnering wider customer acceptance. In response to the growing interest of customers about a smart home, big companies such as Qualcomm, AT&T, Comcast, Intel,

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Google, and Apple announced their own solution and framework for smart home.

A. Home Networking Protocol

Currently, several different home networking protocols co-exist in the smart home. Among these are ZigBee, Bluetooth, Wi-Fi, and the privately developed Z-Wave. Wi-Fi is the most commonly used for in-house connectivity. Bluetooth is widely used in consumer electronics and health devices, while ZigBee has emerged as a technology leader for home automation, energy management and smart meter devices. We summarize below, some key standards and interoperability initiatives worldwide that show a reasonable adoption rate.

- ZigBee is a set of application level protocol specifications based on the IEEE 802.15.4 home area network (HAN) standard to enable smart home applications that involve reliable, secure and interoperable communication and control between low-power, low data rate, long battery life wireless sensors and a range of smart devices in a connected home. The ZigBee protocol is being developed under the aegis of the ZigBee Alliance, an open, non-profit association of members comprised of businesses, universities and government agencies. Some of smart home enabling applications profiles being developed by the ZigBee alliance include the smart energy profile, the home automation profile, etc.

- Z-Wave is a wireless communications protocol designed for smart home automation applications. Z-Wave uses low power RF radios embedded or retrofitted into home electronics devices and systems, such as lighting, home access control, entertainment systems and household appliances. While currently Z-wave is more popular than ZigBee for home automation applications, many industry experts caution that Z-wave suffers from some fundamental limitations when compared with ZigBee including Zigbee has lower latency (10 msec) and higher throughput than Z-wave (latency 100 msec). While Z-wave has some mesh networking capability, it is not as robust as Zigbee's mesh capability. Z-wave might claim superior interoperability, but it's a single source vendor and not a consensus type standard. Z-Wave operates in the 908.42 MHz in unlicensed ISM in the U.S. and Canada but uses other frequencies in other countries depending on government regulations. The Z-Wave protocol is developed under the aegis of Z-Wave Alliance, an international consortium of smart home device manufacturers.

- Wi-Fi, a trademark of the Wi-Fi Alliance, is designed to enable connectivity between devices such as a personal computer, video game console, smartphone, or digital audio or video player. Such devices connect to the Internet when within range of a wireless network connected to the Internet. The alliance has generally enforced its use to describe only a narrow range of connectivity technologies including wireless local area networks (WLAN) based on the IEEE 802.11 standards, device to device connectivity such as Wi-Fi peer to peer, and a range of technologies that support personal area networks (PANs) and local area networks (LANs). In recent years, there have been efforts to utilize Wi-Fi for home energy management applications such as automated control of programmable thermostats etc. The Wi-Fi Alliance is a global non-profit industry association of hundreds of leading companies devoted to seamless connectivity. With technology development, market building, and regulatory programs, the Wi-Fi Alliance has enabled widespread adoption of Wi-Fi worldwide.

B. Smart Home Market Trends

The growing smart home market presents an opportunity for service providers, retail, and device manufacturers alike.

We have seen a number of device manufacturers introduce smart home products. Phillips introduced a smart LED light bulb called "Hue". Nest Labs introduced its first product, the Nest Learning Thermostat, and recently introduced its second smart home device, the Nest Protect smoke and carbon monoxide detector.

Some mobile/broadband service providers including Comcast, Time Warner Cable, AT&T and Verizon, have begun offering complete and externally managed home automation and home security solutions that lease networked systems of devices in a subscription model together with externally managed services instead of selling individual solutions. Mobile operators, providing mobile broadband connectivity to complement fixed broadband, will also be able to leverage femto cells to provide a home gateway to control smart home devices.

Security service providers such as ADT, Securitas Direct, Vivint and a multitude of smaller firms are also offering home security solutions. They are educating their prospects and subscribers about the benefits of home automation for enhancing security. U.S retail stores such as Lowe's, Best Buy, most recently, Staples and Amazon launched major initiatives to attract consumers to purchase their smart home products.

Energy providers including Centrica (British Gas and Direct Energy), E.ON, and NRG are leading the energy saving plan to raise consumer awareness of home energy management solutions. For example, Nest Labs is partnering with several energy providers in the U.S. to offer more than 90 million people the opportunity to earn money and save energy.

C. Emergence of New Smart Home Platforms

It is also becoming increasingly clear that no one smart home technology provider can succeed and dominate the smart home market on their own, partnerships throughout the value network are required for success. In other words, the success of smart home cannot be driven by a single company. In order to put together an attractive solution of smart home, there needs to be collaboration among companies.

Apple and Google, which are the leaders in mobile OS platform, recently introduced smart home platform. Apple introduced Homekit, a smart home platform, at their developer conference. This smart home platform will allow customer to control various connected devices such as door lock, LED light, garage door and thermostat. Partners of HomeKit include Philips, OSRAM, iHome, Haier, SkyBell, August Smart Lock, Kwikset Smart Key, Broadcom, Netatmo, and Honeywell. Honeywell already developed a digital automatic temperature control system based on HomeKit.

Google, which dominated the mobile market through its Android operating system (OS), is now targeting smart home businesses. Nest Labs, acquired by Google, opened its smart home platform and announced the developer program to third-party developers and partners. The program already has a number of partners including LIFX light bulbs, Whirlpool, Jawbone, and Mercedes-Benz.

D. *Emergence of New IoT/Smart Home Initiative*

There have also been several activities for establishing an alliance for smart home and IoT such as AllSeen, OIC (Open Interconnect Consortium), and Thread.

The AllSeen alliance was launched to create standard for IoT in December 2013, using AllJoyn technology. The AllJoyn is an open source application framework for a proximity-based device-to-device communication and was initially developed by Qualcomm. It uses mesh networking to create connection among connected products regardless of manufacturers of devices, and can automatically discover devices and negotiate connection which whichever wireless protocol are available. The member companies of AllSeen alliance include Qualcomm, LG, Microsoft, Panasonic, Haier, etc.

The OIC is also a new industry consortium focused on improving interoperability and defining the connectivity requirements for the billions of connected devices. It was founded by Intel, Samsung, Broadcom, Dell, etc.

Thread has been most recently announced by its founders including Nest Labs, Samsung, ARM, freescale, etc. Thread's main goal is to develop a new and better wireless networking protocol to connect products in the home. While all three alliances are standard bodies, Thread focuses on a wireless network protocol, while AllSeen and OIC are working on IoT platforms.

III. SMART HOME PROTOCOL

In this section, we provide an overview of our smart home protocol (SHP), followed by a detailed description of RESTful API for smart appliances.

A. *SHP Overview*

SHP is designed to provide cloud-based seamless smart home services. Figure 1 depicts high level architecture of SHP, composed of controller devices, controlled devices, and cloud server. As shown in figure, controller device is an entity which can control controlled devices using communication functionality. Generally the controller device can interact with the controlled devices via the cloud server or directly using D2D (Device-to-Device). Further, the Controller device may access and control controlled devices from outside of home network via the cloud server.

The Controlled device is an entity that has communication functionality with other smart home service entities like a controller device and/or a gateway/cloud server via a variety of wireless methods (e.g. Wi-Fi, ZigBee, Z-Wave, etc.). For example, home appliances such as air conditioners, washers, refrigerators and door locks, LED light bulbs could be a controlled device. According to connectivity capability, the controlled device can be categorized into an IP-based device and non-IP device. In SHP, it is assumed that IP-based device is a Wi-Fi supported device and non-IP based device is ZigBee or Z-Wave supported device.

It is assumed the controller device supports only Wi-Fi connectivity. In case of smart phone, it can use the mobile network also. Thus the controller device can directly connect to Wi-Fi smart home devices only. In the case of connection with non-IP controlled devices, IP based SHP protocol shall be translated into non-IP protocol such as ZigBee/Z-Wave via the bridge device.

Figure 2 depicts the structure of our SHP stack and services. SHP uses TCP/IP as a transport protocol and adopts HTTP RESTful interface in order to provide service extensibility and interoperability.

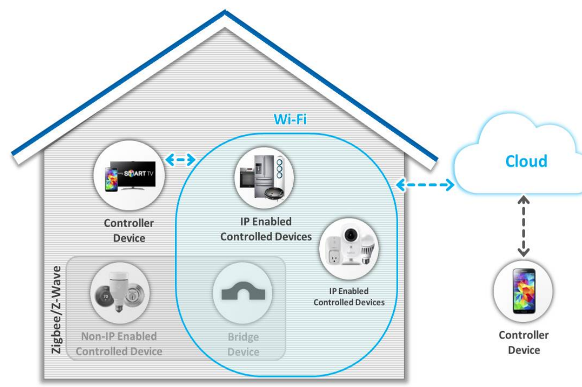

Figure 1. High level architecture of SHP.

Our smart home services can be divided into largely five parts: easy setup, registration, control, event notification and remote access. Easy setup is a procedure by which the controller device assists new controlled device to access the home network. Registration is a procedure by which the controller device assists the controlled device register to the cloud server. Control is a procedure by which the controller device acquires smart home device information and controls the controlled device based on information acquired. Event notification is a procedure by which the controlled device informs specific event to the controller device. And remote access is a procedure by which a remotely located controller device gains access to the home network via the cloud server and then controls controlled devices.

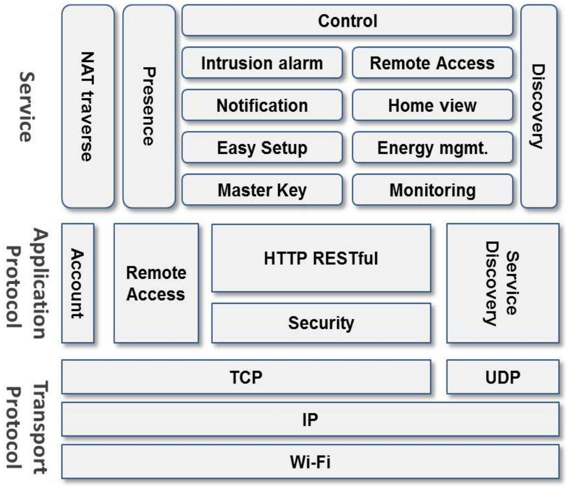

Figure 2. SHP stack and services.

B. *RESTful Architecture*

SHP follows a RESTful API design, meaning that SHP uses standard HTTP methods to retrieve and manipulate resources. RESTful is a style of software architecture for distributed systems such as the World Wide Web. More precisely, RESTful architecture is a stateless client-server architecture in which the web services are viewed as resources and can be identified by their URIs. Clients initiate requests to servers; servers process requests and return appropriate responses. Requests and responses are built around the transfer of representations of resources. A resource can be essentially any coherent and meaningful concept that may be addressed. A representation of a resource is typically a document that captures the current or intended state of a resource.

Within SHP, we define a server as the device that hosts a resource, and the client as the device that obtains, extends, updates, or deletes representations of that resource. Devices may be both clients and servers. Clients poll servers to obtain representations of the current state of a resource, and take action based on that state.

RESTful applications use HTTP requests to post data (create and/or update), read data (e.g., make queries), and delete data. Thus, REST uses HTTP for all four CRUD (Create/Read/Update/Delete) operations. Supported HTTP methods are: GET, POST, PUT, and DELETE. The following table summarizes the actions taken on an SHP defined resource for the possible set of received HTTP methods.

TABLE I. RESTFUL API HTTP METHODS

Methods	Collection URI, such as http://example.com/resources/	Element URI, such as http://example.com/resource/item
GET	**List** the URIs and perhaps other details of the collection's members.	**Retrieve** a representation of the addressed item of the collection.
PUT	**Update** the multiple addressed item of collection.	**Update** the addressed item of collection.
POST	**Create** a new entry in the collection. The new entry's URL is assigned automatically and is usually returned by the operation.	Not allowed in SHP.
DELETE	**Delete** the entire collection.	**Delete** the addressed item of the collection.

HTTP v1.1 is the default supported version of HTTP. Responses to HTTP methods follow the rules defined by HTTP. The SHP protocol makes use of specific response codes to indicate success of a request (2XX class) or failure of a request or other error scenario (4XX and 5XX class).

C. *Data Model*

All of the resources identified within SHP API are directly addressable using a resource URI. Actions taken on the resource are indicated by the HTTP method that is received by the RESTful SHP server that has as the URI a valid resource URI. Figure 3 shows the example of resource sets defined for an air conditioner device.

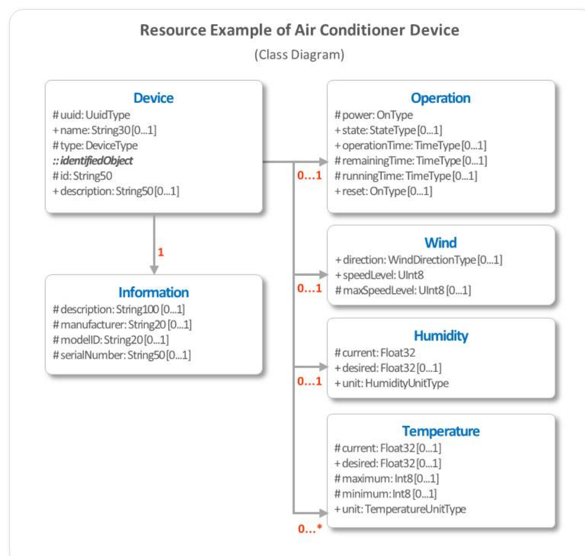

Figure 3. Example of resource sets defined for an air conditioner device.

Resource has two kind of attribute in aspect of updatable. In data model, '+' marked attributes can be updated by client's request and '#' marked attributes can be updated only by server itself. The client can only read '#' marked attributes. Attributes defined in resource are mandatory by default. To specify that the attribute is optional, "[0..1]" is used.

Figure 4 shows the example message format when the client sends the control command to the air conditioner device. All resources in SHP are made up of a set of attributes. When details about a resource are provided over SHP, either in a response to a request or in a request itself, these attributes are sent and returned in JSON (JavaScript Object Notation) with UTF-8 encoding.

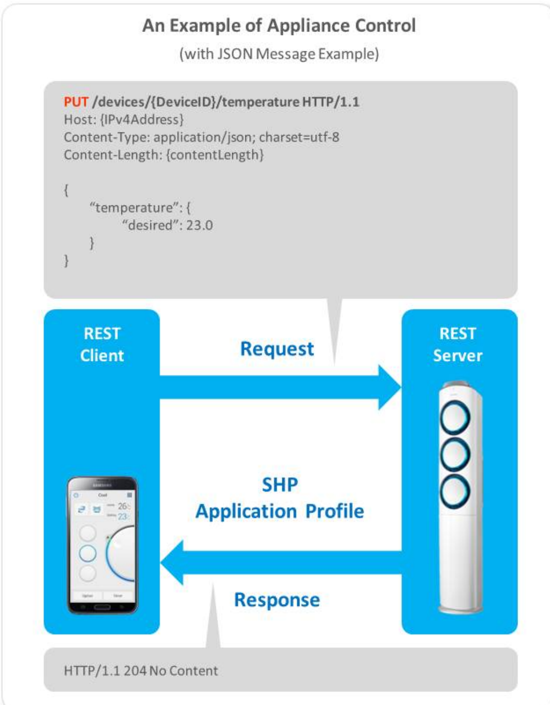

Figure 4. An example of appliance control.

IV. IMPLEMENTATION OF SHP

In this section, we introduce our smart home services and describe the implementation of RESTful API developed in smart home applications and smart appliances for smart home services.

Our smart home services provide three main service features that are described below.

- Customized Device Control: With device control, customers can use customized settings on their mobile devices or Smart TV to monitor or control home devices (e.g. turning on air conditioning or activating lighting) while inside or outside the home, or even while travelling abroad. In addition, customers can control multiple controlled devices simultaneously through an integrated application no matter where they are. For example, when a user toggles the "Going Out" button on in application, selected appliances and LED lighting are turned off.
- Home Monitoring: Customers can use their smart phone to receive real-time views of a home via controlled devices such as IP cameras.
- Smart Customer Service: This service notifies users in real-time when it's time to service appliances or replace consumables and provides assistance in after-sales servicing.

Figure 5 and 6 show the screenshots of smart home application for smart TV and smart phone, respectively. Using the smart home application developed based on SHP RESTful API, customers can easily connect with various connected home devices including refrigerators, washing machines, air conditioners, dryers, ovens, robot vacuum cleaners, lighting and more through smart phones/tablets, smart TV, and wearable devices from anywhere.

Today, there are two major mobile OS platform: iOS and Android. Application developers usually develop their application for both iOS and android. Our smart appliances are operated on proprietary platform. In addition, other device and appliance manufacturers also have their own platform. If there are no standardized application profiles for smart devices with Wi-Fi connectivity, it is too difficult to develop application that run on various OS platform. As explained in previous section, our application profile designed based on RESTful architecture is platform-independent and language-independent. All devices and applications mentioned above can be implemented using same application profile.

To our understanding, this study is important, since it is a basis for enabling connectivity between our smart home products as well as those from other device and appliance manufacturers. We also have a plan to expand the Smart Home service to cover home-energy, secure home access, healthcare, and eco home applications through the partnerships with third-party service providers in these sectors, helping foster joint commercial opportunities and grow the connected home service marketplace.

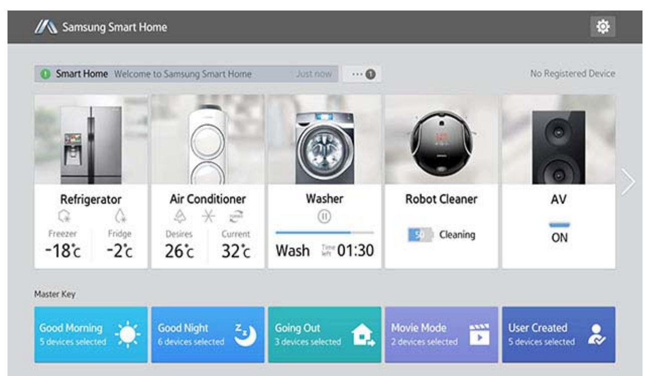

Figure 5. Screentshot of smart home application in smart TV

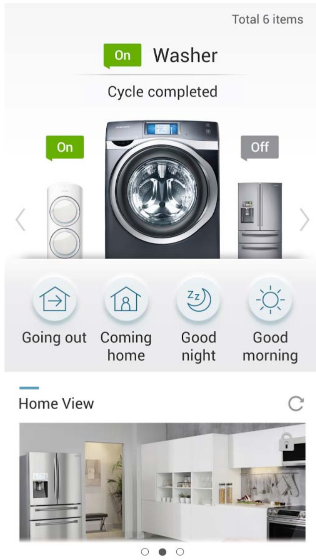

Figure 6. Screentshot of smart home application for mobile smart phone

V. Conclusion

In this paper, we have summarized recent activities of major players in the field of smart home and IoT. We present an overview of our smart home protocol (SHP), followed by a detailed description of architecture and RESTful API for smart appliances. We also introduce our smart home services and describe the implementation of smart home protocol in smart appliances. To our understanding, this study is very important, since it is a basis for enabling connectivity between our smart home products as well as those from other device and appliance manufacturers.

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