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Citation	2016 IEEE 5th Global Conference on Consumer Electronics: 1-5
Issue Date	2016
Type	Conference Paper
Text version	author
URL	http://hdl.handle.net/10119/14277
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Description	

Management Architecture for Heterogeneous IoT Devices in Home Network

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***Abstract*—The Internet of Things (IoT) is being hailed as the next industrial revolution and it promises billion of IoT devices connected to the Internet in the near future. Emerging networking and back-end support technologies not only have to anticipate this dramatic increase in connected devices, but also the heterogeneity of devices. To this end, a management architecture which combines current management approaches to manage devices in the home network is presented. By inheriting advantages of these approaches, the proposed architecture is able to support multiple device classes, enables management services for time sensitive devices and sleepy devices, mitigates home gateway bottleneck issues and enables local management in the home network. To validate this architecture, a prototype based on the proposed architecture for managing ECHONET LITE devices and Constrained Application Protocol (CoAP) enabled devices was developed.**

***Index Terms*—intelligent gateway, direct management, indirect management**

I. Introduction

With the development of Machine to Machine (M2M) technology, a myriad of heterogeneous devices are expected to be connected to the IoT in the near future. Heterogeneity is one of the fundamental characteristics of the IoT because devices are heterogeneous as they are based on different hardware platforms and networks [1]. The task of managing such an enormous number of heterogeneous devices is very challenging.

In particular, there are two common approaches for managing devices in home networks: direct and indirect management. The main difference between them is the involvement of the home gateway (HGW) for management purposes as shown in Fig 1.

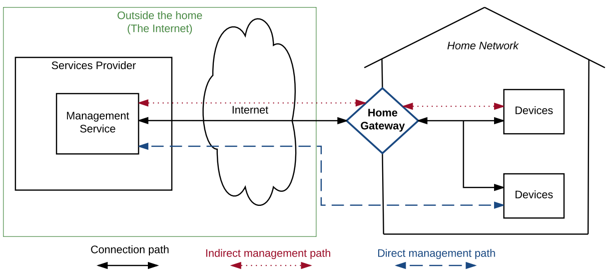

Fig. 1. Home network services architecture

Each of these approaches has its own advantages and application profiles. Currently, many research efforts focus on the management of IoT devices. One such approach is applying direct management as shown in [2]. By implementing LWM2M - a remote device management standard, IoT devices can be directly managed. However, this architecture can only manage devices which enough resources to support a direct connection to the Internet in a secure manner, and can not support multiple device classes which is a high priority requirement in the management of constrained devices [3]. Another approach focuses on indirect management [4] by applying a light version of SNMP [5] and NETCONF [6]. This approach can support multiple device classes from very constrained devices to less constrained devices. However, heterogeneous devices are treated as homogeneous devices, thus wasting device resources and can not deal with the heterogeneity of devices.

In this research, a management architecture which combines current both direct and indirect management approaches to benefit from their advantages is proposed. The prosed architecture is able to deal with large numbers of heterogeneous devices in a home network. To prove the feasibility a prototype based on proposed architecture was implemented.

The rest of the paper is organized as follows. Section II describes characteristics of direct and indirect management and device heterogeneities as well. Section III and IV detail the home gateway design approaches and the proposed architecture. Section V describes the implementation of the prototype based on the proposed architecture. Experiment results are described in section VI. Finally, conclusions and future researches are described in section VII.

II. Background

A. Indirect Management

In indirect management, devices in the home network are firstly managed by a hierarchical topology via the HGW, then these device resources will be managed by management services via the internet. The HGW can handle issues related to incompatible communication protocols, and low-power or constrained devices which can not communicate with the management services directly. Therefore, this approach enables management services for multiple device classes and communication protocols. The HGW enables management of devices

TABLE I
CLASSES OF CONSTRAINED DEVICES

Name	Data size (e.g. RAM)	Code size (e.g. Flash)
Class 0, C0	<<10 KB	<<100 KB
Class 1, C1	~ 10 KB	~ 100 KB
Class 2, C2	~ 50 KB	~ 250 KB

TABLE II
STRATEGIES OF USING POWER FOR COMMUNICATION

Name	Strategy	Ability to communicate
P0	Normally-off	Reattach when required
P1	Low-power	Appears connected, perhaps with high latency
P2	Always-on	Always connected

as a group, thus simplifying maintenance, configuration and improving management scalability.

B. Direct management

In contrast, direct management enables management services manage devices directly without any involvement of the HGW. The management applications and the management agent communicate directly, without the need for intermediate processing of data by the HGW. Thus in turn simplifies the design of the HGW, achieves better performance and lowers latency between devices and service providers. For devices that primarily exchange real-time sensory and control data in small but numerous messages, direct management should be preferred due to the aforementioned advantages.

C. Device heterogeneity and applicable management approaches

The problem of device heterogeneity spans a wide range of aspects, but this research focuses on the heterogeneity in terms of (i) device characteristics and (ii) communication patterns.

1) Device characteristics: In [7], devices are classified by many aspects. However, there are two main aspects which impact on management: (i) memory and processing capabilities and (ii) strategies for power usage because the existing management technologies utilize the different protocol stacks and the different protocol stacks consumes different amount of memory and power. Table I is the classification of devices according to RAM and storage. Devices which belong to class 0 can not be managed in direct management approach due to they are very constrained devices and do not have the resources required to communicate directly with the Internet in a secure manner. However, both direct and indirect management approaches can be applied to devices which belong to class 1 or class 2.

The general strategies regarding power usage for communication can be categorized as in Table II. Low-power or normally-off devices should not be managed in direct management approach due to they can not maintain the connection with the management service.

2) Device's communication patterns: In [8], the four basic communication models demonstrate the underlying design strategies used to allow IoT devices to communicate are outlined in Fig. 2.

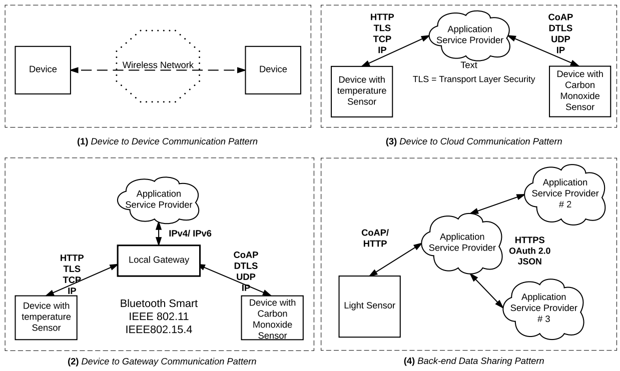

Fig. 2. Device communication patterns

Devices which utilize device-to-device or device-to-gateway communication pattern must be managed using indirect management approach because they can not support direct connection to the internet. However, indirect management approach can not be applied to devices which utilize device-to-cloud or back-end data sharing pattern.

The summary of devices and their applicable management approach can be seen in Table III.

This analysis shows that a management architecture which combines both management approaches to benefit from their advantages to keep up with the heterogeneity of devices is needed.

III. DESIGN DISCUSSION

As recommended in [9], every device in the home network must be connected to the HGW and be indirectly managed. However, direct management now is also applicable to the home network. Basically, the proposed management architecture is based on the recommended architecture presented in [9] that combines both direct and indirect management approaches. The management service architecture is depicted as in Fig. 3.

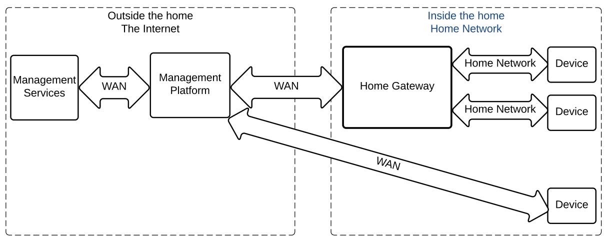

Fig. 3. Management service architecture

In the home network, devices can either be connected and controlled by the HGW or directly managed by the Management Platform (MP). To present a management architecture, we have to clarify how can the MP directly manages device, how can the HGW locally manage home network and which approach is used by the HGW to sync home network data to the MP.

TABLE III

DEVICES AND CORRESPONDING MANAGEMENT APPROACHES

	Direct management	Indirect management
Suitable devices	Device to Cloud communication pattern supported devices	Device to Device communication pattern supported devices
	Back-end data sharing communication pattern supported devices	Device to Gateway communication pattern supported devices
	Class 1 devices, Class 2 devices	Class 0 devices, Class 1 devices
	Always-on devices	Normally-off devices, Low-power

As in [10], there are two common approaches to implement a HGW: simple gateway and intelligent gateway. In general, a simple gateway forwards data from local network to the MP without any data processing. It is simple but it burdens the MP and the devices in the home network must incorporate a management agent task. In contrast, intelligent gateway extends the functionality of the simple gateway by providing processing resources and intelligence for handling local data. Although the design of such HGW is substantially more complex, it can reduce complexity and cost for end devices and the MP.

IV. PROPOSED ARCHITECTURE

The proposed architecture is based on intelligent gateway approach, the HGW could evaluate and filter data from the home network. After evaluating data, the HGW could determine whether a critical threshold has been passed. If so, the HGW can produce some action to locally handle this event or alert an appropriate manager. Enabling intelligence in a gateway addresses both interoperability issues on a local level while minimizing the changes required to connect appliances. Rather than require full intelligence in each appliance, the gateway can provide the base intelligence for all devices. The proposed method is depicted in Fig. 4.

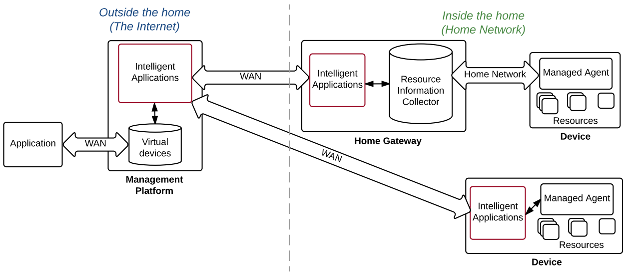

Fig. 4. Proposed architecture

Each device has its own Managed Agent. The managed agent on the device is responsible for configuring and gathering device information. Indirectly managed devices are connected to the HGW and provide information or execute instruction to and from the Resource Information Collector in the HGW.

The HGW has Intelligent Applications (IAs) which process data from the Resource Information Collector to provide management functions. The IAs at the HGW connect to the IAs at the MP to exchange data. After that the data is stored into a database as logical devices and these logical devices are provided to the applications or services to be treated as web resource.

Directly managed devices are not managed by the HGW but directly by the MP. Each device has its own Managed Agent to collect device information. The Intelligent Applications of devices handle the collected data for local management and exchange resources with the MP.

V. IMPLEMENTATION

To validate the feasibility of proposed architecture, a prototype to manage a home network which contains ECHONET LITE [11] devices and CoAP [12] enabled devices was developed. The overview of this prototype is presented in Figure 5.

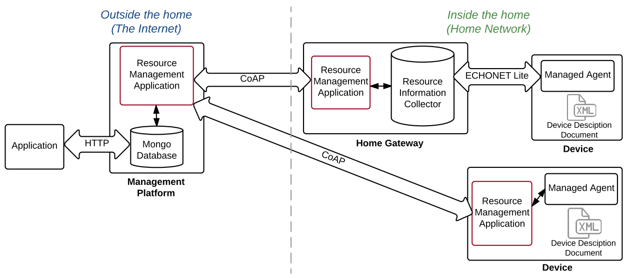

Fig. 5. Prototype overview

Two kinds of devices can be managed by this prototype. Each device has a Device Description Document (DDD) which is an XML document that contains device resources. Managed Agent interacts with devices through this DDD. The managed agent on the device executes configuring and gathering the home environment information following the instructions of the Resource Information Collector on the HGW.

The HGW manages devices in the home network using ECHONET Lite protocol. The Resource Information Collector has functions to collect and convert ECHONET Lite data into readable data and also convert commands and configuration information then apply to devices.

Resources will be processed by Resource Management Application to provide management functions such as: monitoring devices, configuring devices, observing devices, etc. The HGW communicates with the MP to exchange data for management and interact with users using CoAP protocol.

The resource management application on the MP provides the function to gather information of the home network resources which the managed agent directly sent to it or passed from the HGW . It also manages the internal status of the device, the network device and the network capacity for each of the HGW. The information is stored into the database as virtual devices.

Web interface interacts with the database at the MP to provide the graphic user interface (GUI) for users. It also provides functions to allow users interact with the HN devices.

A. *Message structure*

1) ECHONET Lite message structure: The message structure of ECHONET Lite devices which referred from [13] is described in Fig. 6.

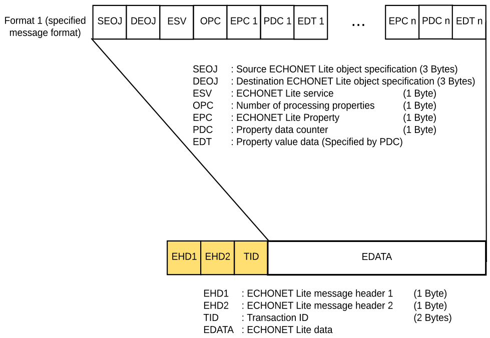

Fig. 6. ECHONET Lite message formart

ECHONET Lite Header 1 is a 1-byte value specifies ECHONET protocol type. EHD1 with value **00010000** indicates ECHONET Lite protocol. **ECHONET Lite Header 2** is a 1-byte value indicates format of EDATA filed. There are two options : **10000010** (EDATA is in arbitrary message format) and **10000001** (EDATA is in Format 1 as describing in Figure 6). **TID** is a 2-byte transaction ID parameter that matches the request and response. **EDATA** is variable-length ECHONET Lite data field of message exchanged between ECHONET Lite devices.

2) CoAP message structure: The message structure of CoAP enabled devices which referred from [12] is described in Fig. 7.

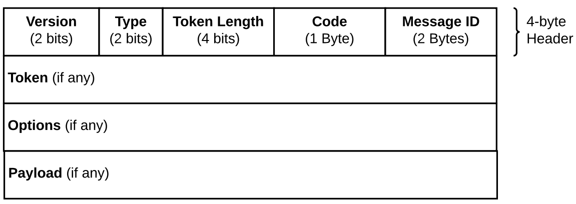

Fig. 7. CoAP message formart

CoAP message starts with 4-byte header followed by a 0 to 8 bytes **Token**. Following the **Token** is **Options** in Type-Length-Value format followed by a **Payload**.

VI. Experiment and Result

To measure the efficiency of the proposed architecture, an experiment has been made and the network diagram of this experiment is shown in Fig. 8.

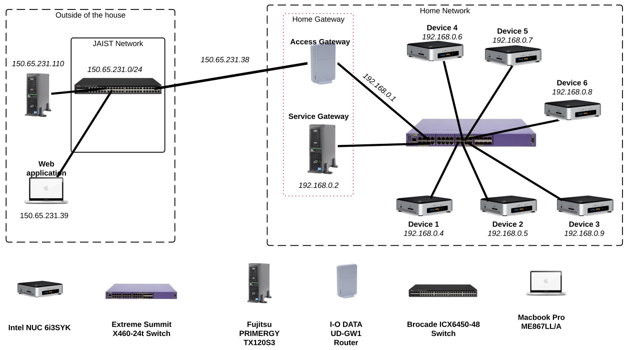

Fig. 8. Experiment network diagram

- **Time measurement**

	Direct Management	Indirect Management	Proposed Architecture	
			Direct management	*Indirect management*
RTT to register resources	136 ms	5372 ms	133 ms	4172 ms
RTT to update resources	28 ms	4440 ms	26 ms	3010 ms

Fig. 9. Average round-trip time (RTT) to register and update device resources

Fig. 9 shows that the proposed architecture can support both time sensitive devices (by applying direct management) and sleepy devices (by applying indirect management).

- **Packets and Bytes measurement**

	Outside the home		Inside the home	
	Exchanged packets (to and from MP)	**Exchanged bytes (to and from MP)**	**Exchanged packets (Devices and HGW)**	**Exchanged bytes (Devices and HGW)**
Direct Management	796 packets	50KB	-	-
Indirect Management	227 packets	47 KB	187,518 packets	11352 KB
Proposed architecture	619 packets	45 KB	95,253 packets	5766 KB

Fig. 10. Exchanged packets and bytes using three approach within 1 hour

Fig. 10 shows that the proposed architecture reduces large number of packets exchanged in the home network thus mitigating the home gateway bottleneck issues.

To compare the efficiency of simple gateway and intelligent gateway, Wireshark [14] was used to capture the exchanged packets between (i) devices and Home Gateway, (ii) Home Gateway and Management Platform using intelligent gateway and simple gateway. The result is shown in Fig. 11 and Fig. 12.

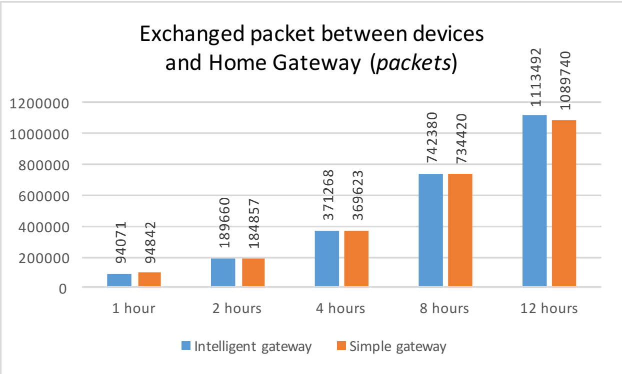

Fig. 11. Exchanged packets between **devices** and **home gateway** using simple gateway and intelligent gateway

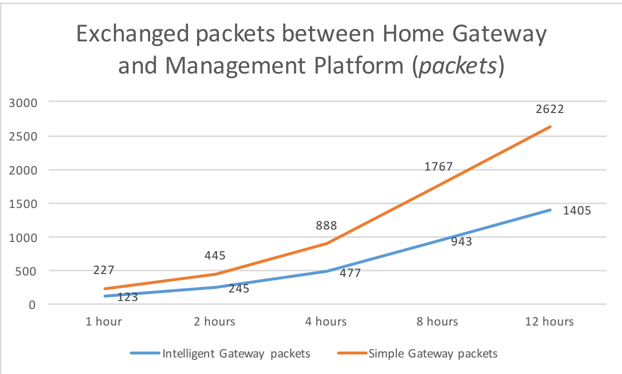

Fig. 12. Exchanged packets between **home gateway** and **management platform** using simple gateway and intelligent gateway

VII. Discussion

We can easily see that exchanged packets by simple gateway are much higher than the intelligent gateway as in Fig. 12. The reason is the simple gateway exchanged a lot of meaningless information due to lack of local data processing. By applying intelligent gateway, the transmission cost is dramatically reduced but it incurs higher implementation and operation cost for the home gateway and higher latency between devices and management services. However, there is only one home gateway in the home network and home gateways are often attached to the power source so problems related to cost can be ignored. The latency problem can be handled by the combination approach because it provides the option for time-sensitive devices to be directly managed.

Direct management enables low latency management comparing to indirect management approach as shown in Table 9 and it is suitable for time-sensitive devices. However, this approach requires devices with high capabilities of processing power and power for communication. For devices with limited processing power and energy source, indirect management is applicable.

Indirect management is designed for very constrained devices. Due to the constraints, devices might only handle their attributes one by one, thus increasing number of packets and overhead in the home network. Therefore, it can cause bottle neck issues on the home gateway and introduces the higher latency between devices and management services.

The proposed approach benefits from both direct and indirect management. It enables management services for multiple device classes from very constrained to less constrained devices and provides low latency management services for time-sensitive devices. The proposed architecture also reduces the traffic for the home gateway and enables local management in the home network.

VIII. Conclusions and Future Works

We have proposed a management architecture to handle the heterogeneity of devices in the home network by combining current management approaches. With this architecture, we can manage multiple device classes from very constrained devices to less constrained devices relatively unconstrained by resources, provide options for managing time sensitive devices, enable local management to support local fault detection and recovery and reduce the traffic for the home gateway to mitigate home gateway bottleneck issues. To verify this management architecture, a prototype system for the management of ECHONET LITE devices and CoAP enabled devices was developed.

As future research, the use of artificial intelligence could be pursued to provide auto configuration, fault detection and self management or exception handling functions.

References

[1] ITU-T, *Overview of the Internet of things*, Y.2062, March 2012.

[2] S. Rao, D. Chendanda, C. Deshpande and V. Lakkundi, *Implementing LWM2M in Constrained IoT Devices*, ICWiSe, p.52-57, 2015.

[3] [RFC7547] M. Ersue, D. Romascanu and J. Schoenwaelder, *Management of Networks with Constrained Devices: Problem Statement and Requirements*, RFC 7547, May 2015.

[4] A. Sehgal, V. Perelman, S. Kuryla and J.Schonwalder, *Management of Resource Constrained Devices in the Internet of things*, IEEE Communitcations Magazine,, Volume 50, p.144-149, 2012

[5] [RFC3411] D. Harrington, R. Preshun and B. Wijnen, *An Architecture for Describing Simple Network Management Protocol (SNMP) Management Frameworks*, RFC 3411, December 2002.

[6] [RFC6241] R. Enns, M. Bjorklund and A. Bierman, *Network Configuration Protocol (NETCONF)*, RFC 6241, June 2011.

[7] [RFC7228] C. Bormann, M. Ersue, and A. Keranen, *Terminology for Constrained-Node Networks*, RFC 7228, May 2014.

[8] [RFC7452] H. Tschofenig, J. Arkko, D. Thaler and D. McPherson, *Architectural Considerations in Smart Object Networking*, RFC 7452, March 2015.

[9] ITU-T, *Requirements and architecture of home energy management system and home network services*, Y.2070, January 2015.

[10] Joe Folkens, *Building a gateway to the Internet of Things*, December 2014.

[11] ECHONET CONSORTIUM, *http://www.echonet.jp/english/*.

[12] [RFC7252] Z. Shelby, K. Hartke and C. Bormann, *The Constrained Application Protocol (CoAP)*, RFC 7252, June 2014.

[13] ECHONET CONSORTIUM, *ECHONET Lite Communication Middleware Specification Version 1.12*, May 2016.

[14] Wireshark version 2.0.5, Available online at: *https://www.wireshark.org/*.