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A Distributed Middleware Based on Semantic Web Service for Sensor Web

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Abstract. Due to the rapid development of computing and communication technologies, the capacity of the microprocessor chip is becoming stronger with a smaller size and a lower price. The increasing availability of abundant sensor devices play an important role in our everyday life as the interface between physical and digital worlds under the technologies of sensor network mature and increasing deployment. A challenge is emerging, which varied sensor data can be exchanged automatic among heterogeneous sensor networks and end-users can access information easily everywhere over the Internet. In this paper, a distributed middleware based on semantic web service is proposed to address this issue. The functionalities of sensor networks are encapsulated within web services, which will be described semantically and registered in the middleware. It provides a mechanism that varied sensor networks can be connected to the middleware and exchange information by a uniform data format based on SML. Service consumer can access sensor networks and integrate the sensor to their special applications through a stack of Internet standard protocols.

Keywords: sensor web; semantic web; web service; distributed middleware; Internet of Things

1 Introduction

Due to the rapid development of computing and communication technologies, the capacity of the microprocessor chip is becoming stronger with a smaller size and a lower price. The increasing availability of abundant sensor devices play an important role in our everyday life as the interface between physical and digital worlds under the technologies of sensor networks mature and increasing deployment. However, the current sensor networks are designed either for specific domain applications or for data collection purposes. Although these more closed sensor systems are significant for special or other commercial applications, it is very difficult for the end users to access and use the vast available sensor data easily. A challenge is emerging, which varied data can be exchanged automatic among heterogeneous sensor networks and end-users can access information easily everywhere over the Internet. The main barriers are lacking of uniform operations and standard representation for sensor data that can be used by diverse sensor applications. In order to address these issues, Sensor Web [1, 2] concept is proposed. A definition of Sensor Web was defined by NASA that A Sensor Web is a system of intra-communicating spatially distributed sensor pods that can be deployed to monitor and explore new environments [3]. Sensor Web is a revolutionary concept towards achieving a collaborative, coherent, consistent and consolidated sensor data collection, fusion and distributed systems [4]. Achieving the vision of Sensor web has also met some challenges [5]. First is the abstraction level in which sensor data can be obtained, processed and managed in general; Second is the adequate characterization and management of the quality (and quality of service) of sensor data; Third is to do with the integration and fusion of data coming from heterogeneous sensor networks; Fourth is the identification and location of relevant sensor-based data sources; Finally, is enable to create application rapidly.

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Since web service is modular, self-describing and self-contained, especially it can be deployed, discovered and invoked through a stack of Internet standard protocols, such as HTTP, WSDL [6], SOAP [7], XML [8] and UDDI [9]. Web service is adopted in widespread fields and is rapidly emerging paradigm of distributed architecture for integrating heterogeneous or homogeneous system (or software components) within or across organization boundary. The limitation of web service is that all properties of web service and data representation are described by XML. Although XML provides a uniform data representation on syntax level, the machine can't understand the meaning of data. Web Service can't achieve some operations automatically, such as discovery, invoking. Semantic Web [10] is presented to a direction to address this limitation. The integration of Semantic Web, Web Service and Sensor Web that may be an efficient way to achieve the vision of Sensor Web.

In this paper, a DMBSWS (Distributed Middleware Based on Semantic Web Service) for Sensor Web is proposed. The capabilities of varied sensor networks will be encapsulated within web services and be registered in DMBSWS. It provides a mechanism that varied sensor network can be connected to DMBSWS and exchange information by means of a uniform data format based on SML. End users can access these services directly through the Web browser or integrate them into their applications by interfaces.

The remainder of this paper is organized as follows. Related work on existing approach for sensor web is described in Section 2. Section 3 describes a distributed middleware based on semantic web service for sensor web and the design and implementation of its architecture. Section 4 describes a simple testbed to proof the effectivity of the presented approach. The summary and the future work are concluded in section 5.

2 Related Works

In order to achieve the vision of Sensor Web, many approaches for Sensor Web have been proposed in the past years. The Sensor Web Enablement (SWE) initiative proposed by the Open Geospatial Consortium (OGC) is a revolutionary approach for exploiting web-connected sensors and the goal of SWE is the creation of web-based sensors and repositories of sensor data discoverable, accessible and where application controllable via the Web[11]. Although a set of specifications and services are defined, SWE has some drawbacks[4].Firstly, Semantic interoperability is still a problem because SWE framework has no explicit ontological presentation. Second, SWE mostly addresses data acquisition but neglects filtering and information overload. Finally, SWE wants support for deploying, discovering and accessing Sensor Web applications. GeoSWIFT [12] (Geospatial Sensor Web Information Fusion Technology) is proposed by GeoICT Lab of York University, which serves as a gateway that integrates and fuses observations from heterogeneous spatial enabled sensors. The framework consists of three layers, the bottom layer is sensor layer that comprises the actual sensor devices; the middle layer is communication layer, which controls the data/command transmission within and between the sensor layer and the information layer; the top layer is information layer, where the sensing resources can be stored, exchanged, managed, displayed and analyzed. The framework is based on web services and it advocates use of the OGC SWE standards for integrating and exposing sensor data. IrisNet [13] (Internet-scale Resource Intensive Sensor Network Services) is also distributed architecture that comprises two layers: sensing agents and organizing agents. Sensing Agents implement the generic data acquisition interface to access sensors and organizing agents store the service specific data that the sensing agents produce in a distributed database. The feature of IrisNet is that sensing agents provide pre-processes and reduces raw data from physical sensors. Organizing agents collect and analyze data from sensing agents to answer the special queries related to the services. Both GeoSWIFT and IrisNet address the challenge by providing a distributed framework for publishing, discovering and accessing sensor network. However, they have some limitations i.e. lacking semantic, i.e. belonging to a single or a group of organizations. SWAP (Sensor Web Agent Platform) [4] has been proposed to address the issue of lacking semantic. The SWAP architecture leverages the MAS (Multi Agent System) infrastructure services and the ontological infrastructure described above to deliver sensor web applications to end-users. The architecture aims to address the three key technical challenges of automatic discovery and utilization of sensor resources, sensor and simulation data fusion and context-based information extraction. The architecture is based on three-tier architecture, separating Sensor Layer, Knowledge Layer and Application Layer. Sensor agents will access physical or virtual sensors directly or make use of intermediary services like those specified by the Open Geospatial Consortium on the sensor layer. Messages sent and received by sensor agents follow a specific structure that is described in ontologies. All agents on the knowledge layer process and exchange (raw) data from sensor agent based on a common understanding of exchange formats and a general concept specified in multiple ontologies. The application layer has provided user interfaces that allow humans as well as machines to interact with the platform.

3 Descriptions of DMBSWS

Although Sensor devices will be relatively cheap instruments, sensors' computing processors will be faster than ever due to the highly competitive and advanced semi-conductor industry. The prominent character of Sensor Web is universality in that existing multiplies redundant and varied sensors. The DMBSWS integrates the technology of Semantic Web, Web Service and Sensor network to create a distributed middleware on the Internet. End-users can access sensor information, discover sensor services easily and create application quickly. Figure1 describes the deployment of DMBSWS on the Internet. All DMBSWS nodes will be organized by Peer-to-Peer architecture and become a sensor service oriented overlay network on Internet. Both end-users and sensor service providers can access varied sensor networks easily.Figure2 describes the architecture of DMBSWS, which is consisted of four layers, i.e. the physical layer, i.e. the adaptive layer, i.e. the knowledge layer and the application layer. The detail of each layer is described as follow.

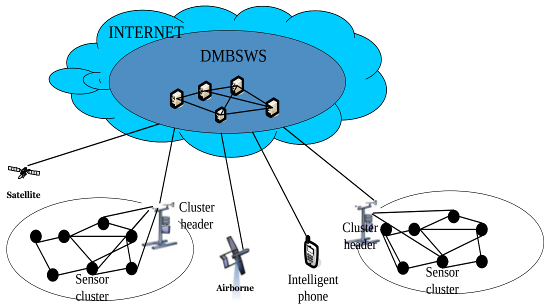

Figure1: The deployment of DMBSWS

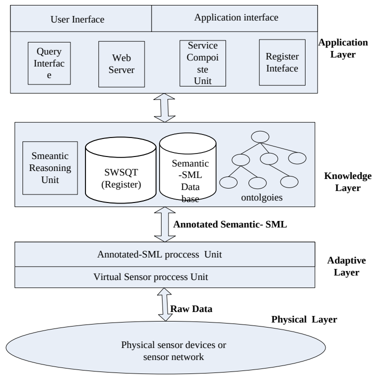

Figure2: Architecture of DMBSWS

3.1 The physical layer.

The functionalities of this physical layer are just like the previous approaches. Sensor provides a usable output in response to a specific physical quantity, property or condition which is measured [14].Due to low-cost mass production, most sensor nodes have no global ID unlike traditional computer networks, especially those nodes may be scattered deployment. In this paper, sensor nodes are classified to two kinds. One is that sensors have relative static location and long lifetime, such as camera, satellite; the other is that the cluster header nodes in a cluster, which manage and receive data from other nodes in its cluster.

3.2 The Adaptive layer.

In the physical layer, sensors transmit and process raw data, which will have varied representation for heterogeneous sensor networks. This paper also advocates the use of the OGC SWE specifications to describe sensor data on syntax level, such as SML [15] (Sensor Model Language) and wants to build a unify exchange data format by means of SML. A Virtual Sensor Node is defined by the middleware, which connects, manages the physical sensor nodes and receives raw data from physical layer. Each cluster header or relative static sensor will connect to Virtual Sensor respectively. The Virtual Sensor Node just as a Sensor network gateway, which has two core functionalities. One is that it receives raw data from physical layer and re-presents the data by SWE standards. The other is that it annotates semantic to the SML format by XLink [16] or RDFa.

(http://www.w3.org/TR/rdfa-syntax/) The semantic-SML file will be inferred by reasoning tools, such as Jena, RACER on the knowledge layer. Although sensor networks belong to different organization and have varied raw data format, data can be exchanged with SML among them. When sensor network connects to the middleware, it will be needed to provide a special Virtual Sensor, which can convert its special data format to SML automatically.

3.3 The Knowledge Layer.

The knowledge layer has three core components. First is semantic processing component. The annotated semantic-SML file is received from the adaptive layer, which will be analyzed in deeply and semantic inference by semantic processing component and the analyzed information will be stored as knowledge in database for end-users querying. Second is register component. Although UDDI is an industry standard to solve web service discovery problem and it also is a registry that allows service providers to describe, register their web services and discovery web service for service consumer to fit their requirements or integrate within their application, it can't fit the Sensor Web for some self limitations [17] and characters of sensor web [18].In this layer, a SWSQT (Semantic Web Service Query Tree) is presented, which organizes web services efficiently. Firstly, it retrieves the semantic information of web service's properties from semantic profiles and calculates the semantic similarity of web services; and then SWSQT will be built for storing their relationship with a tree structure. The trunk node stores metadata of web service and the leaf node stores each web service's detail information and its relationship. Finally, a quick semantic query algorithm based on SWSQT is proposed. The detail of SWSQT and quick query algorithm will be introduced in another paper due to limited space of this paper. The third is ontology component, which stores the ontologies that will be used, i.e. OWL-time Ontology.

3.4 The Application Layer.

The application layer is mostly oriented to end-users, which provides user interfaces for humans and application interfaces for machine. A sensor web server is built on the middleware and end-users can access sensor web information everywhere on Internet by a web browser. In this layer, it has three core components or interfaces. One is register interface, which help for sensor service providers register sensor services. Service providers will encapsulate the functionalities of sensor networks within web services and add semantic to profiles of web services. They submit Virtual Sensor service and the semantic profiles of web services, i.e. SAWSDL, OWL-S. If they want to register the sensor instances, they also need to submit the metadata of the sensor nodes. The registering service or sensor instances will be organized by SWSQT on the knowledge layer. Another is query interface. End-users can discover web services of sensor network, sensor instances and query knowledge information. Last is service composition component. Although end-user can access the primitive service of sensor network easily, it can't satisfy some of their requirements, which need multi-primitive service to collaborate. The service composition component aims to solve this problem. In this scene, the composition component can discover, select some primitive web services and composite them to a compound web service.

4 Primitive Experiments

A test-bed is presented in the section in order to evaluate the proposed approach. Six temperature sensors, five humidity-sensors, two digit cameras and a smog sensor will be installed in a computer servers' room. These sensors can monitor the condition of the room and users can query information of the Room everywhere in the Internet easily. Each sensor connects to a virtual sensor in DMBSWS by ZigBee protocols and digit cameras connect to virtual sensor by WLAN. The virtual sensor receives the raw data from physical sensors and converts the data to Semantic-SML file. The annotated semantic-SML will be stored in database and be queried by SPARQL. DMBSWS will provide a query interface that encapsulated the functionality of SPARQL. A sensor alert service will be provided by the smog sensor. When smog sensor detects smog in the room, it will send an alert message. End-users not only can access and manage the entire sensors in the room by DMBSWS, but also they can get the analyzed information benefit from reasoning the semantic-SML data.

5 Discussion and Conclusions

In this paper, a distributed middleware based on semantic web service for achieving vision of sensor web is described. Sensor service providers can develop and deploy sensor web applications over the Internet by means of the middleware and end-user can also access sensor information easily. The use of the OGC SWE standard is advocated for reaching a common exchange data format on the syntax and DMBSWS adopts the Semantic Web technologies to add semantic to common data format, so it can easily achieve data fusion among the heterogeneous sensor networks. In the middleware, a register mechanism is proposed which can organize the service efficiently and query service quickly. Compared existing approaches, it has another two core features. One is that end-user can achieve varied operation directly over Internet by a web browser; the other is Virtual sensor mechanism that it provides a way to exchange information among varied sensor networks. The role of Virtual Sensor in DMBSWS is the same as to the role of IP protocol in Internet.

Although the research of sensor web is still in infancy, the presented middleware do not aim to address the all challenges of sensor web. It hopes the presented Middleware is a beneficial attempt in achieving the vision of Sensor Web. Our future works will focus on the following directions. Firstly, an efficient service organizing mechanism and quick query algorithm are key technologies of Sensor Web. It will be more difficult to organize service of sensor web and sensor instances because they are mobility and low-lifetime. The register needs to consider this condition and can update the query index when they are invalid. And then, the auto data fusion is very important for integrating varied sensor networks. Finally, the middleware will be explored deeply in order to satisfy varied requirements of Sensor web. Due to amount of sensor and sensor networks increasing and deploying, the Sensor Web will be more important in the next network, especially in the IOT (Internet of Things) and it may be an interoperable infrastructure of IOT.

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