Modelling and Analysis of a Semantic Sensor Service Provider Ontology

Faiza Tila and Do Kim
Computer Engineering Department, Jeju National University, South Korea

Abstract: *The realization of Internet of Things has gained a huge amount of momentum in the past few years. It's vision is to interconnect devices from all over the world. These devices are heterogeneous and produce data that is multi modal and diverse in nature. The heterogeneity of the devices and data makes interoperability an issue in IoT. In this paper we are presenting the modelling of a semantic sensor service provider and its ontology i.e., the Sensor Service Provider (SSP) ontology. The semantic sensor service provider is a module which is a part of a larger system i.e., a semantic IoT system based on context aggregation of an indoor environment. To provide interoperability between the devices used by the system, we have developed ontologies for each domain of the system. The modelling of the ontology presented in this paper reuses the SSN ontology to define the basic concepts and observations of a sensor, and has been extended to define concepts related to the module itself. Simple Protocol and Resource Description Framework (RDF) Query Language (SPARQL) queries are used to retrieve data from the ontology as well as manipulate the data stored to it.*

Keywords: *RDF, web ontology language, internet of things, SPARQL, semantic sensor service provider, and semantic sensor service provider ontology.*

Received May 4, 2015; accepted January 13, 2016

1. Introduction

In simple words, Internet of Things (IoT) refers to objects ("things/resources") and the virtual representations of these objects on the internet. The aim of IoT is to represent real world entities on the internet and to interconnect them to provide real world services. These services are offered by various heterogeneous resources or objects. A lot of successful research in the network area and device capabilities have allowed these devices to obtain communication and computation capabilities for connecting and interacting with their surrounding environment. These objects produce data/services that represent information about the real world and how to interact with it. To enhance these real world data/services they must be able to integrate with data from different sources. Defining these data/services in a uniform way not only allows integration but also support autonomous reasoning and decision making mechanisms [6].

The main support for realizing IoT comes from the progress in wireless sensor and actuator networks, and from constructing low cost and energy efficient hardware for sensor and device communications. Data collected from different devices and sensors is usually heterogeneous i.e. diverse in nature. This diversity, inconsistency and pervasiveness of the data makes it a challenging task to process, integrate and interpret it. This makes interoperability among things on the internet one of the most important challenge. The word semantic literally means meaning of something. The aim of the semantic web is to provide meaningful data rather than focusing on the structure or representation of data [14]. Its vision is to connect and to attach meaning to data on the internet for the machines and humans to be able to understand what the data is and where is it coming from. Issues related to interoperability and ambiguity leads to semantic oriented solution towards IoT. Applying semantic technologies to the things on IoT will make its data unambiguous and transparent for both the users and the applications using it. It also provides efficient data access and integration, resource discovery, reasoning and knowledge extraction.

For different stakeholders to get access and interpret the data, semantic interoperability is required. Things on the IoT need to exchange data among each other and with other users on the internet [2]. Semantic annotation of data can provide machine interpretable descriptions on what the data represents, where it originates from, how it can be related to its surroundings and who is providing it. The Semantic Web is defined by the W3C Semantic Web Activity as an entity that is the extension of the World Wide Web in which the meaning or semantics of information on the web is annotated to it so that it is machine understandable [17]. Semantic Web is growing with each day passing. To relate the data or information to make it machine interpretable, the semantics or definitions for information is defined through ontologies.

The principal technologies for Semantic Web includes the data representation model Resource

Description Framework [12], the ontology representation languages such as Resource Description Framework (RDF) Schema, the Web Ontology Language (WOL) [11], and SPARQL [15] RDF query language is now a common method of querying the ontology data. Various domains can get benefits from these technologies mainly with issues like heterogeneity, complexity, and volume. These technologies are helpful in managing, querying and combining sensors and observation data. Semantic web technologies could Be used in isolation or in augmenting SWE standards in the form of Semantic Sensor Web [7].

In this paper a semantic sensor service provider ontology is modelled. The proposed ontology model is considered as the key solution for the devices to convey their context as useful data. On to logy and data descriptions of the contextual data makes it interoperable for the users and stakeholders using the same ontology. The proposed ontology portrays the functionality of the semantic sensor service provider module which is a part of the semantic IoT system for indoor environment control. The system is an IoT structure that consists of several service modules. To provide interoperability between these domains in order to use their services, we have using semantic technologies. In this paper we have presented the design and implementation of the semantic sensor service provider module and the ontology related to it. The semantic sensor service provider's function is to store and provide sensor information to the modules above it. It provides services for manipulating the sensor information as well as for provision of the sensor information. The semantic sensor service provider ontology is a knowledge base representing sensor information and its relationships to other modules in the system. The ontology provides a machine interpretable definition of all the concepts defined in the semantic sensor service provider module. It describes the different attributes of the sensors in a network by defining the data property component of ontology. It uses the SSN ontology to define the sensor concepts.

The rest of the paper is structured as follows. Section 2 presents the related work describing different studies using semantic technologies for IoT, Section 3 provides the design architecture of the SSSP and section 4 presents the ontology modelling of the semantic sensor service provider. Section 5 gives the performance analysis of the system based on SQL and Simple Protocol and RDF Query Language (SPARQL) queries. Finally Section 6 illustrates the conclusion and future work.

2. Related Work

Various physical objects or resources are referred to as things on the IoT. These things can be of interest to humans, e.g., a heater to control temperature, a parcel to track, the motion in a room to detect, or an industrial machine to monitor. These things are connected to the IoT using different technologies based on their behaviour. According to the authors in [10], there will be 25 billion devices connected to the internet by 2015 and 50 billion by 2020. These devices will need to connect and communicate in multiple ways. Due to the large diversity of these devices, IoT requires interoperability to support different tasks such as object addressing, tracking, information representation, storage and exchange. The research conducted in [6] is based on developing an ontology that acts as a mediator to hide the heterogeneity of IoT entities. They focus on three different tasks that are:

a) The alignment of IoT entities metadata and matchmaking.
b) Semantic registration of IoT entities.
c) The alignment of message exchange during the device to application communication.

Sara *et al*. [9] have used the approach of semantic technologies to address the issue of interoperability and flexibility in IoT. The research includes an overview of a service oriented middleware solution for the internet of things. The middleware provides interoperability using a knowledge base composed of ontologies. The focus of the study is modelling a set of ontologies that describe the devices and their functionalities. The functionalities of the things on the internet are provided as services on appropriate devices through the middleware. Wang *et al*. [16] presents context information in smart environments by using OWL ontologies. They have emphasized the quality of information using OWL language to allow and support the semantic interoperation, sharing of context knowledge and reasoning on the context collected.

The term ontology has been used in a variety of contexts. The idea of using ontology driven information system for sensor networks was introduced in [1]. The authors have presented a two phased solution that can be employed to enable a real world wireless sensor network to adapt itself to variations in environmental conditions. The first phase executes an efficient algorithm to dynamically calibrate sensed data, and the second phase executes an efficient ontology driven algorithm to determine the future state of the network under existing conditions. The ontology captures the most important features of a sensor node that describe its functionality and its current state.

Use of sensing devices for collecting data is increasing due to its applications in various areas. This increase is causing an upsurge of data with different data formats from different devices, which requires advanced analytical processing and interpretation by machines. This sensor data is becoming the focus for many researchers these days. The Sensor Web Enablement (SWE) [14] initiative of the Open

Geospatial Consortium (OGC) defined data encodings and web services to store and access sensor-related data. The models, encodings, and services of the SWE architecture enables implementation of the interoperable and scalable service oriented networks of heterogeneous sensor systems and client applications.

In this regard, SemSOS has proposed ontology models for sensor domain and sensor observations, with semantics annotated to the sensor data and using these models to reason sensor observations. This enables SemSOS to provide the ability to query high level knowledge of the environment as well as low level raw sensor data [8].

An ontology based prototype sensor repository referred to as OntoSensor [5] has also been developed. OntoSensor is a repository containing concepts and relations definitions from SensorML [4]. It extends concepts from the IEEE SUMO ontology, and reference terms from ISO 19115. The authors approach is to use upper level ontologies to deploy a framework in which translation among different domain ontologies can be more readily accomplished. The definitions of high level concepts pertaining to sensors can be used as background knowledge for the integration of data from heterogeneous sensors.

Barnaghi *et al*. [3] have presented a semantic model for heterogeneous sensor data representation. A sensor data description model is created by using the common standards and logical description frameworks proposed by the semantic web community. The work describes a sensor data ontology which is created based on the SWE and SensorML data component models.

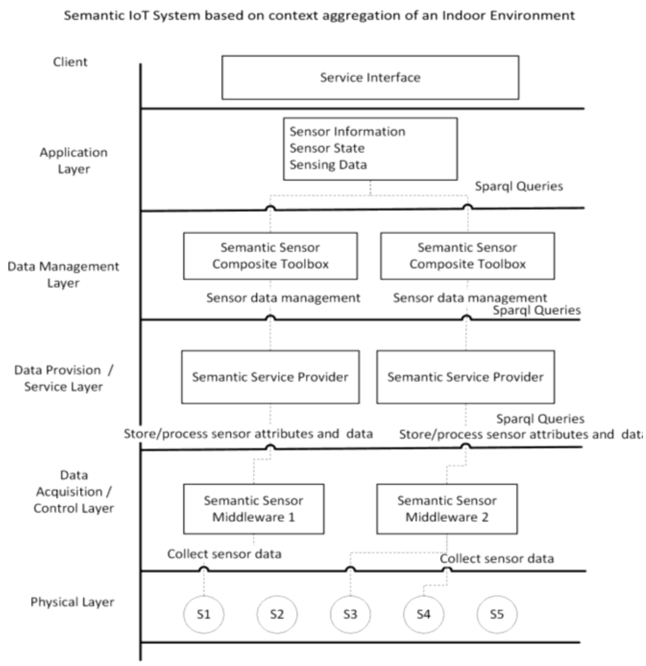

Figure 1. Semantic IoT system based on context aggregation of an indoor environment.

Based on the systems described above, it can be seen that ontologies can be very helpful in representing data from disparate sources in a meaningful way. In the proposed system we have used the same idea. The architecture of the system is shown in Figure 1. It is a layered architecture, with each layer having a specific functionality. Physical layer consists of the devices used by the system to collect environmental data. Data Acquisition layer consists of the middleware's developed for the system to collect the context data of the devices. The Service layer consists of service providers that stores and uses the data collected from the Acquisition layer. Data Management layer consists of toolboxes developed for each service provider. These can be used by the users to create their own services as well as to manipulate the data stored in the ontology. The next layer is the Application layer that uses the provision services of the service providers to bind resource to its location. The topmost layer is a web base application client which is a simple visualization tool. It offers a simple interface for viewing the bonded devices and their information.

3. Semantic Sensor Service Provider Design

The semantic sensor service provider is a module that collects processes and manages the information of the sensors registered in the ontology. This module provides services that are used by the other modules in the system. The detailed configuration of the sensor service provider layer is shown in It shows the functionalities offered by each service provided by this module. Figure 2 also gives an illustration of the sensor service provider ontology and database. The sensor service provider ontology reuses the Semantic Sensor Network (SSN) ontology. The semantic service interface provides access to the modules that uses the services of the semantic sensor service provider. Semantic queries are run and processed using dotNetRdf API. The three services provided by this module are semantic content service, semantic provider service and sensing service. Semantic content service is used for middleware information and sensor information management. Middleware information management involves storing middleware id, IP and service access information. Sensor information management involves creation and management of sensor information (such as sensor id, code, name and explain). Semantic provider service is utilized for searching sensors, sensor information provision, and sensing data provision. Sensor search requires a search keyword to retrieve a list of sensor ids.

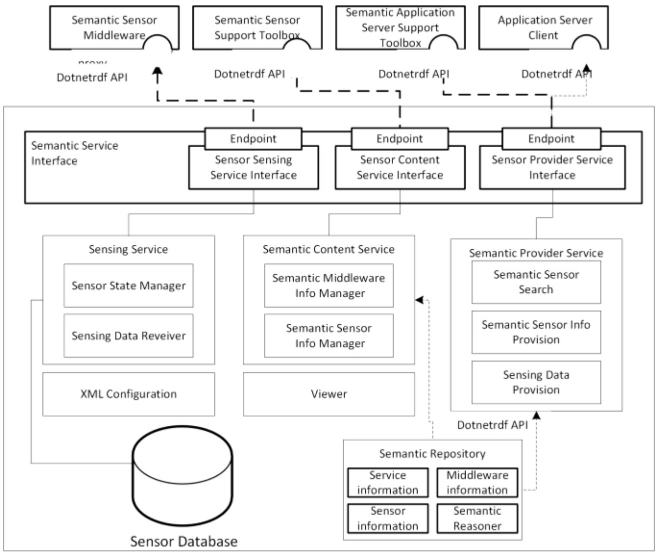

Figure 2. Semantic sensor service provider configuration.

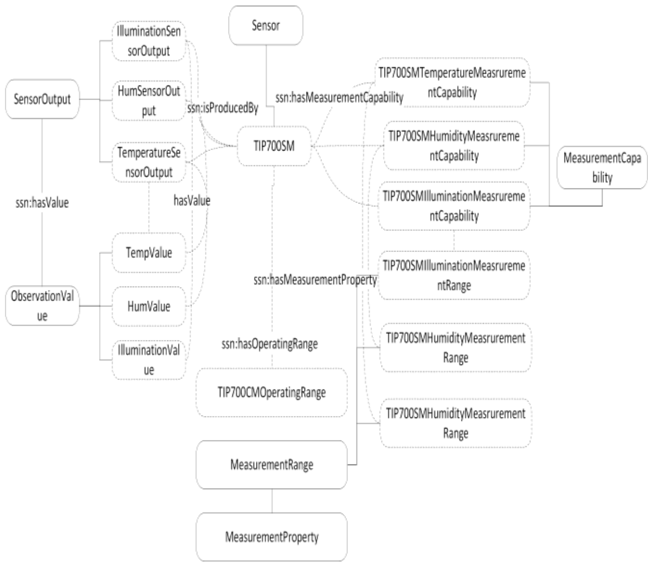

Figure 3. SSN concepts.

Sensor information provision supplies sensor information stored in the ontology based on the sensor id. Sensing data provision supplies the real time sensing data stored in the service provider database to the client. The last service is the sensing service that performs two functions sensor state management, and sensing data receiving. Sensor state management keeps the record of the sensing state of sensors, and sensing data receiver provides the functionality of receiving sensing data collected from sensor middleware and storing it to the database.

4. Semantic Sensor Service Provider Ontology Modelling

With the rapid growth in sensing devices and systems, semantic technologies are used in various studies to manage the enormous amount of data generated as well as the sensors themselves. A huge number of applications are using sensors nowadays ranging from meteorology to medical care to environmental monitoring to security and surveillance. With this the volume of data and the heterogeneity of devices and data formats also grow massively. By using semantics users can manage and query sensors and data. Indeed as the scale and complexity of sensing networks increases, machine interpretable semantics may allow autonomous or semi-autonomous agents to assist in collecting, processing, reasoning about and acting on sensors and data. For their own part, users generally want to operate at levels above the technical details of format and integration, and rather work with domain concepts and restrictions on quality, allowing technology to handle the details. The SSN-XG is a W3C incubator group initiated by the CSIRO and The Wright State University as a forum for the development of an OWL ontology for sensors and to further investigate annotation of and links to existing standards.

We have used SSN's sensor definition to represent the sensors that are registered in sensor service provider ontology as shown in Figure 3. The Measurement Capability class is connected to the sensor by the Measurement Capability object property. This class collects together measurement properties (accuracy, range, precision, etc.,) and the environmental conditions in which those properties hold, representing a specification of a sensor's capability in those conditions [13]. The Measurement Capability class consists of a number of measurement properties, of those we have used the measurement range defined by the Measurement Range class. Measurement Range class consists of a set of values that the sensor can return as the result of an observation under the defined conditions with the defined measurement properties. Operating Range is another property we have used to define the power range in which system/sensor is expected to operate. This is represented using the Operating Power Range class.

Observes only defines the relation between a sensor and the property it can observe. Sensor Output class represents an observed value produced by a sensor, the value itself is represented by the Observation Value class. Each observed value has a unit of measurement and a quantity value as represented in the figure. An Observation is a Situation in which a Sensing method has been used to estimate or calculate a value of a Property of a Feature of Interest. Observation is a subclass of DUL: Situation, which represents things that have a ssn: observed Property property who must be a ssn: Property. The SSN classes and properties represented above describe the characteristics and observations of sensors; there is no information about actuators or the location of sensors and actuators. In this study we developed ontologies to represent sensor and actuator information as well as their location information. It will allow the users to not only query sensor and actuator data but also locate them.

Figure 4 is used to describe the ontology model for semantic sensor provider module. As mentioned earlier it uses some of the concepts of the SSN ontology. Sensor class is defined in the SSN ontology and reused here. TIP700SM is an instance of the Sensor class. It is connected to ssn: Measurement Capability class by ssn: has Measurement Capability property which shows that this sensor has the capability to measure some property. In this particular class TIP700SM has the capability to measure Humidity, Temperature and Illumination values which is shown by the instances TIP700SMTemperatureMeasurementCapability, TIP700SMHumidityMeasurementCapability, and TIP 700 Illumination Measurement Capability respectively. The state of the TIP700SM is shown as idle which the instance of the State class. It also shows that TIP700SM is connected to Sensor Middleware1 which is an instance of Sensor Middleware Class. Models are Sensing Device, Sensor Middleware, Semantic sensor service provider, Sensor Support Toolbox, SP-Services, Management, Output, Category, and Type Information.

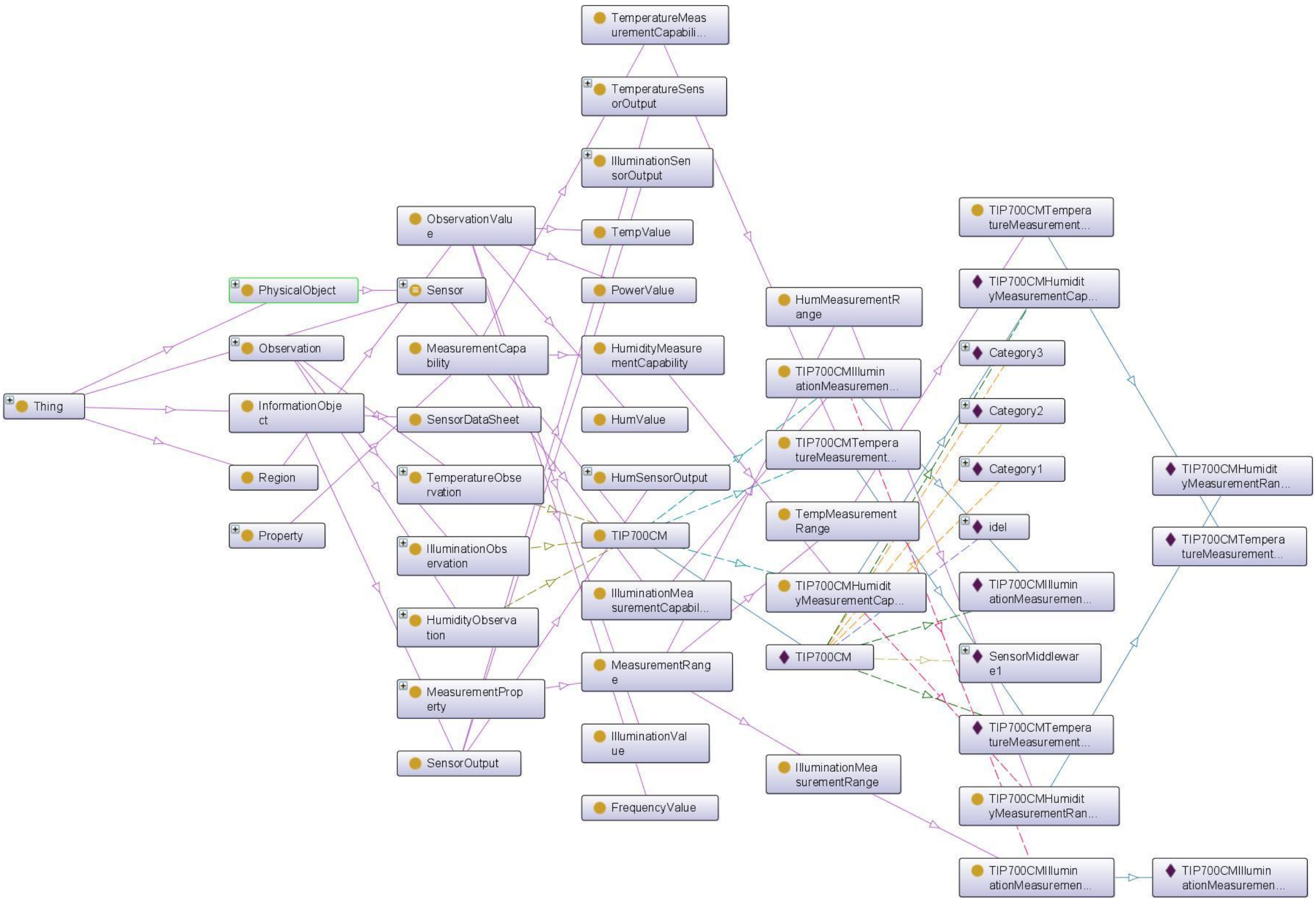

Figure 4. Sensor service provider ontology model.

It also shows the subclass relations that exist between some of the classes for example SP- Services class has 3 subclasses namely Content Service class, Sensing Service class, and Provider Service class. The application server layer retrieves sensor information using the provider service. From here it can also update the state of the sensor. This is done using the SPARQL query shown in Figure 5. It shows a query from Sparql 1.1 Update query, which is an update language for RDF graphs. This query updates the sensor state in the sensor ontology graph. The first triple pattern deletes the hasState property associated with the specific sensor given in the Uri. The second triple pattern assigns a given value to the hasState property of the specified sensor. The WHERE clause identifies data in existing graphs, and creates bindings to be used by the template.

```
DELETE {
<http://www.semanticweb.org/faiza/ontologies/2015/0/serviceproviderontology/sensor01>
spo:hasState ?st.}
INSERT {
<http://www.semanticweb.org/faiza/ontologies/2015/0/serviceproviderontology/sensor01>
spo:hasState 'working'.}
WHERE {
<http://www.semanticweb.org/faiza/ontologies/2015/0/serviceproviderontology/sensor01>
spo:hasState ?st.}
```

Figure 5. SPARQL query for updating sensor state.

5. Performance Analysis

As mentioned earlier the services provided by the semantic sensor service provider are used by the layers above it. The client layer uses the provider service to retrieve sensor information and to retrieve the state of the sensor. These functionalities are performed using SPARQL queries. In this section we have presented an analysis of using SPARQL vs SQL queries for performing the same function. 10 iterations are taken at random resource utilization level of the host system.

The differences between the two queries have been recorded in terms of min, max and average time in milliseconds for the 10 iterations. The results show that SPARQL queries take less time to retrieve and display the results to the client than the SQL query. The graph displayed in Figure 6 shows the time taken in milliseconds by SPARQL and SQL queries. The min time taken by SPARQL query is 106.5ms, the max time is 246.5, and the average time is 169.78. Whereas the mix, max and average time taken by the SQL query is 104.9, 498.3, and 244.42.

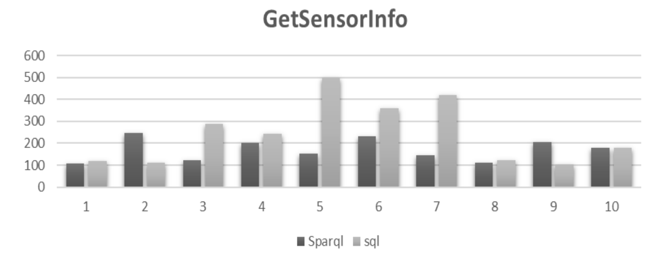

Figure 6. Query comparison for retreiving sensor information.

The graph shown in Figure 7 illustrates the SPARQL and SQL query comparison for retrieving sensor state from the semantic sensor service provider repository. The time taken by SPARQL query is min 46.1ms, max 201.43, and average 86.29ms. The time taken by SQL query to retrieve sensor state is min 48.92ms, 225.16ms and average 114.92ms.

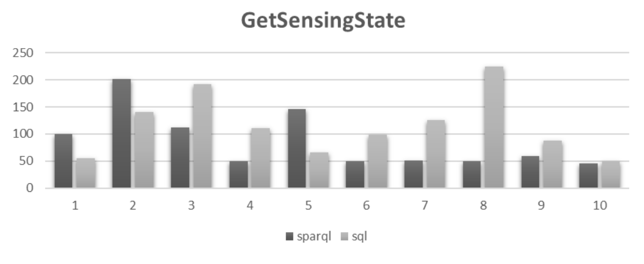

Figure 7. Query comparison for retreiving sensor state.

6. Conclusions

Semantic technologies are gaining huge importance in the field of IoT. These technologies are used by the IoT experts to fill the semantic gap between the applications as well as between the application and associated devices. Ontology for a particular IoT device provides all the necessary semantics needed for its deployment. It makes the device self-explainable. The various components in the proposed system carry meaningful information about their state and environment. In the Semantic sensor module, we have reused the SSN ontology. Reusing existing ontologies increases application interoperability both on syntactic and semantic level. Stakeholders using the same ontology are assumed to agree on the concepts used in the ontology. We have used SSN ontology to define basic definition of sensor, its properties and its observations. We have extended this ontology by adding additional attributes related to our system. We did performance analysis of the system based on the SPARQL and SQL queries. The time taken in milliseconds for these queries to execute has been calculated for 10 iterations of each query. The results of the analysis shows that the overall response of the SPARQL queries is better than the SQL queries. Future work includes linking the RDF data by publishing the ontologies online. By publishing the ontology online it can be interlinked to existing ontologies and become more useful through semantic queries.

Acknowledgments

This work was partly supported by Institute for Information & communications Technology Promotion (IITP) grant funded by the Korea government (MSIP) (No.10043907, Development of high performance IoT device and Open Platform with Intelligent Software). and This research was supported by the MSIP (Ministry of Science, ICT and Future Planning), Korea, under the ITRC (Information Technology Research Center) support program (IITP-2015-H8501-15-1017) supervised by the IITP (Institute for Information & communications Technology Promotion). Corresponding author: DoHyeun Kim.

References

[1] Avancha S., Joshi A., and Patel C., "Ontology-Driven Adaptive Sensor Networks," *in Proceedings of 1st Annual International Conference on Mobile and Ubiquitous Systems: Networking and Services*, Boston, pp. 194-202, 2004.

[2] Barnaghi P., Wang W., Henson C., and Taylor K., "Semantics for the Internet of Things: Early Progress and Back to the Future," *International Journal on Semantic Web and Information Systems*, vol. 8, no. 1, pp. 1-21, 2012.

[3] Barnaghi P., Meissner S., Presser M., and Moessner K., "Sense and Sensability: Semantic Data Modelling for Sensor Networks," *in Proceedings of ICT Mobile Summit*, United Kingdom, pp. 1-9, 2009.

[4] Botts M. and Robin A., OpenGIS Sensor Model Language (Sensorml) Implementation Specification. *OpenGIS Implementation Specification OGC*, 2007.

[5] Compton M., Henson C., Lefort L., Neuhaus H., and Sheth A., "A Survey of the Semantic

Specification of Sensors," *in Proceedings of the 2nd International Conference on Semantic Sensor Networks*, Washington, pp. 17-32, 2009.

[6] De S., Barnaghi P., Bauer M., and Meissner S., "Service Modelling for the Internet of Things," *in Proceedings of Federated Conference on Computer Science and Information Systems*, Szczecin, pp. 949-955, 2011.

[7] Eric M. and Koivunen M., "W3C Semantic Web Activity," *W3C. Semantic Web Kick-Off in Finland*, 2001. Online Available: http://www.w3.org/2001/12/semweb-fin/w3csw, Last Visited, 2001.

[8] Henson C., Pschorr J., Sheth A., and Thirunarayan K., "SemSOS: Semantic Sensor Observation Service," *in Proceedings of International Symposium on Collaborative Technologies and Systems*, Baltimore, pp. 44-53, 2009.

[9] Hachem S., Teixeira T., and Issarny V., "Ontologies for the internet of things," *in Proceedings of the 8th Middleware Doctoral Symposium*, Lisbon, 2011.

[10] Kotis K. and Katasonov A., "An Ontology for the Automated Deployment of Applications in Heterogeneous Iot Environments," *Semantic Web Journal*, 2012.

[11] OWL Web Ontology Language Reference, W3.org, Last Visited, 2015.

[12] RDF-Semantic Web Standards, W3.org, Last Visited, 2015.

[13] Semantic Sensor Network Ontology, W3.org Last Visited, 2014.

[14] Sikos L., "Introduction to the Semantic Web," *in Proceedings of Mastering Structured Data on the Semantic Web*, CA, pp. 1-11, 2015.

[15] SPARQL Query Language for RDF, W3.org, Last Visited, 2015.

[16] Wang X., Zhang D., Gu T., and Pung H., "Ontology based Context Modeling and Reasoning Using OWL," *in Proceedings of IEEE Annual Conference on Pervasive Computing and Communications Workshops*, Orlando, pp. 18-22, 2004.

[17] W3C Semantic Web Activity, W3.org, Last Visited, 2015.

Faiza Tila received the B.Sc. degree in Computer Software Engineering from University of Engineering and Technology Pakistan in 2012. She completed her Masters from the Department of Computer Engineering, Jeju National University South Korea in 2016. Currently she is working as a lecturer at the Computer Science Department in Bacha Khan University Charsadda Pakistan. Her research interest includes Semantic Web Technologies, sensor web and Internet of Things.

Do Kim received the B.S., M.S. and P.D degrees in Electronics Engineering from Kyungpook National University, Taegu, Korea, in 1988 and 1990, 2000 respectively. He joined the Agency of Defense Development (ADD), Korea, in 1990. Since 2004, he is currently a professor at the Department of Computer Engineering at Jeju National University, Korea. His research interests include sensor web, optimization algorithm and context prediction.