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Adaptive Internet of Things and Web of Things convergence platform for Internet of reality services

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Abstract Recently, Internet of things (IoT) and Web of Things (WoT) lead us to the excellent era of connected everything device. However, the devices hardly show the property of the autonomous connectivity and the self-cooperation for applying in real-world environments. The purpose of this paper was to propose the adaptive IoT and WoT convergence platform that enables things to dynamically implement the smart Web without any controls from users. The adaptive IoT and WoT convergence platform, proposed in this paper, is a new type of platform which provides global inter-compatibility to help users to easily communicate with things by connecting through the webs. Through mashup of the things connected to the Web, coarsely or finely, this proposal can guarantee an efficient IoT or WoT platform management, adaptive synchronization between the things, a stable platform environment, and creating new services. The performance of our proposed platform is tested via experiments which verify that its simulations are satisfactory.

Keywords Internet of things (IoT) · Web of things (WoT) · IoT/WoT platform · IoT/WoT services · Adaptive synchronization things

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1 Introduction

With the rapid development of the Internet and the sharp increase of its users, a variety of new network services have been developed and commercialized. Recently, around three billions people around the world use the Internet, sending and receiving emails, playing games, accessing multimedia services and content, using social networking services and many other tasks [1–5]. The Internet of Things (IoT) is a global-scale network based infrastructure which utilizes many things such as the physical devices or virtual things with attributes, Auto-IDs and self-configuration receptivity within the standard communication. IoT means that everything including user, things, and spatial data are connected to one another through the Internet, so that the information can be produced, collected, and used [1,2,6–8]. This IoT is a new paradigm that is quickly gaining ground in modern wired and wireless telecommunications. Recently, as the number of IoT devices for personal or home intelligence increases, the need for unified control and cooperative utilization is required. Things in IoT are generally heterogeneous and resource constrained. And such physical things and virtual things are connected with each other over low power and network resource [2–5]. Also, still, most of these physical things and virtual things are connected to very small and limited group of devices and things. Most important challenges in current development and research in the IoT service and application are the definition of architectures, protocols and development of algorithms for efficient connection of objects, both between the objects themselves as well as with the future Internet. Therefore, an intelligence in the IoT services makes possible many things via the IoT communications. Those also transform data of these things into useful information which enables real-time knowledge discovery and decision making [9–11].

According to our literature review, with the development of communication technology and equipment technology, equipment capabilities and services connected to the communication are being enabled. In fact, all the things that can be controlled in real-time search and social is growing. In fact, everything that can be controlled in a real-time searching and socialization is growing. Therefore, all things on the Web so that you can access and control the implementation of WoT, then realizing ubiquitous world will be able to play a large role. WoT was proposed to realize intelligent and autonomous thing-to-thing communications using Web standard technology [3,12–14]. WoT to realize, we have to provide connectivity of devices, integrated descriptions of things and sensor, things with state and relevant information. The general characteristics of the Web are that the WoT is on the verge of experiencing a great evolution [13,15,16]. Integrating real objects and devices on the Web, which are only accessible from the Web can be described as a service. These services are based on WoT. Each new mashup service using the service function of the support should also be available. Furthermore, service and application development is only the URI of each service using the service development and possible mechanisms. In this way, Web development tools and techniques can be directly applied to the real-world environment.

According to the recent research of literature, the definitions of IoT and WoT are not clear as much as it is not clear for IoT and WoT platform. They merely explained the basic role and function of the platform and about whether it will be implemented as a product accompanying academic researches. The existing IoT technology cannot synchronize things of the physical world with services of the virtual world, due to its demerit that it could not guarantee various domains independently developed or their interoperability. Consequently, to activate the IoT technology, an embedded platform is necessary that can guarantee the autonomous linkage between various things and information, communication among low-power things, and interoperability among things. Especially, it is necessary to study the performance of smarter customizable services, using free mashup and operation among things without any intervention of user. In short, it is essential to study the autonomous linkage between various things and information based on the Web technology. In addition, it is directly necessary to study the IoT and WoT platform that can realize people-centered services.

The purpose of this paper was to propose the adaptive IoT and WoT convergence platform which is essential in implementing smart webs through dynamic mashup without any intervention of user. The adaptive IoT and WoT convergence platform, proposed in this paper, is a new type of platform which provides inter-compatibility to help users to easily communicate with each other by connecting through the webs, and helping user and things easily commune with each other. Through mashup of the things connected to the Web, coarsely or finely, this proposal can guarantee an efficient IoT or WoT platform management, adaptive synchronization between the things, a stable platform environment, and creation of new services. The performance of our proposed platform is tested via experiments which verify that its simulations are satisfactory.

This paper is organized as follows: In Sect. 2, the key related work for IoT and WoT platform and its services are stated. In Sect. 3, the proposed platform based on adaptive IoT and WoT convergence is presented. In Sect. 4, the experimental results and performance simulations are described. Finally, in Sect. 5, the conclusion and future research direction are discussed.

2 Related work

2.1 Internet of Things

The IoT is a new paradigm that is quickly gaining ground in the service and scenario of modern wireless telecommunications. The basic idea of IoT concept is the rampant presence around us of a variety of devices or things—such as tags, sensors, Radio-Frequency Identification (RFID), mobile phones, actuators, etc.—which, through sole addressing schemes, are able to interact with each other or collaborate with their neighbors to reach common goals [1,4,17,18]. The IoT is a global-scale network-based infrastructure which utilizes many things such as the physical devices or virtual things with attributes, Auto-IDs and self-configuration receptivity within the standard communication. IoT means that everything including user, things, and spatial data are connected to one another through the Internet, so that the information can be produced, collected, and used. Thus, IoT follows the ‘anything connected’ vision by ITU and assumes that any virtual or physical thing which cloud benefit from a connection to the Internet will eventually be connected. Gartner forecasts that 4.9 billion connected things will be in use in 2015, up 30 % from 2014 and will reach 25 billion by 2020. By

2020, there will be a quarter billion connected vehicles on the road, enabling new in-vehicle services and automated driving capabilities, according to Gartner, Inc. During the next five years, the proportion of new vehicles equipped with this capability will increase dramatically, making connected cars a major element of the IoT [19]. This IoT research is expected to be the foundation for the connection of various devices that will enable the advancement into the hyper-connected society, appearance of the wearable computing services, and development of the new IT convergence services.

Over the past 30 years, the Internet has exponentially grown from a small research network, to a worldwide pervasive network, comprising only a few nodes that services more than a billion users. The cost reduction and further miniaturization of devices makes it possible to expand the Internet into a new dimension: to smart things or devices, i.e., everyday physical things that are enhanced by a small electronic device to provide local connectivity and intelligence to the cyberspace established by the Internet. The electronic device, a computational element that is attached to a physical thing or object, bridges the gap between the information world and the physical world. A smart thing or object is thus a cyber-physical system, consists of elements and things that processes the IoT sensor data and supports a wireless communication link to the Internet. The progress of the IoT is not in the practical capability of a smart thing and object but in the expected size of billions or even trillions of smart thing and object that bring about new societal and technical issues that are related to size. Some examples of these issues are self-organization of network and autonomic management of smart things, identification of a smart thing, goal-oriented behavior and context awareness, maintenance and diagnostics, and intrusion of the privacy. The emergence of low-power wireless communication enables the communication with a smart thing without the need of a device or physical connection. Mobile smart things can move around in the real-world space while maintaining their identity. The wide reliability of signals from the global positioning system makes it possible to make a smart thing time-aware and location and offer services that are tuned to the current context of use. Certainly, the major strength of the IoT idea is the impact it will have on several aspects of life and behavior of latent users. From the point of a private user, the most significant effects of the IoT introduction will be visible in both domestic fields and working. In this assisted living, e-health, context, enhanced learning are only a few examples of possible application services and scenarios in which the novel paradigm will play a leading role in the near future. Especially, application of the IoT technology is the core research field including 'connected car' that automobile manufacturers implement various smart systems within a car, 'healthcare' that is related to individual health, and realization of 'smart home'. A schematic of the inter-networking of things or devices is depicted in, Fig. 1, where the services and applications are chosen based on the scale of the effect of the thing and object data generated.

IoT is defined by various organizations such as ITU-T, ETSI, IEEE, IETF, etc., but conceptually can be defined as "A global infra which provides intellectual services by converging context-awareness based intelligence and interacting autonomously among self-recognized things on the common information network". With the IoT, things and devices can exchange information with other things and can exert effects by executing the communications with physical events and placing corresponding measures into effect, and build services without person intervention. The IoT has mainly focused

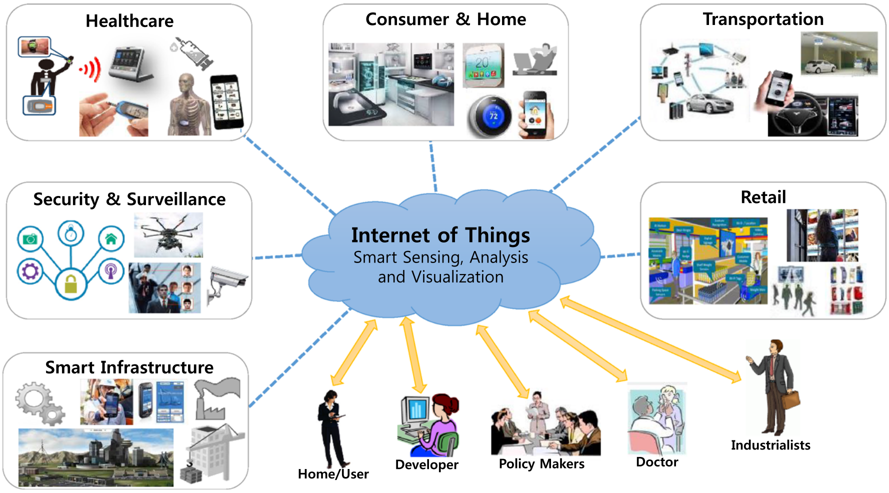


Fig. 1 IoT schematic showing the users and applications

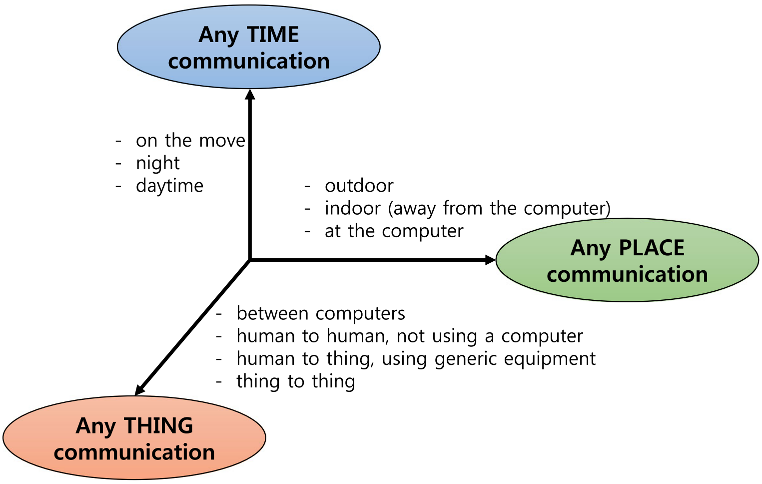


Fig. 2 The dimension introduced in the Internet of Things [9]

on setting connection in a grab bag of challenging, constrained, and unconstrained network configuration. Additionally, people will be able to interact with diverse smart devices, converge and create applications, and mutually participate without special interworking technologies [2,3]. As shown in Fig. 2, the IoT adds the three dimensions 'Any THING communication' to the information and communication technologies which already provide 'any TIME' and 'any PLACE' communication [20]. Physical things occur in the physical world and are capable of being connected, actuated and sensed. Examples of Physical things include the electrical equipment, industrial robots and surrounding environment. Virtual things occur in the information world and are capable of being accessed, processed, and stored. Examples of virtual things include application software and multimedia content [2,21].

Exactly, many challenging issues still need to be addressed and both technological as well as social knots have to be untied before the IoT idea being widely accepted. Significant issues are making a full interoperability of connected things or devices possible, providing them with an always higher degree of smartness by enabling their autonomous and adaptation behavior, while privacy, guaranteeing trust, and security. Also, the IoT idea raises and poses several novel problems concerning the inter-networking aspects. In fact, the things or devices composing the IoT will be characterized by low resources and low power in terms of both energy capacity and computation. Accordingly, the proposed solutions need to pay special caution to resource effectiveness besides the obvious availability and scalability problems. Several standardization, industrial, and research bodies are now involved in the activity of development of solutions to fulfill the highlighted technological requirements [2,4]. The main purpose is to give the reader the chance of understanding what has been done and what still remains to be addressed, as well as which are the enabling elements of this incremental process and what are its risk elements and weaknesses. In order to activate this IoT technology, mashup is necessary among universities, research institutes, and various companies, and it is needed to establish the ecosystem to support IoT research and activation of technology. In addition, although IoT research and technology are prepared, various platforms and criteria for services are absent, and there are not enough researches to cope with the explosive increase of the amount of IoT data. In order to resolve these problems, researches on establishing the IoT ecosystem and platforms that can accelerate the convergence among IoT areas should be initiated.

2.2 Web of Things

With the generality of the Web, the WoT and IoT are on the edge of experiencing vast progress. Today, we are one step closer to this vision due to latest advances in Web services, identification technologies, convergence services, wireless networks, which make communication capabilities and processing power available in increasingly smaller packages. Obviously, the Internet is evolving into the so-called 'Web of Things' (WoT), an environment where everyday devices such as traffic lights, sidewalks, buildings, and commodities are recognizable, identifiable, addressable, and even controllable via the Internet [13,15,22–24]. Certainly, starting from an Internet of nearly on thousand million computers, the Web now turns to be an Internet of nearly 100 billion of things or devices presaging transition from an IoT to a WoT. Thus, in a WoT platform the workload is put at the extreme level and scalability is a compulsory requirement.

This does not refer to any technology or any network structure, but only to the idea of interconnecting devices as well as interconnecting computers with the Internet. Use of the Web as the platform hosting and exposing connected devices can be explained by multiple technological and business benefits, a few of which include deployment, high availability and versatility, use of standardized communication protocols and the ecosystem created thanks to Web 2.0 paradigm. A thing or object becomes Internet-enabled if it is associated with networking ability and fusibility, which peculiarly identifies it on the Internet (refer to Fig. 3a). Recently, devices or objects such as electric

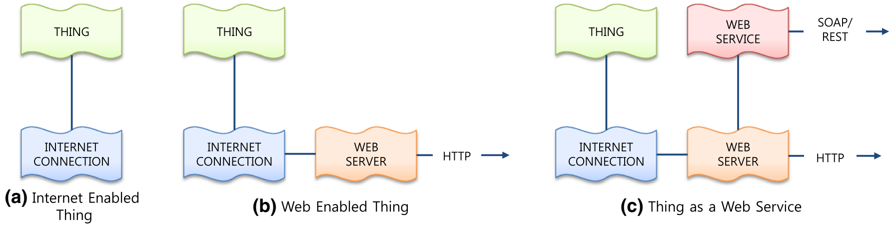


Fig. 3 Connecting things on the Web

meters, access cards, street lights, and sensors are already accessed and networked on to Internet [22]. A thing or object becomes Web-enabled when it is augmented with a Web server (refer to Fig. 3b) so that it can exploit its functional and non-functional abilities on the Web through HTTP. Researchers have long ago successfully embedded tiny Web servers on resource-constrained things, making Web-enabled things or devices a reality. Certainly, there is a domain for Representational State Transfer (REST) in the area of Web services. The advances in REST based web service structure are the abstraction of physical things as services on the Web. This trend gives rise to the possibilities of wrapping things in the physical world as Web services (refer to Fig. 3c).

Dominique and Pham [24] completely demonstrated Web mashups by exposing real-world things and devices as RESTful Web applications and services. Dominique [25] represents the WoT Architecture and the four layers it is based on: the device accessibility layer, findability layer, sharing layer, and composition layer as shown in Fig. 4. The goal of this architecture is to facilitate the integration of smart things or devices with various services on the Web and to facilitate the creation Web applications using smart things or devices. As illustrated in Fig. 4 the development of services and applications using smart things and devices on top of their protocols, native operating system and libraries still requires particular skills and is, for the greater part, only accessible to embedded systems experts. The overall goal of each layer of the WoT architecture is first to bring this development closer to Web developers and technically skilled hobbyists [24–26]. Therefore, it brings the development and usage of IoT services and applications closer to end-users, enabling them to create simple services and applications tailored to their needs.

2.3 IoT and WoT platform services

With the increasing need for adaptive and intelligent service applications and decreasing cost of maintenance IoT things, it is likely that a wide diversity of IoT environment will be deployed in the future [27]. In this IoT environment, the way to access heterogeneous IoT things communication and the way to integrate data from various IoT things or devices are very important [28–30]. Many studies on wireless sensor networks have concentrated on routing within energy conservation, a sensor network, network query, and so on [30–32]. They force on specific issues, such as computation capacity, query optimization and power consumption under the assumption that

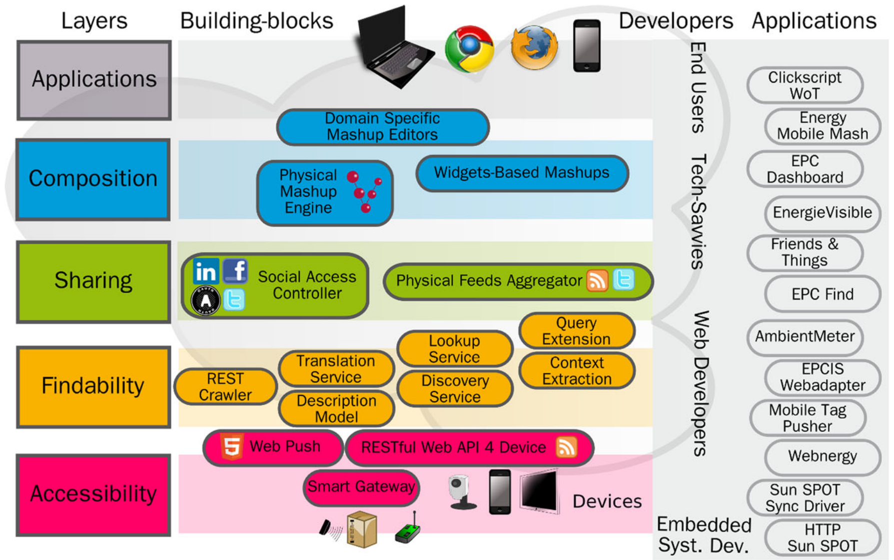


Fig. 4 The four layers of the WoT architecture [24]

all kinds of IoT sensor networks are heterogeneous or homogeneous. Recently, with the increasing activation of IoT and WoT services, studies about the IoT platform or the IoT sensor Web service have been prevalently progressing. Figure 5 describes the COSMOS ubiquitous sensor network (USN) middleware architecture [27]. It consists of three layers: the sensor network abstraction layer, sensor information processing layer, and the USN service layer. The COSMOS middleware provides general functions required for various services and applications. In this middleware architecture, it is very suitable to place a general application platform between the heterogeneous IoT thing networks, various services and applications.

The IoT and WoT platform design involves the application and service of experiential in the structured way to satisfy users' specified needs [18,33]. The platform users' demands continue to change and planners are subject to these requests such as increasingly complex heterogeneous systems, rapidly changing technology, and multidisciplinary domains. Recently, collaborative product development is in-depth studied to help planners to enhance the decision-marking [18,34,35]. Especially, a distributed collaborative product development system, which is being done more often by temporally and geographically distributed planners, is paid more interest. Many studies have been taken into account in the collaborative product development systems, e.g., communication tools, information system architecture, product geometric representation, heterogeneous IoT or WoT services, engineering IoT applications, etc [29,36,37]. Existent collaborative product development systems primarily focus on supporting such practices as collaborative visualization and common access of IoT data and design of components. By applying distributed collaborative product development system in the design process, many issues can also be contemplated and solved in an early plan stage. For example, those issues are the components belonging to other

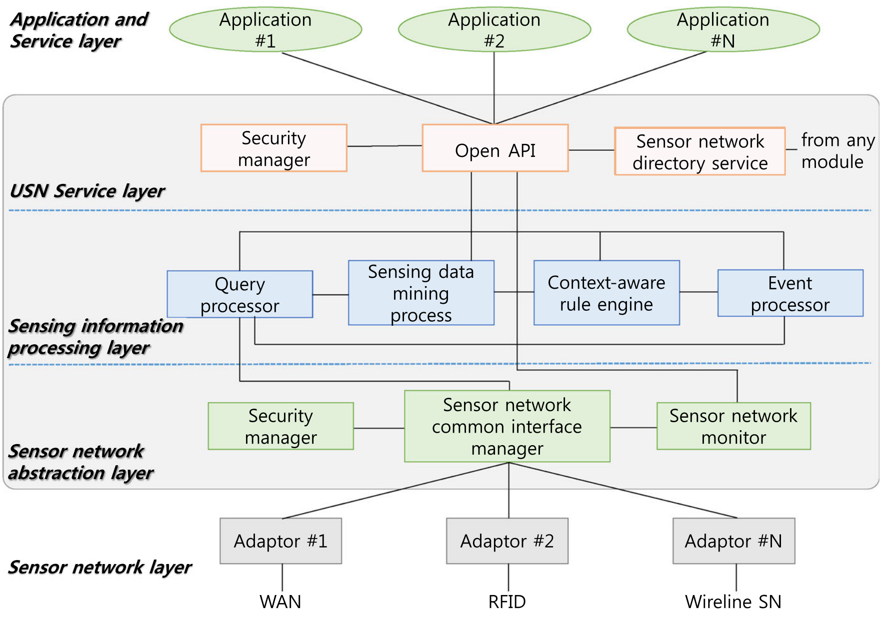


Fig. 5 COSMOS middleware architecture [27]

IoT services and IoT thing manufacture ability. The detailed design is to indicate all the accurate parameters for each module and part. In detail, using engineering specification or modeling, the planner can determine the size, tolerances, shape and other parameters of each part. Taking into account the significance of drawing flow from the view of supply chain, the planner should also invite outside experts again to compete in order that the planner can gain more realistic suggestions. Based on the explanations above, we can get the general design flow chart as Fig. 6.

3 Overall adaptive IoT and WoT convergence platform

The purpose of this paper was to propose the adaptive IoT and WoT convergence platform that enables things to dynamically implement the smart web without any controls from users. The adaptive IoT and WoT convergence platform, proposed in this paper, is a new type of platform which provides global inter-compatibility to help users to easily communicate with things by connecting through the webs. Through mashup of the things connected to the Web, coarsely or finely, this proposal can guarantee an efficient IoT or WoT platform management, adaptive synchronization between the things, a stable platform environment, and creation of new services. Our proposed platform architecture is very suitable to place an IoT and WoT common application platform between the heterogeneous IoT thing and device networks, various services and applications. Also, Our IoT and WoT convergence platform provides general functions required for various services and applications. These general functions are

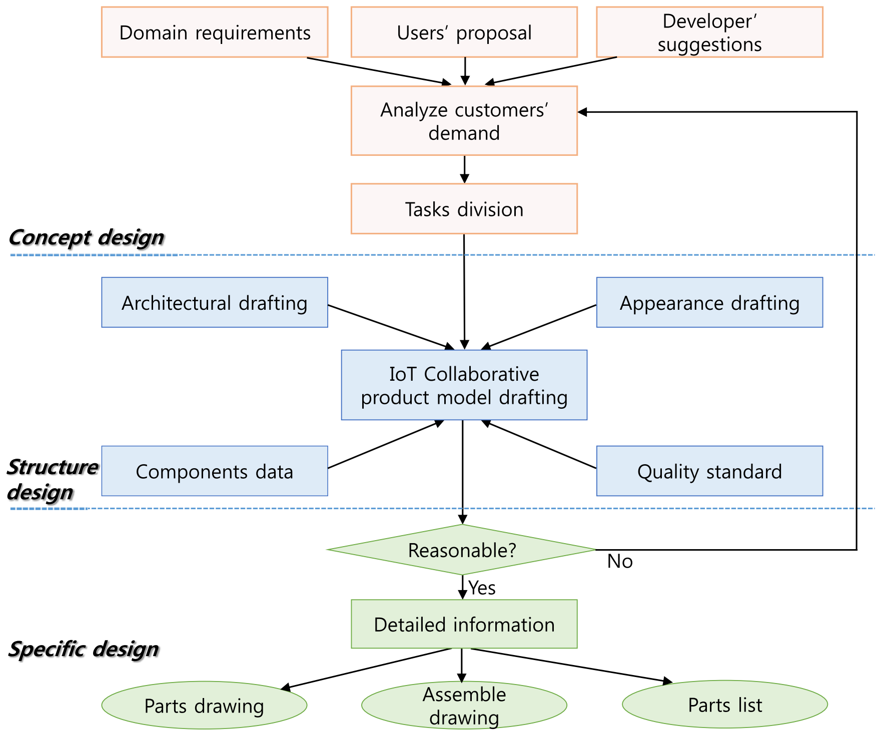


Fig. 6 General product design based on supply chain concept

derived from service and application viewpoints, and they include Web plug-in networking, things and devices metadata storage, thing retrieval and recommendation, and integrated thing query processing functions. Figure 7 illustrates an overall concept of adaptive IoT and WoT Platform which is proposed in this paper. As we can see in Fig. 7, adaptive IoT and WoT convergence platform consists of three layers: IoT and WoT Web plug-in and networking layer, adaptive IoT and WoT platform layer, and application and service layer.

3.1 IoT and WoT Web plug-in and networking layer

The IoT and WoT Web plug-in and networking layer includes the HTTP communication manager, things and devices resource manager, internal message networking and monitor, and the security functionality and things metadata repository. The IoT and WoT Web plug-in and networking layer general interface manager plays in interconnection role between the various IoT and WoT things, devices, and objects. The IoT and WoT Web plug-in and various things network monitor provides real-time network monitoring function and metadata repositions. Also, this layers in the real-world things, objects and provides a management function of the network device and the area network communication plug-in via the Web. The users have access to things through

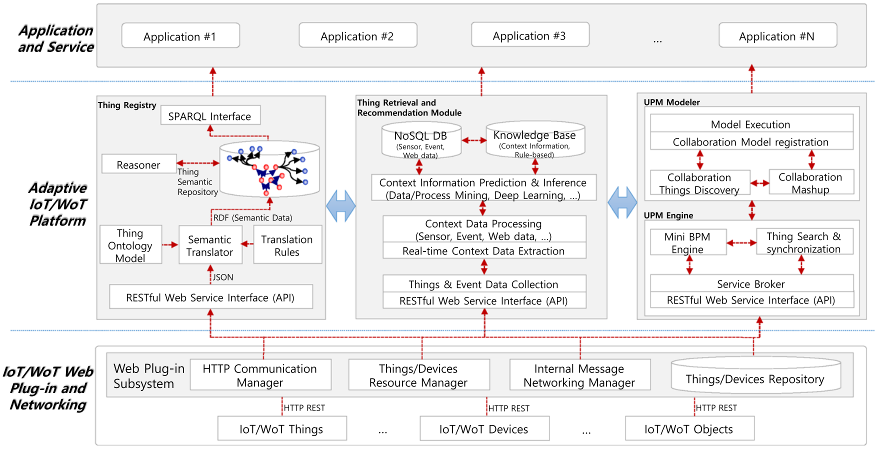


Fig. 7 Our proposed system for the adaptive IoT and WoT convergence platform

the Web and perform a search for the thing resource information acquisition and control functions. Additionally, this layer includes Uniform Resource Identifier (URI) list of thing resource, thing control command transmission, storage and maintenance of the things, subscription requests and notifications about things change.

3.2 Adaptive IoT and WoT platform layer

The adaptive IoT and WoT convergence platform layer is composed of semantic-based thing storage and inference module, things retrieval module using adaptive synchronization technology, and Ubiquitous Process Management (UPM)-based thing dynamic collaboration modules. Semantic-based thing storage and inference module performs the conversion to the non-semantic data, in the semantic data of support suitable service and things retrieval. The semantic Resource Description Framework (RDF) data are automatically converted and generate a semantic ontology data conversion rules and conversion models. Then, semantic RDF data are performed through a semantic inference and reasoning stored in a semantic repository. Last, services and applications may be provided with a useful semantic search result through the API to handle the SPARQL query. Adaptive synchronization module enables dynamic collaboration between technology to make IoT things smooth to operate and provides the ability to synchronize their associated IoT and WoT things. In addition, this module provides an interface for the things of the Web resource synchronization and autonomous synchronization of physical and virtual things, and things were designed to include retrieval and recommendation capabilities for the situation. UPM-based thing dynamic collaboration module can cooperatively performs the associated tasks to configure two or more things between communities. This module supports collaborative monitoring thing resource identification, services mashup with smart devices, thing-to-thing communication, and thing monitoring capabilities for collaboration. Furthermore, the things are dynamically binding to the services according to the changing conditions, and location-based service collaboration between things was designed to perform exception handling.

3.3 Application and service layer

The concept of IoT and WoT, with its vision of Internet or Web-connected things of various abilities and form factors, could improve the role of ICT as innovation enabler in a variety of service and application markets. The IoT and WoT application and service layer include the open API, the autonomous collaboration applications and services, and the new services generation through a mashup of applications and services. In application fields and domains where IoT and WoT solutions can provide competitive merits over current solutions, we verified various fields which we do believe can play a leading role in the adoption of IoT and WoT technologies; smart homes and buildings; smart cities; health-care and surveillance; smart business and product management. For example, IoT and WoT technologies can enable the research and development of a new generation of decision support and monitoring system, providing enhanced granularity and real-time abilities over current solutions. Another case in which the sensing capability of IoT and WoT things support the environmental safety is represented by danger detection. Obviously, rapid response has the consequence of saving human lives and in general reducing the level of calamity.

4 Experiment and analysis

In our experiment, a real-time adaptive IoT and WoT convergence platform was built using Web-based. Also, an experiment and things retrieval was developed that enabled us to evaluate the retrieval result of our test system. We designed semantic things and devices retrieval of IoT and WoT environment, semantic retrieval system for the real-time data collection, things retrieval system for efficiency, and meaning analysis. More specifically, our system enables interoperability between separate thing data and improves analysis by optimizing the situational awareness, as well. Figure 8 illustrates an efficient things retrieval system based on semantic Web technologies and the flow paths.

An ontology is a formal representation of each service and domain, composed of concepts and named relationships. At a broad level, our module can create ontologies along the five types (Thing ontology, Geo ontology, Time ontology, Service ontology, User ontology) of semantics associated with IoT and WoT thing data representing the IoT and WoT domain. The overall architecture of our proposed ontology model is given in Fig. 9.

In our experiment, semantic things retrieval was tested based on the things ontology model. In order to establish the experiment setting, the weather station of Netatmo, which is a company providing weather information for individuals, was selected as the IoT device. Through a mobile App, the weather station enables users to check the current humidity, interior and exterior air pollution, carbon dioxide, and extraneous noise information. In addition, based on the collected information, it recommends

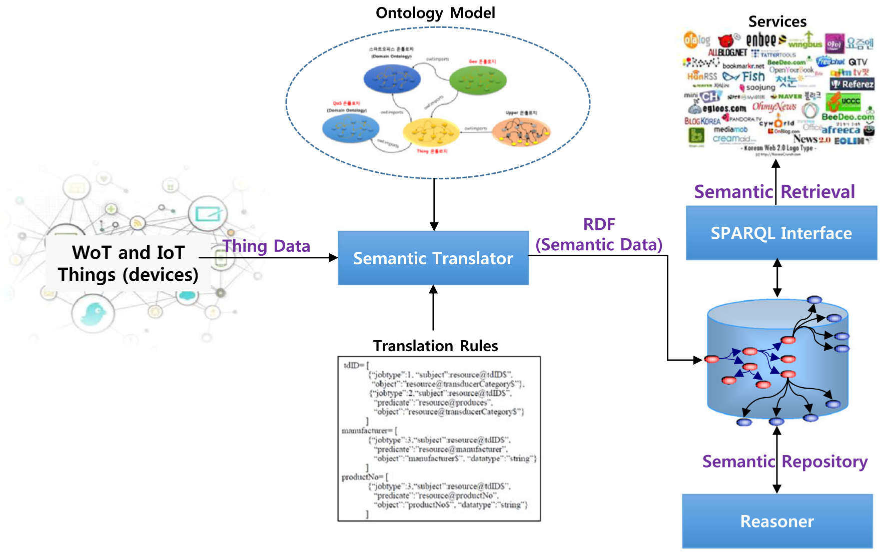


Fig. 8 Semantic things retrieval in our IoT and WoT platform

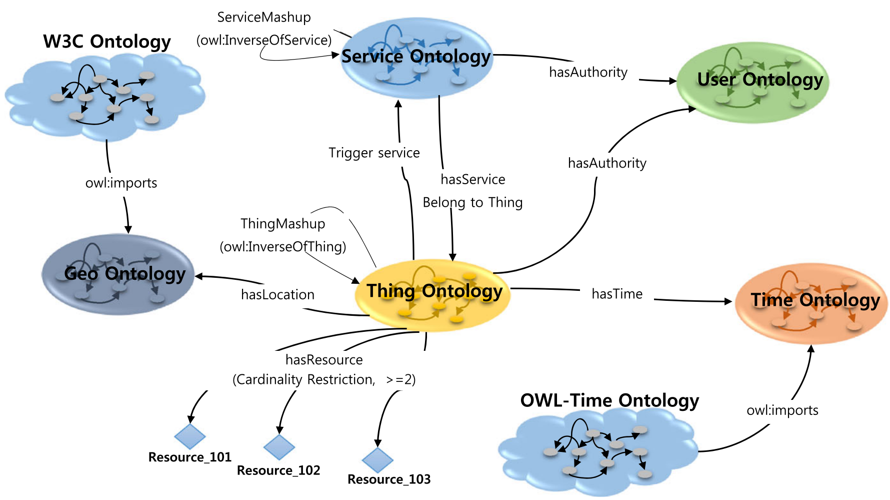


Fig. 9 Ontology model architecture in IoT and WoT environment

appropriate actions to users. In this paper, we built a test environment for the experiment as shown in Fig. 10 below.

For the experiment, various things of the IoT and WoT environment were registered at our platform. Next, the function to check and control the retrieval of the list for the whole things, conditional retrieval, and authority of things were confirmed through the experiment. First, whether things were registered was confirmed by checking the <resource> list of <application> registered at our platform. The result of registering

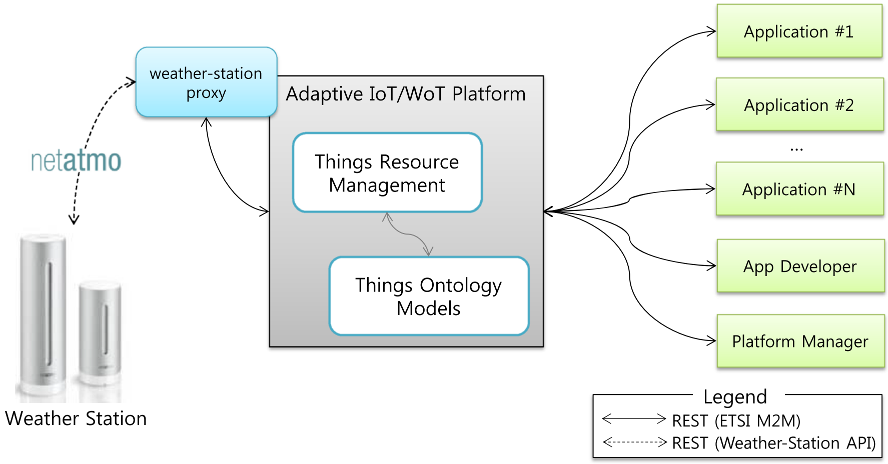


Fig. 10 Test environment structure for the semantic things retrieval

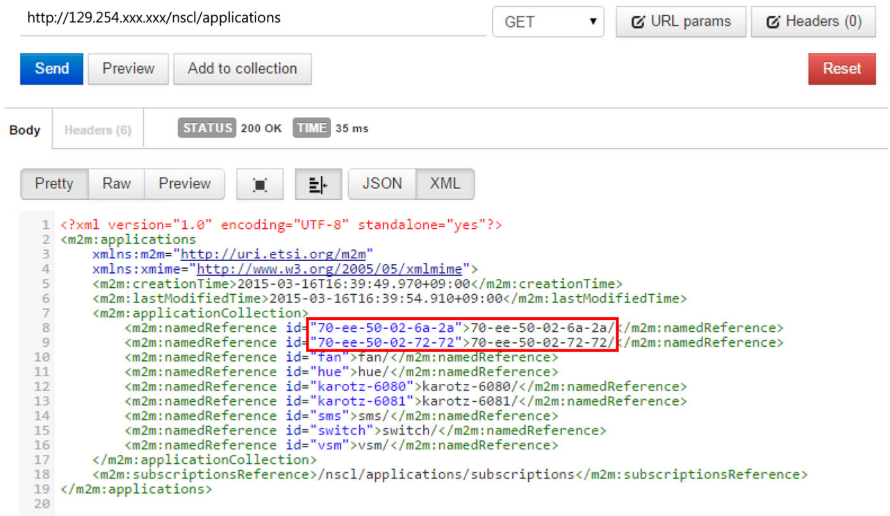


Fig. 11 Registers the weather-station on our platform

weather station things of Netatmo at the adaptive IoT platform is shown in Fig. 11 below.

Next, retrieval of all the things registered at our platform was performed as shown in Fig. 12 below. The result of retrieval provides the URI of the things registered at the platform and the metadata information.

Figure 13 shows the result of checking things according to conditional retrieval. The platform proposed in this study has an additional function of retrieving by combining location, time, service, user, etc., provided by the already defined things ontology model. Thus, users can efficiently perform the retrieval of things and services using various conditional retrievals, according to the purpose and circumstances.

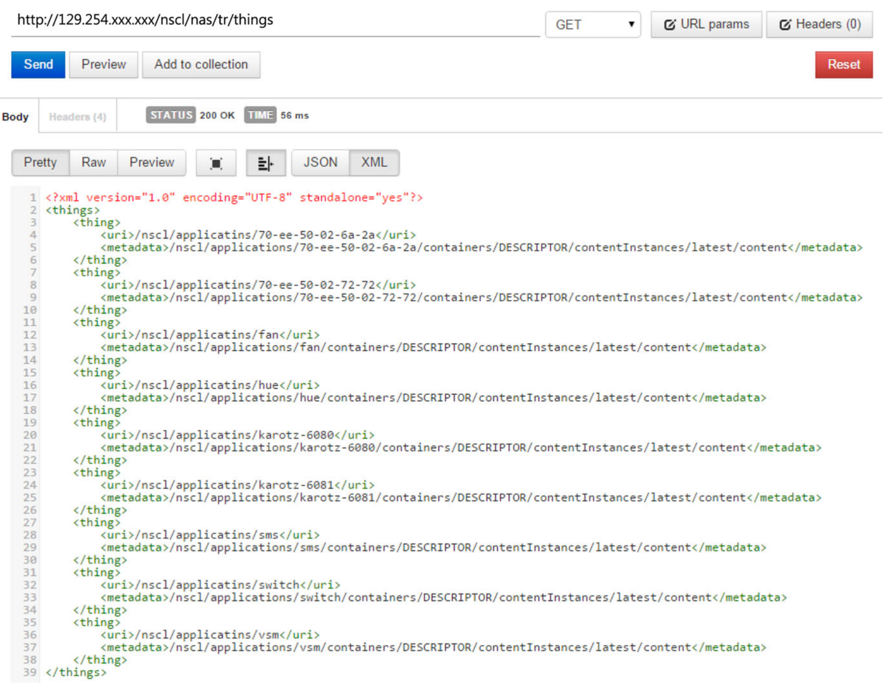


Fig. 12 Full list of retrieval things registered in the platform

Fig. 13 Query things using retrieval conditional

Figure 14 shows the results of the query to the metadata of the searched physical and virtual things. The metadata provides the things of URI, operation, type, name, owner, location, etc.

Figure 15 below provides the actual data collected from the selected things and their values. For example, it was confirmed through an experiment that if a user asks for environmental information (temperature, CO_2, humidity, interior and exterior noise, pressure), the measured values can be provided for the user.

Figure 16 is the result of performing operations to control weather station things. Each thing can have a different operation, and the result of controlling things is deliv-

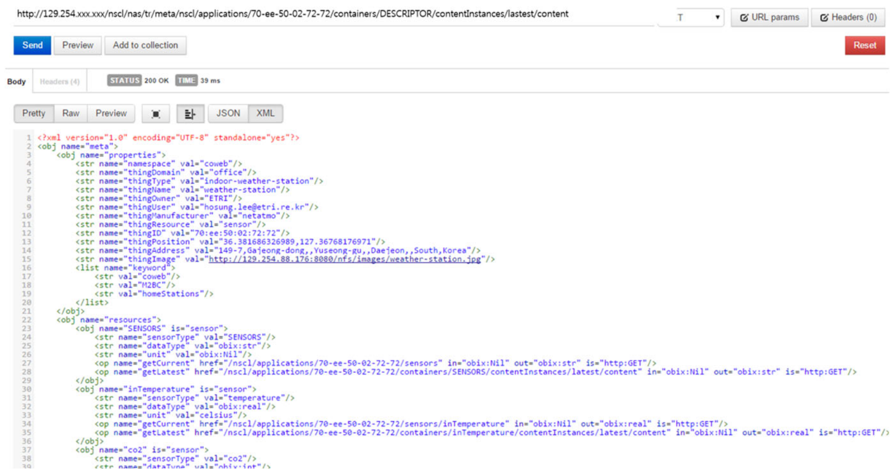


Fig. 14 Metadata retrieval of things

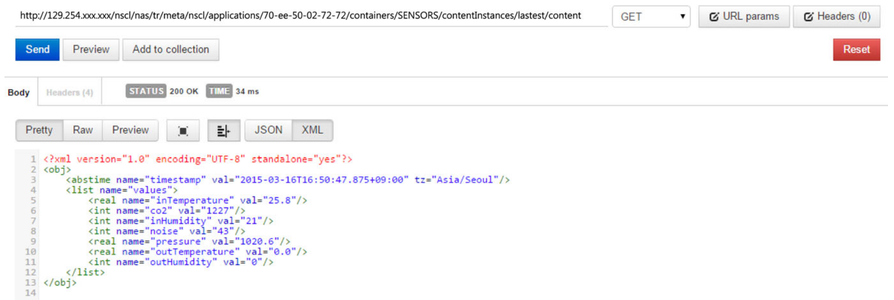
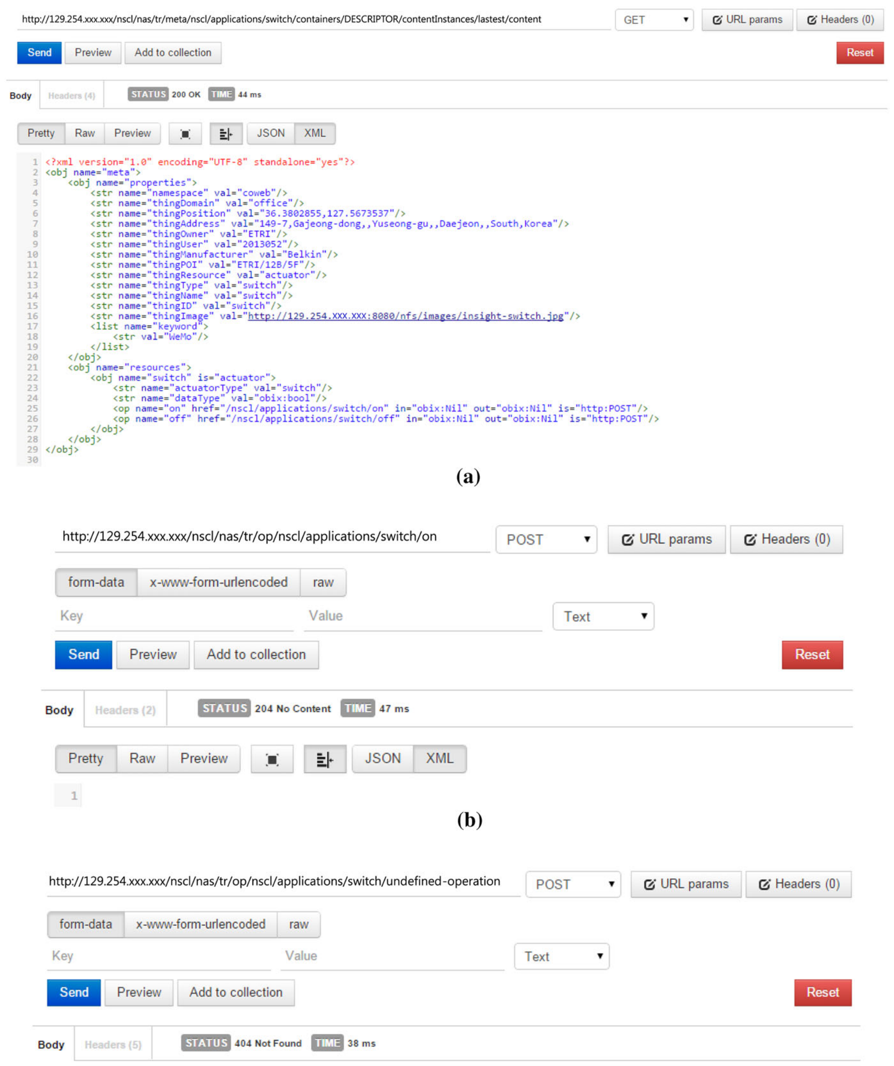


Fig. 15 The actual values collected from the things

ered in the HTTP status code value. If the status code value is 204, it means that the control of things is successful, and other values indicate failure [38].

5 Conclusion

In this paper, we proposed an adaptive IoT and WoT convergence platform on IoT services and applications that can perform mashup of various things and efficient operation in IoT and WoT environments. The purpose of this paper was to propose the adaptive IoT and WoT convergence platform that enables things to dynamically implement the smart web without any controls from users. The adaptive IoT and WoT convergence platform, proposed in this paper, is a new type of platform which provides global inter-compatibility to help users to easily communicate with all things by connecting through the webs. Through mashup of the things connected to the Web, coarsely or finely, this proposal can guarantee an efficient IoT or WoT platform management, adaptive synchronization between the things, a stable platform environment, and creation of new services.



(a)

(b)

(c)

Fig. 16 Things control example and results; **a** metadata of Belkin switch for things controlling; **b** experiments 'on' operation provided by the Belkin Switch; **c** operation requests that do not provide the results

For future research, we will utilize the system of the proposed adaptive IoT and WoT convergence platform to establish services on our methodology. Also, we will include useful IoT and WoT platform involved in the mechanism of intelligent IoT applications and services.

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