NETCONF-based Integrated Management for Internet of Things using RESTful Web Services

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Abstract

Considering the rapid development of Internet of Things, this paper tries to solve its integrated management problem. The aim of this paper is then to introduce new-generation network management standardization that is NETCONF and propose the use of RESTful Web Services from the viewpoint of lightweight requirements for integrated management of Internet of Things. Using the proposed approach, this paper discusses the definitions of management operations based on NETCONF over HTTP for integrated management of Internet of Things. In the end of this paper, two typical integrated management scenarios for Internet of Things are provided, in order to validate the feasibility of the proposed approach.

Keywords: *Internet of Things, Integrated Management, NETCONF, RESTful Web Services*

1. Introduction

In 2005, International Telecommunications Union (ITU) published an annual report titled *ITU Internet Reports 2005 Executive Summary: The Internet of Things* [1], which formally establishes the concept of Internet of Things, and also extends this concept by presenting the desire for future development that is any time, any place, any things connection, ubiquitous networks and ubiquitous computing. In 2010, Hammersmith group released a research report titled *The Internet of things: Networked Objects and Smart Devices* [2], which contains the following three key points relying on the market size and assumptions. First, networked objects generate significant information trails; second, smart appliances support energy conservation through demand response strategies; third, networked objects can create lifestyle benefits. Additionally, many other research institutes and companies have also presented its particular understanding or solution [3], which may promote the continual development of the Internet of Things in a global domain.

As an important research area, network management should be an indispensable part for the design of Internet of Things, instead of being a post-accession function in the traditional sense. As to Internet of Things, the integrated management problem becomes more prominent. From the viewpoint of Sensor as a Service [4], the function part of smart devices (main components of Internet of Things) can be seen as services, and Service-Oriented Architecture (SOA) can then be utilized for management of Internet of Things. Remarkably, Reference [5] applies SOA to interconnection of real-world embedded equipments, the infrastructure of which can be utilized by users to dynamically select, choose and use real-world services. The aim of this paper is then to discuss the integrated management problem of Internet of Things based on SOA, introduce new-generation network management

standardization that is NETCONF, and propose the application of RESTful Web Services from the viewpoint of lightweight management requirements by Internet of Things.

The remainder of this paper is organized as follows. Section 2 introduces new-generation network management standardization that is NETCONF and proposes the use of RESTful Web Services from the viewpoint of lightweight requirements for integrated management of Internet of Things. Then, Section 3 discusses the definitions of management operations for integrated management of Internet of Things by utilizing NETCONF over HTTP. Section 4 provides two typical integrated management scenarios for Internet of Things, in order to validate the feasibility of the proposed approach. Section 5 concludes this paper.

2. Proposed Integrated Management Framework

As for smart devices in Internet of Things, integrated management is proposed to be implemented in a standardized way based on NETCONF using RESTful Web Services.

2.1. Standardization by NETCONF

Typically, network management adopts the Manager-Agent model, which defines the principles of operations for protocol-based management solutions [6], and managed resources are then modeled as Managed Objects (MOs) and a particular set of MOs is named as Management Information Base (MIB). Novel network management solutions should adapt to meet the developing requirements of Internet of Things. Interconnecting smart devices with IP is a prospective direction, and IP-oriented standardizations can be utilized for integrated management of Internet of Things.

As the new-generation network management standardization, NETCONF has overcome the weaknesses of Simple Network Management Protocol (SNMP), and it provides a better configuration of IP network devices due to the effective use of XML and related technologies. NETCONF is divided into four layers, which are content, operations, Remote Procedure Call (RPC) and transport protocol, as is shown in Table 1.

Table 1. The Four Layers for NETCONF

Layer	Related RFC	Example
Content	RFC6020, RFC6021, RFC6110	MIB defined by YANG
Operations	RFC4741, RFC5277	<get-config>, <edit-config>, <notification>
RPC	RFC4741	<rpc>, <rpc-reply>
Transport Protocol	RFC4741, RFC4742, RFC4743, RFC4744	BEEP, SSH

In summary, NETCONF-based network management has emerged as a promising approach to standardize XML-based network management for the sake of automation, especially in the field of configuration management, the function of which is often not remarkable in other solutions. This paper tries to make full use of NETCONF to promote the standardization of integrated management for Internet of Things.

Figure 1 proposes an integrated management framework for the Internet of Things using the Manager-Agent model based on NETCONF.

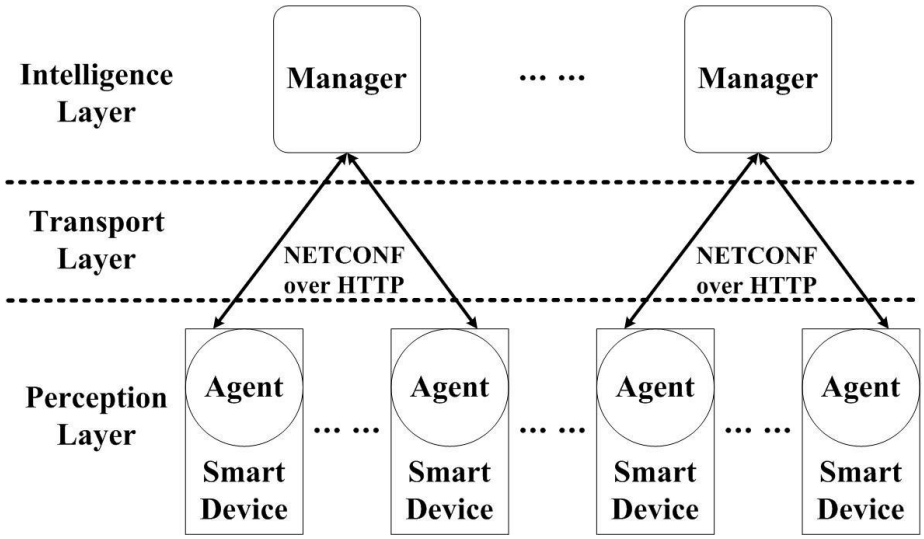

Figure 1. Proposed integrated management framework for the Internet of Things using Manager-Agent model based on NETCONF

As is depicted in Figure 1, Internet of Things is divided into three functional layers, which are Perception Layer, Transport Layer and Intelligence Layer. And based on this hierarchical classification, the Manager-Agent management model is adopted.

2.2. Application of RESTful Web Services

When considering the use of SOA for integrated management problem of Internet of Things, if Web Services based on Simple Object Access Protocol (SOAP) and Web Services Description Language (WSDL) are directly reused for the management of Internet of Things, the cost for encoding and decoding is incompatible with the limited resources provided by smart devices. From this point of view, RESTful Web Services can be utilized for the lightweight implementation of integrated management of Internet of Things, and the RESTful Web Services approach based on NETCONF is then proposed. REST is not an architecture, but a set of design criteria [7], which means that, Resource-Oriented Architecture (ROA) is a RESTful architecture that provides a commonsense set of rules and a step-by-step procedure for designing RESTful Web Services complying with these design criteria [8].

When applying the RESTful Web Services approach to manage Internet of Things in an integrated manner, the key points are listed as follows.

·MOs and MIB are modeled as resource identified by URI, and they can be described by HTML, XML or JavaScript Object Notation (JSON)

·HTTP are used as transport protocol for management messages

·Management operations can be performed as HTTP actions

3. NETCONF over HTTP for Integrated Management

As is informed in RFC6244 [9], NETCONF can run over any transport protocol that meets the requirements defined in RFC 4741, including connection-oriented operation, authentication, integrity and confidentiality. Combined with the use of the RESTful Web

Services approach, NETCONF over HTTP is proposed for integrated management of Internet of Things.

3.1. NETCONF-based Management Operations for MO

Based on NETCONF over HTTP, the RESTful Web Services approach promotes the definition of integrated management operations for Internet of Things. Table 2 presents the definition of management operations supported by the MO resource.

Table 2. The Definition of Management Operations Supported by the MO Resource

Resource	Format	Management Operation	Function	HTTP Action
MO	HTML /XML /JSON	GetRequest	Getting the instance value of a particular MO	Manager sends a HTTP GET request to Agent
		EditRequest	Editing the instance value of a particular MO	Manager sends a HTTP PUT request to Agent
		CopyRequest	Copying a particular MO	Manager sends a HTTP POST request to Agent
		DeleteRequest	Deleting a particular MO	Manager sends a HTTP DELETE request to Agent
		MOResponse	Responding for a management request operation supported by the MO resource	Agent returns a HTTP response to Manager for a request operation supported by the MO resource

3.2. NETCONF-based management operations for MIB

In a similar way as above, Table 3 provides the basic definition of management operations supported by the MIB resource based on NETCONF over HTTP.

Note that, when establishing the communication session between Manager and Agent, HelloRequest is required to notify its capability to the peer. Support of NETCONF capabilities will result in definition of new management operations or modification of current management operations. Table 4 provides the extended definition of management operations supported by the MIB resource with the use of NETCONF capabilities.

Table 3. The Basic Definition of Management Operations Supported by the MIB Resource

Resource	Format	Management Operation	Function	HTTP Action
MIB	HTML /XML /JSON	HelloRequest	Exchanging the supported capabilities between peers	Manager sends a HTTP POST request to Agent
		AddMORequest	Adding a new defined MO	Manager sends a HTTP POST request to Agent
		GetConfigRequest	Getting instance values specified by the filter of MIB	Manager sends a HTTP GET request to Agent
		LockRequest	Locking the target MIB before configuration operations	Manager sends a HTTP POST request to Agent
		UnlockRequest	Unlocking the target MIB after configuration operations	Manager sends a HTTP DELETE request to Agent
		EditConfigRequest	Editing instance values specified by the filter of MIB through merge or replace	Manager sends a HTTP PUT request to Agent
		CopyConfigRequest	Copying MIB from the source to the target	Manager sends a HTTP POST request to Agent
		DeleteConfigRequest	Deleting the target MIB	Manager sends a HTTP DELETE request to Agent
		CloseSessionRequest	Closing the current session in a normal way	Manager sends a HTTP DELETE request to Agent
		KillSessionRequest	Forcing the termination of a session	Manager sends a HTTP DELETE request to Agent
		MIBResponse	Responding for a management request operation supported by the MIB resource	Agent returns a HTTP response to Manager for a request operation supported by the MIB resource

Table 4. The Extended Definition of Management Operations Supported by the MIB Resource with the Use of NETCONF Capabilities

Resource	Format	Management Operation	Supported Capability	Function	HTTP Action
MIB	HTML /XML /JSON	CommitRequest	:candidate	Submitting the configuration data and maintaining consistency	Manager sends a HTTP POST request to Agent
		DiscardChangesRequest	:candidate	Reverting the candidate data to the target MIB	Manager sends a HTTP POST request to Agent
		ValidateRequest	:validate	Validating the contents of the MIB resource	Manager sends a HTTP GET request to Agent
		CreateSubscriptionRequest	:notification	Subscribing to event notification	Manager sends a HTTP POST request to Agent
		CancelSubscriptionRequest	:notification	Canceling the subscription of event notification	Manager sends a HTTP DELETE request to Agent
		EventNotification	:notification	Notifying subscripted event	Agent sends a HTTP PUT request to Manager

4. Integrated Management Scenarios for Validation

In order to validate the feasibility of the proposed approach, this section discusses issues related to two typical integrated management scenarios for Internet of Things, which are active management from Manager to Agent and passive management from Agent to Manager.

4.1. Active management from Manager to Agent

Figure 2 demonstrates the management scenario of operation requests using the RESTful Web Services approach based on NETCONF in the Internet of Things. Note that, due to the resource constraint in Internet of Things, MIBs are maintained by the Manager. Thus in this case, resources are created at the end of Manager after capability exchanging through HelloRequest.

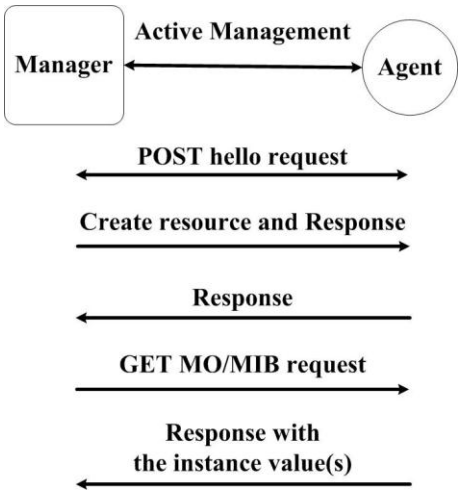

Figure 2. The Management Scenario of Operation Requests using the RESTful Web Services Approach based on NETCONF in the Internet of Things

4.2. Passive Management from Agent to Manager

Figure 3 demonstrates the management scenario of event notifications using the RESTful Web Services approach in the Internet of Things.

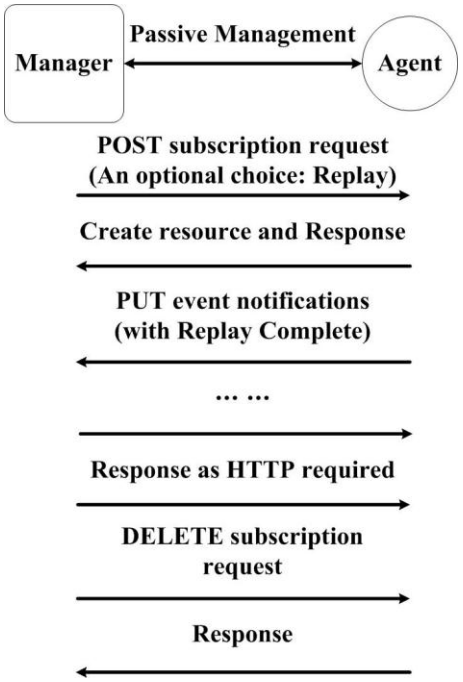

Figure 3. The Management Scenario of Event Notifications using the RESTful Web Services Approach based on NETCONF in the Internet of Things

As is indicated in Figure 3, Manager uses HTTP PUT operations for event notifications, but as for network management specifications, responses are not essential, which are just

required by HTTP. Additionally, RFC5277 [10] specifies the use of notification replay, which is the ability to create an event subscription that will resend recently generated notifications, or in some cases send them for the first time to a particular NETCONF Manager. And these notifications are sent the same way as normal notifications, as is shown in Figure 3.

5. Conclusions

The main contribution of this paper is to introduce new-generation network management standardization that is NETCONF for integrated management of Internet of Things, and propose the use of RESTful Web Services from the viewpoint of lightweight management requirements. This paper discusses the basic and extended definitions of management operations based on NETCONF over HTTP for integrated management of Internet of Things, and provides two typical integrated management scenarios for Internet of Things for validation of the proposed approach. The validation result shows that, the proposed approach based on NETCONF with the use of RESTful Web Services is feasible for integrated management of Internet of Things.

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References

[1] International Telecommunications Union, "ITU Internet Reports 2005 Executive Summary: The Internet of Things", **(2005)**.
[2] Hammersmith Group, "The Internet of things: Networked Objects and Smart Devices", Research Report, **(2010)**.
[3] L. Atzori, A. Iera and G. Morabito, "The Internet of Things: A Survey", Computer Networks, vol. 54, **(2010)**, pp. 2787-2805.
[4] S. Alam and J. Noll, "A Semantic Enhanced Service Proxy Framework for Internet of Things", Proceeding of 2010 IEEE/ACM International Conference on Green Computing and Communications & 2010 IEEE/ACM International Conference on Cyber, Physical and Social Computing, IEEE Press, **(2010)**, pp. 488-495.
[5] D. Guinard, V. Trifa, S. Karnouskos, P. Spiess and D. Savio, "Interacting with the SOA-based Internet of Things: Discovery, Query, Selection, and On-Demand Provisioning of Web Services", IEEE Transactions on Services Computing, vol. 3, no. 3, **(2010)**, pp. 223-235.
[6] ISO/IEC 10040, "Information Technology -- Open Systems Interconnection -- Systems Management Overview", ITU-T Recommendation X. 701 **(1998)**.
[7] F. Belqasmi, R. Glitho and C. Fu, "RESTful Web Services for Service Provisioning in Next-Generation Networks: A Survey", IEEE Communications magazine, vol. 49, no. 12, **(2011)**, pp. 66-73.
[8] L. Richardson and S. Ruby, "RESTful Web Services", O'Reilly & Associates **(2007)**.
[9] P. Shafer, "An Architecture for Network Management Using NETCONF and YANG", Internet Engineering Task Force, RFC6244, **(2011)**.
[10] S. Chisholm and H. Trevino, "NETCONF Event Notifications", Internet Engineering Task Force, RFC5277 **(2008)**.

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