Verification of Device Compatibility for Heterogeneous Internet of Things (IoT) Devices

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Abstract:
The current advancements in technology with its utilization have improved the better usage of smart objects in a smart home system or smart building. Generally, the interconnection of this large number of heterogeneous devices into a common system leads to an interoperability problem due to its standardization in terms of devices and its protocols, which leads to a challenging task for the joint execution of interoperation. This interoperability problem arises in all existing smart environments, such as smart homes, smart industries, and smart cities. Due to the massive quantity of devices involved to share information in a smart home system, there exists an interoperability problem due to its different data formats and devices. For a typical smart home system having five hundred heterogeneous devices for communication for a joint operation to perform, especially desired tasks or services, leads to compatibility issues. Here in this paper tried to propose an ontology model implementing a use case of a smart home environment for device compatibility, device verification, and the device matching time. To evaluate the device compatibility and verification involved five hundred smart devices for which few devices considered as sensory devices for sensing and remaining as actuating devices. In the present work, the device compatibility is checked on the device properties especially in reducing the device matching time and device verification time using the rules engine, the previous ontology was enhanced as lightweight ontology by only considering the important and minimal properties which are required for the present use case implementation. Finally, we proposed an enhanced lightweight ontology model using semantics to distinguish the compatibility of the devices, as well as a query and rules execution time to match the devices.

Keywords:
Internet of things · Interoperability · Ontology · Ontology web language · SPARQL · Semantics · Sematic web rule language

1. Introduction

According to Gartner's report, 5.8 billion IoT automotive and business endpoints will be in action by 2020 [1]. As of now, millions of IoT components are connected to the internet to provide adequate facilities for residents and business applications. The broad proliferation of smart home systems, along with their many services, has resulted in an enormous heterogeneity in the definition of design and data processing of these systems. Smart Home is a smart place accompanied by diverse subsystems that

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optimize its function to the preferences of home users based on the information obtained from the computational system, the context, and the home consumer [2]. Some of the key open problems with smart home devices are the convergence of heterogeneous huge amounts of data from various devices and its capacity to execute specific tasks. Interoperability appears to be the primary objective of the smart home system, which provides a standardized method of significant exposure and attempts to hide the heterogeneity of various smart devices. IEEE describes interoperability as the potential of two or more devices to exchange information and to use the relevant data they have acquired [3].

The smart home system is a combination of multiple subsystems and objects like home automation, surveillance cameras, smoke detectors, fire sprinklers, audio and video streaming, home energy equipment, and so on. The interoperability issue has to turn into a significant challenge for consumer electronics companies to integrate a range of smart home services. Describing ontology is becoming extremely necessary to promote interoperability between applications, resources, software, and stages. Agarwal et al. [4] suggested that ontology is the better way to obtain interoperability between devices, and they had given a standardized ontology focused on overloading, reusability, and increased interoperability. Guarino et al. [5] identified three major significant advantages with ontologies: (i) providing contact between end-users; (ii) creating better connectivity among software systems; (iii) improving the industry system model and the essence of the software development process.

The authors of [6] concentrate on interpreting data collected from various data sources by utilizing ontologies to allow semantic understanding of events and context awareness, and they proposed a framework smart care for a home for integrating multiple devices. Lam et al. [7] present an approach that uses autonomous computing to promote the creation of interoperable IoT devices at the semantic level. Their methodology extends the IoT ontologies and other Semantic web services to the Monitor-Analyze-Plan-Execute-Knowledge framework in autonomous computing. Many of the models in the smart home system work on the models and architectures, but still, there exists a problem with interoperability if the number of devices is increasing rapidly. In the case of IoT systems, ontologies can be used to handle control, connectivity annotation, and knowledge discovery. The typical smart home setting was considered for this device matching verification, as shown in Fig. 1. In this article, a semantic verification for device matching and compatibility using the ontology model was suggested, as shown in Fig. 2, and demonstrates the information flow of the semantic model. Our approach distinguishes between compatible and incompatible devices. The main research objectives of this paper are (i) Proposing a lightweight ontology model with minimal and important properties for use in communication. (ii) Proposed a semantical approach by utilizing the lightweight model to obtain device compatibility using the query. (iii) To verify the device compatibility using the SWRL rules and to distinguish the compatible and non-compatible devices. (iv) To verify the query processing time of the device matching time for device compatibility. (v) To compare the device matching time, triple count, and device compatibility verification time of multiple described devices in the smart home setting using the proposed lightweight ontology model. The objectives strive to differentiate as compatible and non-compatible devices and compare the matching time of 250 and device verification of 500 devices using the previous model with the present proposed ontology model. Finally proposed ontology model provides less device matching and verification time of all described devices. The model also distinguishes the compatible and non-compatible devices for a selection of the particular device.

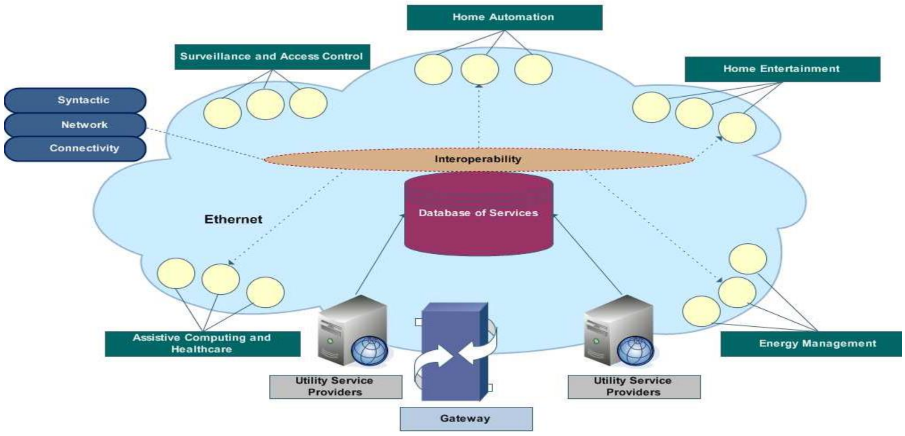

Figure 1: Smart home architecture

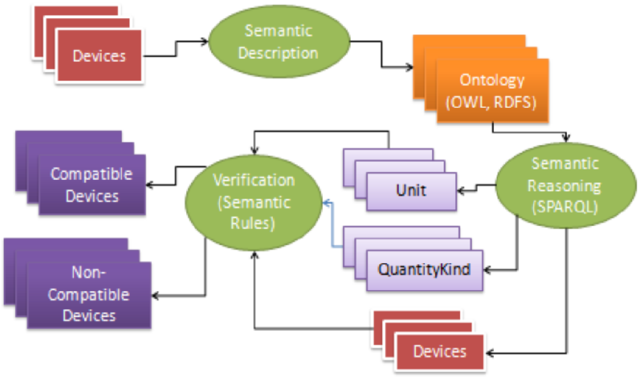

Figure 2: Data flow diagram

2. Related Work

Current miniaturization and significant resource decrease in the various automation sectors have provided sufficient possibilities to enable private residents with low-cost smart home devices to manage and automate a variety of tasks in our daily lives, and these networking technologies and specifications have a key role to play in driving this rapid growth. However, consumer device interoperability and usability are major roadblocks to making intelligent home technology accessible to a broad audience. We looked at how current technologies aid in the deployment of smart homes [8]. To facilitate merging, data transformation, and mediation, the authors in [9] proposed a methodology that analyzes the specific concepts of data and metadata and it has been shown that ontological and epistemological reasons are equally essential for successful design, particularly when dealing with past information in any area. The authors of this paper [10] describe and analyze a few things about smart home environments. They had given a survey on smart objects in-home, smart home projects, and importantly, the challenges to be faced in terms of interoperability and reliability when implementing. For future smart home system vision, the context-awareness is a critical thing to be achieved. It lacks a generic model to avoid an interoperability issue.

To eliminate the barrier, they proposed a five-layered reference model for context representation and reasoning to direct the system design and deployment of semantic technologies and integrating various new concepts into the OSGi-based smart home service network [11]. The goal of the SAPHIRE project [12] is to build intelligent health management and decision-making support system on a platform that integrates data from wireless medical sensors with hospital data systems. This is used to collaborate between the assisted living environment and the hospital system to monitor a patient by diagnosing with the recorded data. A smart home environment involves integrating different physical devices, computer systems, and humans into a single connected network. The authors [13] propose semantic services that use semantic technologies that are used to support smart environments. They are trying to establish the importance of semantic technologies in the smart infrastructure. This service relies on ontologies and guidelines to classify several types of entities that could be involved in smart homes and workplaces and to infer contextual knowledge from high-level to low-level devices in physical environments. A modern home automation system is widely distinguished by the heterogeneity of the elements required to perform tasks together efficiently and effectively. Even though there is an enormous development in infrastructure, applications, and devices in the smart residence environment, the interoperability concepts often seem unclear. This paper explores the perspective of Web Services infrastructure using the Simple Object Access Protocol (SOAP) to solve interoperability criteria for the smart home community, and this protocol offers a data-sharing mechanism and enhanced output for interaction between components residing in a home environment [14]. Most of these heterogeneous structures are stand-alone and do not respond to joint operations. It is, therefore, very difficult to interoperate, particularly to achieve the required services preferred by users. To achieve this interoperation, the authors tried to propose a new rule-based framework for managing heterogeneous systems, and this system is based on the web service technology implementation for achieving interoperability through event-condition-action (ECA) [15]. The author [16] conveyed the message that we are living in an environment, which becomes more intelligent, and there exists more number of devices with their computational power involves in data sharing leads to high risk without leaving clueless. For that, the tries to overcome this issue by presenting that the part of the present going research work on the use of the effective design of semantics to express abstract models of interactions among devices in the smart home. This enables users to recognize and create realistic cognitive structures of the smart world and communicate with them accordingly. The development of smart home technologies offering digital services to home users presents a threat to interoperability.

The authors in [17] argue that the utility of such services can be greatly improved by allowing technologically neutral composition of such home services and that the reliability of these composite services would be of utmost importance in achieving ubiquitous delivery and they also introduce a web service-based abstraction layer for home area managed service design and a semantically aware fault management framework for composite services that can help diagnose and fix composite service problems in smart homes. The definition, architecture, and significant design considerations of the interoperability platform Smart-M3 are established. The platform is focused on ideas about spatial knowledge exchange and semantic web concepts about the representation of information and ontologies. The interoperability model was used as the basis for several case studies [18].

They developed an architecture that consists of a semantic information broker and knowledge processors, and this SIB stores and makes information from processors. When the authors [19] try to link smart devices to each other, they open up many new possibilities. One interesting choice is to allow high-level semantic interaction without having multiple steps on multiple devices. They discuss how ontologies, dynamic task models, BDI models, and architectural patterns can be used to facilitate semantic interaction in general computing, and they offer a way for users to explicitly communicate with devices at a high level of semantic abstraction without having to think about low-level information. Tam van et al. [20] address the implementation of a connected home context-aware framework built on ontology. They address the latest problems in the understanding sense of ontology. Such problems can be defined as the collection of background information from heterogeneous sources (devices, sensors, and agents) into ontology for management, querying, and environmental database issues. Discovering the relationship among users, actions, and context data in the home setting is semantic, so we implement ontology to construct these connections and instead reason them as semantic knowledge.

The authors [21] explore the potential outcomes of reflecting this online technology in the physical reality in which we live, by providing control handles and clues for comprehension, creating conceptual frameworks of connections and interactions that exist and these can be done by creating a semantic abstraction of events from low to high level with a simplifies manner. For that, we need to design ontology for events at a low level and to be reasoned to infer into a high level for implementing the required tasks. This paper [22] introduces a smart and intelligent interoperability structure for smart home environments. SOAP-based Web Services is one of the best ways to manage varied kinds of devices in the home environment. The framework also enables new dependencies to be installed as new home appliances are connected to smart home systems without alteration or external intervention. The authors [23] had given the list of multiple interoperability architectures, and from that base concept, they proposed smart lighting using a semantic interoperability architecture using the Semantic Information Brokers and Knowledge Processors as a concept. They proposed a smart lighting system based on the priority bases such as high and low priorities which uses various consumer electronic devices with platforms to have a heterogeneous network. The current trend of widespread connectivity to application-specific integrated devices connected to the internet, as well as the increasing proliferation of wireless communication protocols, has brought more attention to smarter environments. Such a system comprises sensors, software, and smart connected devices that can be remotely monitored and managed by end-users and cloud providers. The absence of a standard communication protocol for smart homes poses an obstacle to the interoperability of products from various vendors. The architecture [24] is built at the top of the OSGi framework and integrates a semantic model of a smart home network. Therefore, functional interoperability – the capability to incorporate software innovations and drivers into the implemented platform through runtime is achieved. They illustrate how the interaction of various home network protocols can be managed systematically utilizing related device discovery methods. The management of these large elements or systems leads to the increase in administration overhead by the day-to-day increasing of interconnected devices or systems over the network. A big challenge in front of IoT is the management of heterogeneous devices and maintaining track of the configurations, failures, and execution of an expansive number of IoT devices.

3. Proposed Model

Semantic interoperability is not only for the binding of information, syntax but also for the simultaneous communication of meanings with data and also with semantics. It could be achieved by linking every piece of metadata information and data element to the shared vocabulary control. Resource Description Framework, RDF and W3C Web Ontology Language, OWL [25] focus on providing technical terminology for the reuse of existing ontologies. It relies on the consumers on how and where to reuse the currently available ontology and should know how to relate the relationship between the different ontologies logically. Fig. 2 gives the overall basic information of the proposed enhanced lightweight ontology, which is used for the implementation of device compatibility and verification. Now we had taken the enhanced version of the previously proposed ontology to have lightweight for having less query process time. Fig. 3 describes the experimental design of the proposed system.

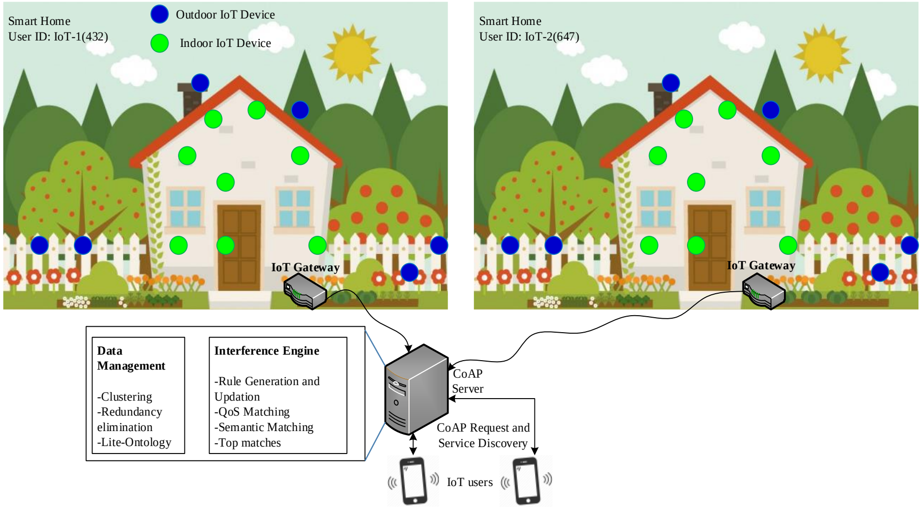

Figure 3: Smart home as a use case

The proposed lightweight ontology is applied as in Fig. 4 for smart home. Similarly it can be applied for other IoT applications also that measures environmental changes that enable to monitor a particular area from remote location. Hereby this can be used for agriculture field too, where the field is analyzed and so the crops are seeded in a particular region. The following are the few devices that are used in the smart home environments. The same can be used for different scenarios that fit its involvement. The few devices that are defined in the use case are given as in Table 1.

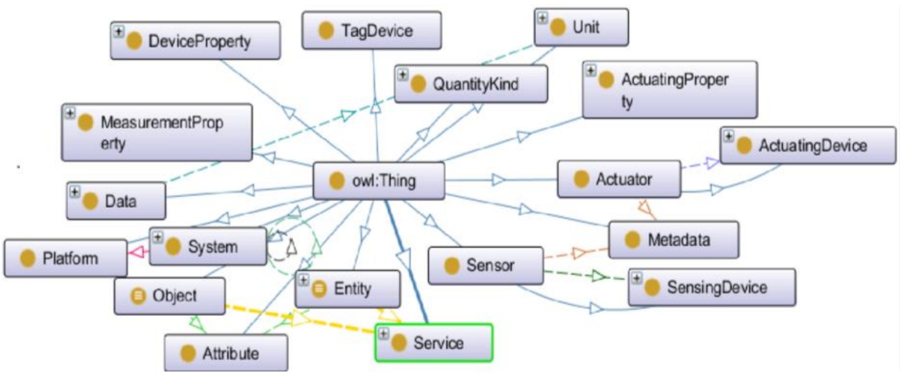

Figure 4: The proposed ontology for device compatibility

Table 1: Device used in the proposed system

Devices	Description
Motion sensor	Monitoring the motion in the home
Open/close sensor	It is used to monitor the door open and close
Temperature sensors	Monitor the temperature in the indoor and outdoor environment
Water leak sensor	Monitor the water leakage in the home
Smoke sensor	Monitor the smoke level of the home
Air quality sensor	Monitor the air quality of indoor and outdoor of the home environment
Light sensor	Monitor the light effect of the home environment
Servo Motor	Controls the speed of the device
Humidity sensor	Monitor the humidity level of the home environment
Air Conditioner	Controls the heat for used space

The proposed model is being used to create semantic information from numerous ontologies such as IoT-Lite [26], M3 Taxonomy [27], Qu [28], and SSN [29] ontology with certain specific properties incorporated on either the sensor and actuator sides that are not considered semantically for IoT device management in the earlier constructed ontologies. Here we tried to include few properties, which are required for device matching to be used in the proposed model that is taken from current ontologies. We derived the proposed model from the combination of existing ontologies like SSN, Iot-Lite M3-Lite, and Qu. We had considered only the required properties of different ontologies and added few properties in the proposed model. Based on the criteria in OWL-based formats, ontologies can be created. We considered fundamental concepts of SSN, M3-Lite, Qu, and IoT-Lite ontologies in this enhanced model. To have the model more specific to the confined application, we reused the important classes and subclasses of the Quantity type, Unit along the sensory and Actuator part of the ontologies and taxonomies listed. To provide more semantics at the system level, we thought of considering novel properties such as data, device properties, measurement properties, and acting properties. Here we used the important concepts for the development of proposed ontology such as sensor data, actuator data, type, property and method. We considered the concepts of iot-lite:object, iot-lite:entity, iot-lite:service, ssn:device, ssn:system as the core concepts for objects, resources and services. We had added few more concepts such as clissa:actuator, clissa:method, clissa:property, clisssa:data, ssn:sensor, clissa:tagdevice, qu:quantitykind and qu:unitunder the device main class and also established the relations and their behavior among the defined classes. To provide additional device compatibility, relevant and related data properties had considered which could accomplish semantic interoperability at the system level. In having few required and added data and device properties, we felt that the devices could be more clearly differentiated, and by using the semantics, we could easily handle the device compatibility.

Fig. 4 describes the proposed ontology model at which device compatibility could be achieved using semantic concepts with certain possible properties taken into consideration. The proposed ontology is compared with the other defined ontologies was given in the paper [32]. The statistics of the proposed ontology was given in the paper and also we had compared with other ontologies in terms of schema metrics, knowledge base metrics and graph metrics. We also mentioned the maximum number of instances possible for the proposed lightweight ontology. The graphs provide all its available properties of all the compared ontologies. In the current enhanced ontology, we took the typical smart home as a use case in which if certain Devices wants to interact with other devices having a problem of compatibility between the devices because of its formats. For example, Device1 and Device2 have their properties, such as different or equal quantity kinds and units having compatibility or non-compatibility issue. Using the SPARQL query language, expect semantics to check the compatibility of multiple heterogeneous devices for semantic interoperability.

3.1 Device Compatibility Checking

The main purpose of this model is to address the compatibility issues and to verify the compatibility of the devices. Here considered multiple smart devices such as sensors and actuators for the smart home setting. We had taken these sensors and actuators based on the applications like energy management, home entertainment, surveillance, and access control, security management, assistive computing, and health care and home automation. Here we describe multiple devices for different applications settings as shown in Fig. 1 and designed smart home application as a use case in Fig. 3. Initially, we described 250 devices and later we extend it to 500 devices. The devices taken in the smart home setting are mostly sensory devices for which the data is sensed in the home environment and few devices have taken as actuator devices. For example, the sensor devices are a temperature sensor, humidity sensor, gas sensor, motion sensor, and many more whereas actuator can be taken as air conditioner, servomotor, light bulb, etc. Due to this setting, there exist a number of devices involved in interacting with each other to have a message transfer, for example, Sensing Devices as Sensors and Actuating Devices as Actuators. Sensors that transmit data to Actuators must have the same form of unit and quantity kind. A sensor and actuator having the same quantity kind and the unit will consider as compatible devices that can be suitable for message sharing to have a certain action otherwise considered as non-compatible devices that cannot be participated in communication. Here we tested the compatibility between 500 devices by defining their properties such as quantity kind and Unit and verified the device matching time. We implemented a semantic-based test to analyze the issue of device compatibility.

Problem (Device Compatibility Problem):

Input: Devices D1, D2

Output: Are D1 and D2 compatible such as (D1, D2) € R

If R is defined as the D1 and D2 compatibility relationship, let R be the system compatibility relationship where R output (D1) is a subset of an input (D2) or output (D2) is a subset of an input (D1). The problem was checked to verify with the 500 devices, at which devices were grouped as 100, 200, 300, 400, and 500, and checked the compatibility between two or more devices.

3.2 Checking Device Compatibility Time

To test the compatibility of the devices, some of the relationships between all the devices defined by R have been considered. We had considered the relations among the devices with only important and useful properties so that the devices can be easily communicated with fewer payloads. Here the particular sensors and actuators have an output or input data having QuantityKind and Unit as parameters. We assessed the compatibility test for the devices with each other based on the R relationship and the time is taken to match the devices for the device compatibility test. Device matching was defined as the time to seek to find the same QuantityKind and Unit for all p combinations of devices. The definition of a limited SPARQL request can be described in the following:

```
#Check the matching time of devices D_n and D_m (m!=n)

ASK{{{sat:DataD2 iot-lite:hasQuantityKind ?quantity1; iot-
lite:hasUnit?unit1}.{sat:DataD6iot-lite:hasQuantityKind ?quantity1; iot-
lite:hasUnit ?unit1}}...
```

The device matching for all devices is verified with each device depending on the relationship, and also the time duration was considered towards matching of the devices. Fig. 5 shows the comparative information of the matching time for the defined devices of previous and present enhanced ontology with a pair of combinations, whereas each node can be considered as a smart device such as either sensor or an actuator. In this paper, we had extended the devices from 250 to 500 devices to compare all possibilities with each other.

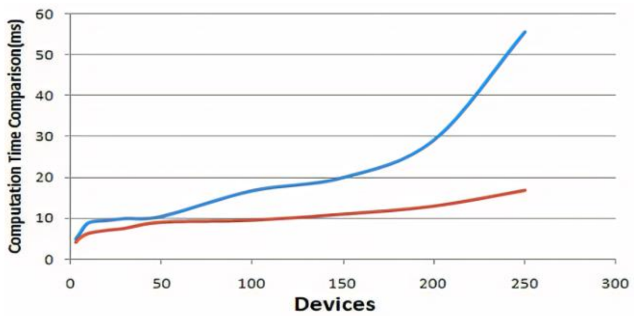

Figure 5: Comparison time for devices

3.3 Device Compatibility Verification

In the proposed model having five hundred smart devices for smart homes, the scenario involves data sharing. The above device compatibility problem has to be verified between the devices. Here tried to verify that a particular device is compatible with whichever devices involved in the data communication in a smart home. SWRL rule has been used to validate the compatibility among various devices that used the conceptual rule engine depending on the various bespoke parameters. To verify the device compatibility, a SPARQL query has been defined to verify the device matching and SWRL rule for device distinguishing as segregation of devices based on the parameters matching. The verification involves distinguishing devices as compatible and non-compatible to each other and the computational time of the rule engine. The example of the SWRL rule has been given as follows:

```
#Sample rule to segregate devices

Data(?D2)^hasQuantityKind(?D2,?quantitykind)^hasUnit(?D2,?unit1)^Data(?D3)^
hasQuantityKind(?D3,?quantitykind)^hasUnit(?D3,?unit1)->satont:isCompatible
(?D2,?D3).
```

3.4 Evaluation

To evaluate the compatibility between the devices, we did some analyses and tests with defined SPARQL queries relying on the properties of the sensory and actuator devices described in an enhanced ontology. Here we had compared the processing time for device matching and device verification of 250 and 500 devices using the SSN and proposed lightweight model. Due to the heavyweight of SSN, ontology, which some properties not useful in the comparison makes more, processing time than the proposed model. We created an individual dependent on the ontology description of those same device properties, generated their triples within the RDF category, and transferred the triples to the Apache Jena Fuseki Server [30] to approve the triple for the similarity check for the devices. We used the SPARQL query operating on the Fuseki Server upon these stored RDF triples of the implementation system to test the compatibility of the devices and take into account consideration the run time of the query for performance and compatibility check. The comparison graph was plotted in terms of triples for both previous and enhanced ontology models of 500 devices are shown in Fig. 6. The blue line indicates the heavyweight ontology triples count whereas the red line indicated the proposed ontology triple count.

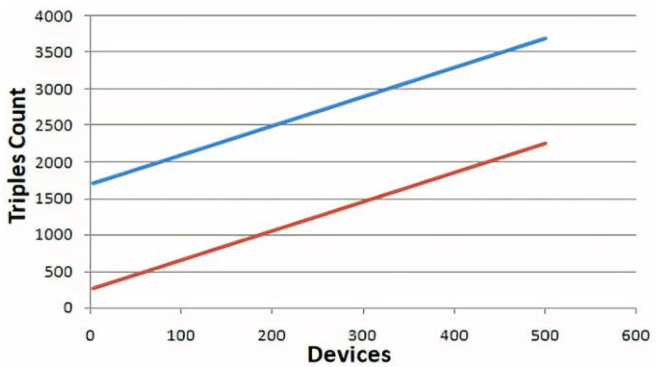

Figure 6: RDF triples comparison

Fig. 6 indicates that the size of the triples exponentially increases concerning the number of devices. Due to the fewer number of triples of the proposed ontology gives fast response than the old SSN, model concerning any set of device count. In Fig. 5, the comparison graph of query processing time was plotted concerning the previously proposed ontology with the current enhanced lightweight ontology for 250 devices. Initially, we conducted a test on 250 devices and found that the device matching time leads to 58ms [31]. Now we considered the typical smart home environment with a maximum of 500 smart connected devices for communication. Here we checked device compatibility and device matching time for these connected devices and found that there is a reduction in processing time for the device matching. Fig. 6 indicates that due to the lightweight ontology model the query processing time exhibits less when compared with the previous SSN model. The Blue line indicates the device matching time of the particular set of devices using the previous model and the red line indicates the device matching time of those devices using the proposed ontology model. The proposed model gives less processing time when compared with the other model. Fig. 7 is a graph obtained by plotting between the verification phases for the devices and indicates the computational time for the performance of the SPARQL query for 500 devices. Fig. 7 indicates that the query processing time of 500 devices is 49.5ms. The same test was done for device verification for distinguishing devices as compatible and non-compatible using the rules engine. Here a comparison was carried out with previous and present enhanced lightweight ontology using SWRL rule for segregation of devices, as shown in Fig. 8. We tested the device compatibility and device segregation verification for a maximum of 500 devices in the lab setting with a personal computer with a configuration of 8GB RAM, Windows 10 operating system, and 1 TB HDD with a maximum possible execution of query processing time of 49.5 milliseconds for device matching and 4200ms for device distinguishing. Performance analysis is carried out as the time of execution of the transition of ontology axioms to the execution engine, the time of execution of the engine which is defined with rules, and the time required for axioms, which reflected ontology between all the devices described in ontology for device distinguishing as compatible and non-compatible devices by using the rules engine and also performed a reasoned on the said evaluation. Finally, it is observed that the present matching time is less for 500 devices when compared to the previous execution of 250 devices. Compatibility testing and verification can, therefore, be carried out in a reasonable time.

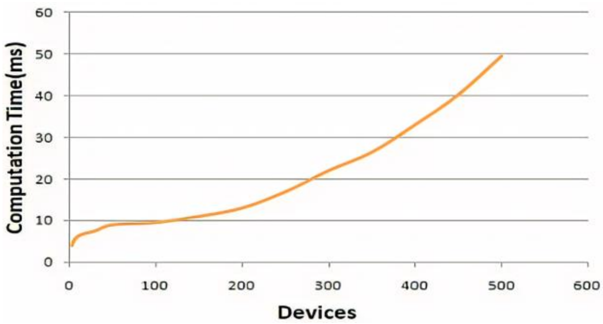

Figure 7: Device matching time

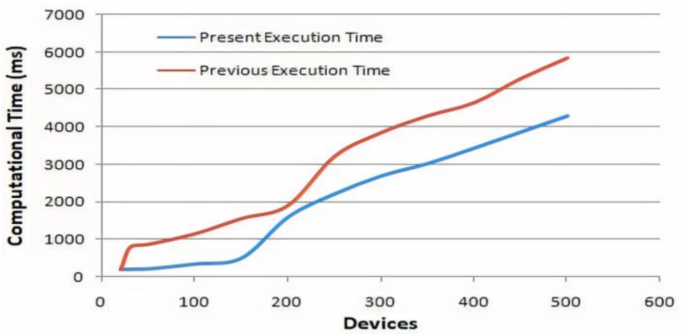

Figure 8: Device verification time comparison

4. Conclusion

At the outset, an ontology model with lightweight has been proposed using semantics with important and minimal properties for the smart home environment to differentiate the different devices using their defined properties. The previously proposed ontology model for device compatibility by considering the few existing ontologies has more triples and size, which leads to more computational time. The previously defined ontologies like SSN, Qu, and M3-Lite has more triples and due to this, the query processing time or execution time is more when compared to the proposed ontology model. To develop a new lightweight ontology with minimal and important properties for smart home use cases reused those existing ontologies to reduce the query processing time. By using, the previous one tried to distinguish the devices using SWRL and verified the device matching time using a SPARQL query, which leads to more processing time than the present one. The previous model exhibits 56ms for 250 devices due to its heavyweight and more triples whereas the proposed lightweight model gives less query processing time of 49.5ms for 500 devices. This result shows that the proposed model gives a better and quick response than the previous ontology model for SPARQL query processing.

The device verification comparison time also shows the less execution time for device verification of 500 devices of the proposed model (present execution time) than the previous existing model (previous execution time). The same implementation with enhanced light lightweight was carried out and observed that there is a reduction in device matching time and device segregation verification. Here specifically done for the smart home environment with considering of 500 devices and proposed an enhanced ontology model from the previous one by considering the few important properties. The enhanced ontology model was the lightweight model for the previously proposed model, which reduces the query processing time for device matching and devices to distinguish. The current proposed model consists of different types of sections for the generation of RDFs using RDFS, OWL semantic technologies, and the reasoning for linking data sets to establish semantics that ought to be stored in the repository for further usage. The SPARQL query and SWRL rule were proposed and used to test the smart home system for device compatibility and checked the matching and evaluation time of the query. By using this model got less query execution time for devices to check the compatibility and to distinguish between the devices. In future we will implement this proposed lightweight ontology model for implementation of semantic CoAP data management and dynamic rule generation for Quality of Service aware with feedback in heterogeneous IoT Ecosystem.

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