Web of Things: Future Internet Technologies and Applications

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Abstract

The recent development on network embedded devices (sensors, smartphones, etc) is offering the opportunity that our world is rapidly evolving towards the new era of Web of Things (WoT) in which all sorts of devices around us are capable of communicating and sharing data over the Internet. Therefore, future Web technologies making them easier to use and integrate in conventional Web applications have become an active research area. In this paper, we overview the recent researches of WoT from various point of views and key challenging technical issues based on recent researches. This work also introduces prototype platforms special focused on systems achieving high building energy performance on WoT. Currently, the smart building energy management system is regarded as an active research field because commercial buildings are consuming high energy and receiving much attention with regard to the potential savings that can be achieved with new technologies.

Keywords*: Web of things, Internet of things, Smart device, Future Internet, future Web*

1. Introduction

For the last several decades, the Internet has evolved amazingly around almost every part of our lives. This technical evolution started from the early research on packet switching and the ARPANET [1] to create a network of geographically separated computers in order to exchange information using a specified protocol. The Internet today becomes a medium to connect people rather computers. It is reported that about 1.7 billion users are connected to the Internet and the National Science Foundation predicts that the Internet will have nearly 5 billion users by 2020. Here, we are able to access new ideas, more information, unlimited possibilities, and a whole new world of communities. It has grown and evolved to influence how we interact, conduct business, learn, and proceed day to day.

Furthermore, people have been connecting things or objects to the Internet known as the IoT (Internet of Things). As a result, the Internet is expected to become a network of devices rather than a network of computers. Today, the Internet has around 575 million host computers, according to the CIA World Factbook 2009. But the NSF is expecting billions of sensors on buildings and bridges to be connected to the Internet for such uses as electricity and security monitoring. By 2020, it is expected that the number of Internet-connected sensors will be orders of magnitude larger than the number of users [2]. This trend opens the vision of IoT in which all devices become connected with each other using low power wireless communications.

As more and more devices get connected to the Internet, the next logical step is to use the World Wide Web and its associated technologies as a platform for smart things (i.e., sensor and actuator networks, embedded devices, electronic appliances and digitally enhanced everyday objects). As a

Received: Nov. 27, 2013, Revised: Dec. 12, 2013, Accepted: Dec. 18, 2013

result, smart things become easier to build upon. In such an architecture, popular Web technologies (e.g., HTML, JavaScript, Ajax, PHP, Ruby) can be used to build applications involving smart things, and users can leverage well-known Web mechanisms (e.g., browsing, searching, bookmarking, caching, linking) to share and interact with these devices [3].

Figure 1 shows the stages of Web technology evolution [4], starting from Web of Content in the 90s of the last century, over to the Web of Communication in the first decade of the current century. Presently the Web of Context arises. Research focuses on the Web of Things presently. Common resources in the Web are content, information, services, people and things. The Web of Things has explored the development of applications built upon physical objects not only connected to the Internet but to the Web. A variety of recent research activities [5-9],–have been launched to address those challenging issues, from the technological to the social aspects.

This paper introduces the concept of WoT and the state of its development by reviewing recent research activities. Also, this survey summarizes the key challenging issues to be concerned technically and future potentials of WoT. For the reference system, this work includes the use case and architectural platform for managing building energy management systems because commercial buildings are consuming high energy and are expected to achieve high energy savings with the help of the technologies of WoT.

The organization of this paper is as follows. Section 2 introduces the background of WoT technologies with prototype systems and Section 3 overviews BEMS. The conclusion is mentioned in the last section.

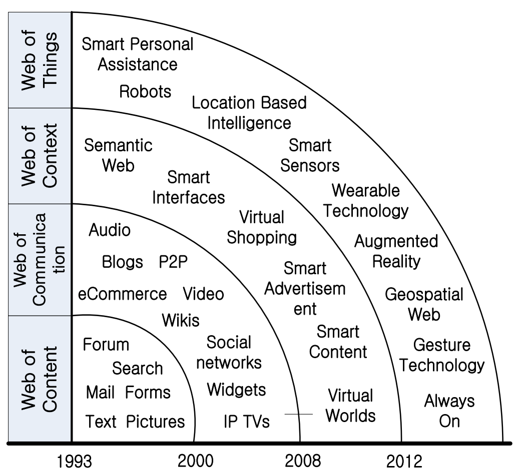

Figure 1. Web technology evolution

2. Background

2.1. Web of Things

In many recent articles and papers, we can find the IoT or WoT, and under the expectation that there will be 1 trillion Internet connected devices by 2025, we can easily imagine the IoT market will grow more rapidly than the one of Smartphones. The concept of WoT extends the Web into the real world other than connecting just computers; the open Web standards are supported for information sharing and device interoperation. By penetrating all embedded devices around us including smart things into existing Web, the conventional web services are enriched with physical world services. This WoT vision enables a new way of narrowing the barrier between virtual and physical worlds [9].

Figure 2 shows the conceptual architecture of WoT. Here, many different kinds of smart things with various capabilities may be integrated into the Web; for this purpose we have to abstract those devices into reusable web services. Web services are defined by the World Wide Web Consortium (W3C) [10] as a software system designed to support interoperable machine-to-machine communications over a network. W3C introduces two different types of web services: REST-compliant Web services using a uniform set of "stateless" operations and arbitrary Web services.

The goal of speech and audio classification is to partition and label an input audio stream into speech, music, and commercials

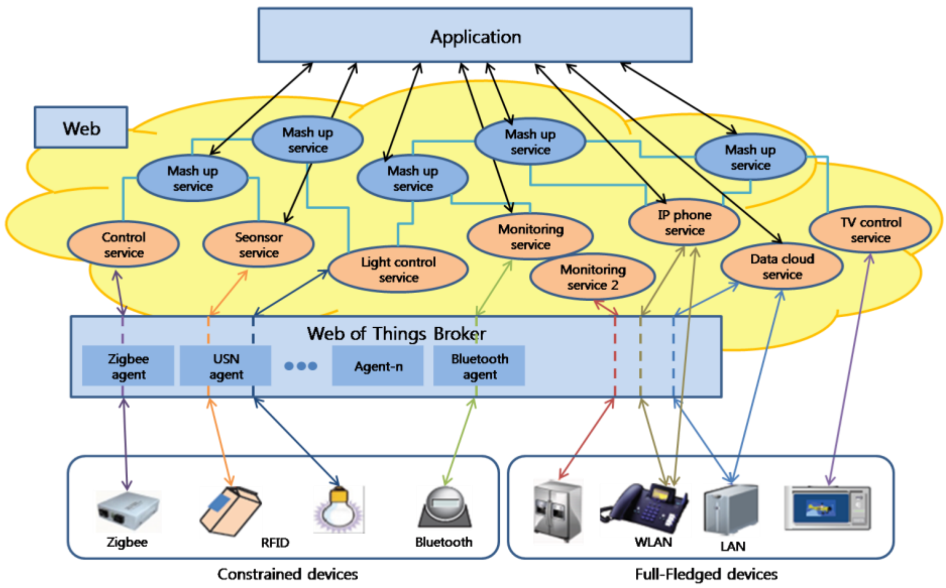

Figure 2. Web of Thing architecture

In [5] this paper proposes two ways to integrate real-world things into the existing Web by turning real objects into RESTful resources that can be used directly over HTTP. First, it describes how an actual Web server can be implemented on tiny embedded devices to turn them into RESTful resources. Second, when computational resources are too limited or devices do not offer a RESTful interface, we propose using an intermediate gateway that can offer a unified REST API to access these devices, by hiding the actual communication protocols used to interact with them.

2.2. Use cases

The article [11] summarizes the applications in detail very well and they are largely categorized into two groups. One covers the idea of millions of heterogeneous "aware" and interconnected devices with unique IDs interacting with other machines/objects, infrastructure, and the physical environment. Typical applications regarding the automation and machine-to-machine (M2M), machine-to-infrastructure (M2I) and machine-to-nature (M2N) communications could be included. The other is about data mining of people's behaviors that can generate useful information for additional applications.

When devices can sense and communicate via the Internet, they can go beyond local embedded processing to access and take advantage of remote super-computing nodes. This allows a device to run more sophisticated analyses, make complex decisions and respond to local needs quickly, often with no human intervention required [12]. So, along with categorization of applications, this work introduces several use cases.

The first use case is TCC&R which refers to remote tracking/monitoring, and if needed, command, control and routing functions for tasks and processes. In this group, all equipments and devices around us will be equipped with more processing capability with a unique ID and be smart. Those smart devices can then be connected via wired or wireless communication, allowing a user to monitor his or her house remotely, and change their operating conditions through mobile devices

The second one is a group of applications in the area of asset tracking. Currently, it is done with barcodes, smart tags, and near-field communication (NFC) and RFID to globally track all kinds of objects, interactively. Some telehealth-related services also belong in this category.

The next area is a field of process control and optimization through monitoring with various classes of sensors to provide data so a process can be controlled remotely.

The fourth one is the area of resource allocation and optimization. As an ideal example of this use case, this article provides the smart energy market in which we can access information about energy consumption and react to the information to optimize the allocation of energy use.

The last one is context-aware automation and decision optimization. This category is the most fascinating, as it refers to monitoring unknown factors (environmental, interaction between machines and infrastructures, etc.) and having machines make decisions that are as “human-like” as possible [12]. Remote patient monitoring is another example relevant to this use case. For instance, imagine an implantable sensing node or body area network that can track biometrics and send signals regarding an abnormal readout for patients. Figure 3 [13] shows an example of this application with typical body area network.

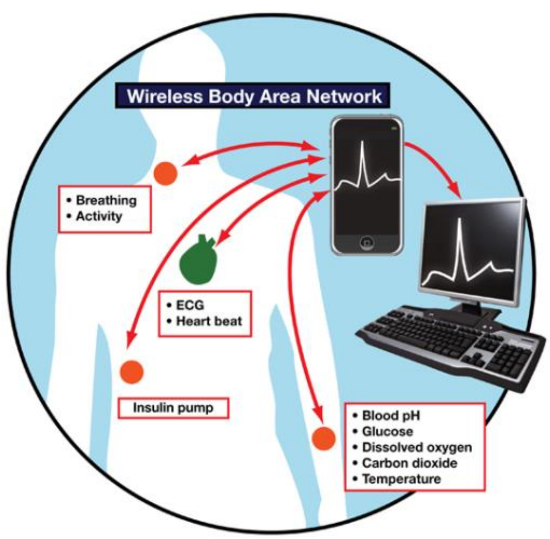

Figure 3. Remote patient monitoring with body area network

For these use cases, an application may have several functional blocks and Figure 4 depicts the functional view of IoT technologies. The major ones are sensing nodes, layers of local embedded processing nodes, remote cloud-based processing, wired and wireless communication capability for connectivity nodes, and so on.

There have been several real prototype systems [9] based on WoT such as the SenseWeb of Microsoft Research [13], the SensorBase of the Center for Embedded Networked Sensing (CENS) at UCLA [14], the Sensorpedia of Oak Ridge National Laboratory [15], and so on. In this paper, we introduce a representative one, The SenseWeb project at Microsoft Research which aims to address these challenges by providing a common platform and a set of tools for data owners to easily publish their data and for users to make useful queries over the live data sources. It offers a platform mainly targeting for participatory sensing. A sensor gateway is used by sensors as a uniform interface to share sensory data. SOAP-based APIs are used to allow developing sensing applications with shared sensing resources.

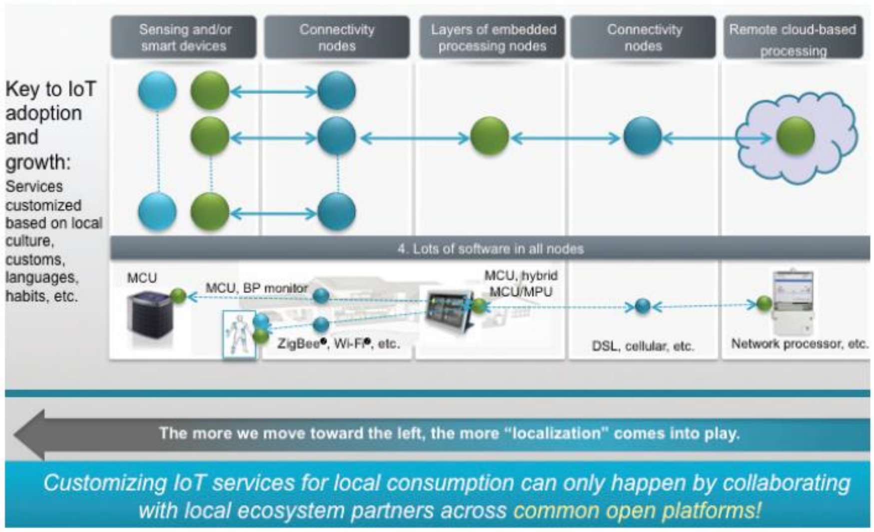

Figure 4. Functional view of Internet of Things technologies [12]

The SenseWeb platform transparently provides mechanisms to archive and index data, to process queries, to aggregate and present results on geo-centric web interfaces. The SenseWeb platform consists of the following four components: the data publishing toolkit which publishes sensor data and metadata, a GeoDB that indexes the data so that it can be queried efficiently, an aggregator which aggregates clusters and summarizes data in useful ways, and the client-side GUI which lets users query data sources and view results.

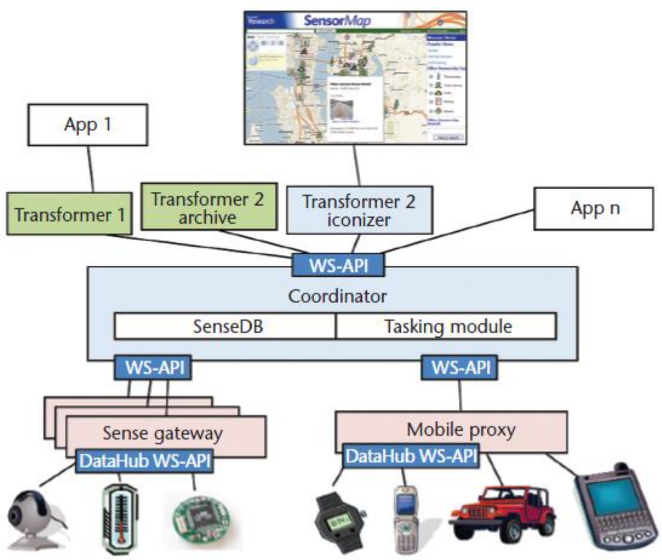

Figure 5. MicroSoft SenseWeb: open system architecture for flexible sharing [16]

3. Building Energy Management System

3.1. Background

The In WoT, we can build applications by configuring several web services with automatic controlling functions. The representative application is the BAS (Building Automation System) which includes HVAC (Heating Ventilating and Air Conditioning), Electrical and Lighting, Integrated Automation, and Communications. Currently, smart building energy management system is regarded as an active research field because commercial buildings are consuming high energy and receiving much attention with regard to the potential savings that can be achieved with new technologies.

BEMS typically aims at offering a more efficient use of building resources, energy cost reduction and a comfortable environment through energy consumption information received from the building. BEMS usually provides the functions of energy monitoring, energy consumption analysis, energy control and management, systematic analysis of building energy, and environment optimized operation plan based on the equipment efficiency analysis. From this point of view, BEMS can have obvious Internet of Things features. Using this technology, we can build applications by configuring several web services with automatic controlling functions. The representative application is BAS (Building Automation System) which includes HVAC (Heating Ventilating and Air Conditioning), Electrical and Lighting, Integrated Automation, and Communications.

In general, BASs have been developed using several standard communication protocols: LonWorks, Building Automation and Control Network (BACnet) and KNX. However, the problem is that they were not enough to cover all of the integration issues. In recent years, this limitation has been overcome with the help of the Web technologies by adopting SOC (Service Oriented Computing) and Web services that are self-contained, and modular software applications that can be published, located, and called across the web [17]. They are based on other Web technologies, such as Extensible Markup Language (XML), Web Services Description Language (WSDL), and Simple Object Access Protocol (SOAP).

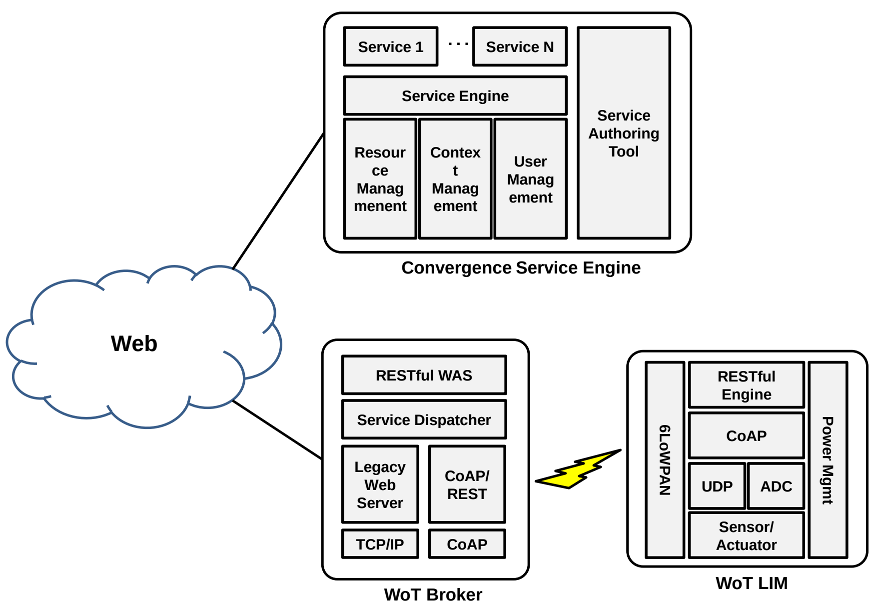

Figure 6. Overall architecture of WoT for BEMS

3.2. System Architecture

In this section, we will introduce a system architecture of smart BEMS (Building Energy Management Systems) based on WoT technology [18]. The proposed architecture is depicted in Figure 6 in which three major components are configured to achieve the purpose of the proposed system. For sensing node, LIM (Local Interface Module) with wireless network communication have built on top of this ecosystem of RESTful devices, and the WoT Broker module is devised for processing all the received data. Finally, in the Convergence Service Engine, several applications are integrated into a service engine based on the convergence of information technology and Web-based control software.

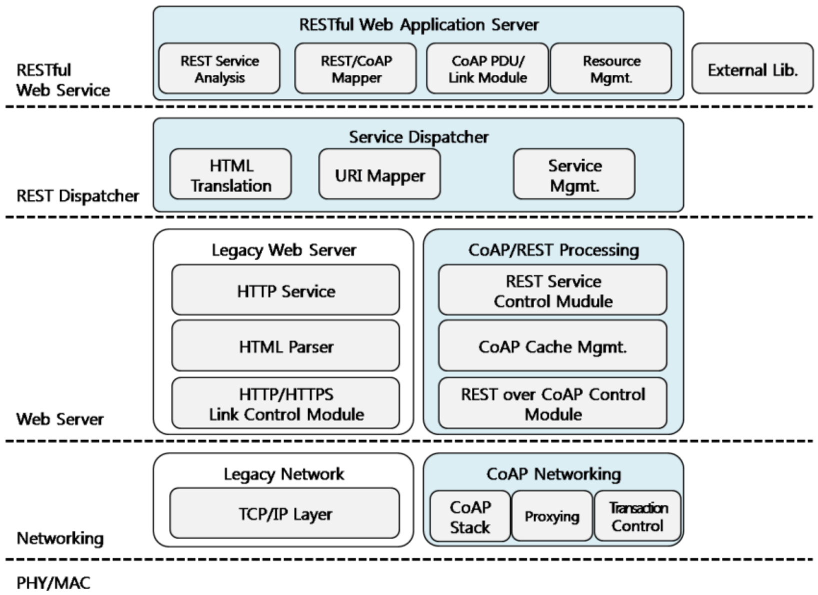

Figure 7. Software structure of WoT for BEMS

The software subsystem consists of four layers: networking, web server, REST dispatch, and RESTful Web service. Details of each layer are depicted in Figure 7. Generally, the nature of Internet of Things is hierarchical information processing and control. Most information processing and control should be finished at the LIM and WoT Broker level rather than at servers. In M2M (Machine to Machine) communications, CoAP (Constrained Application Protocol) is proposed by the IETF to optimize the use of the RESTful web service architecture in constrained nodes and networks.

4. Conclusion

Due to the fast growing communication and processing power technology, the future Internet will be highly focused on connecting things of wide spreading heterogeneous networked embedded devices around us rather than people. This trend allows our computing environments to move towards the era of Web of Things. This paper has provided an overview of the researches and technical issues on Web of Things over recent years. A prototype system was introduced in the field of building energy management systems, a representative WoT application by configuring several web services with automatic controlling functions. The system was composed of three major components: the LIM for the sensing node, the WoT Broker for data processing, and the Convergence Service Engine for web-based controlling. This application has been an active research field because commercial buildings are regarded as a potential area for high energy savings. Future work may include the introduction of the overall system architecture with detailed functional description.

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