Towards Semantic Interoperability in an Open IoT Ecosystem for Connected Vehicle Services

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***Abstract*—A present challenge in today's IoT ecosystem is to enable interoperability across heterogeneous systems and service providers. Restricted access to data sources and services limits the capabilities of a smart city to improve social, environmental and economic aspects. Interoperability in the IoT is concerned with messaging interfaces and achieving a semantic understanding of heterogeneous data. In this paper the ongoing initiative for an open IoT ecosystem is presented. Semantic web technologies are applied to the existing messaging components to enable semantic interoperability. The approach is demonstrated with a proof-of-concept for connected vehicle services in a smart city pilot.**

***Keywords*-Semantic Web of Things, Interoperability, Smart Ecosystem, V2I**

I. Introduction

Currently a strong interest in moving towards smart cities can be perceived. In the smart city concept, ICT facilitates the development of social, environmental, and economic services and solutions. It has been widely acknowledged that IoT-enabled ecosystems have the potential to improve living conditions in cities regarding mobility, environment, governing, healthcare, safety etc. Furthermore, the access to overarching relevant information allows for the development of sustainable solutions regarding global challenges like climate change, food security and resource depletion [1]. Vehicles connected to the infrastructure of a smart ecosystem (referred to as V2I), for example, enables services that could improve transportation, reducing environmental impact and improving the life quality of citizen [2].

In order to achieve these goals in a smart ecosystem, various types of information need to be made accessible and services from across different domains need to interact with each other. The IoT environment nowadays consists of *vertical silos* [3]. These silos are proprietary systems that evolve due to the different interests of involved stakeholders like users, developers, companies and public institutions. As a consequence, the opportunities that a smart city could offer in this case are limited due to the restricted access to data sources and the non-standardized way of publishing services.

In order to overcome this situation and move towards a truly connected city, various challenges regarding interoperability have to be solved, e.g. regarding messaging, semantics and access policies. This paper focuses on semantic interoperability and demonstrates the approach with a use case related to connected vehicles. Section II presents the context of this work and background regarding semantic interoperability. Section III presents relevant components of the smart ecosystem. Section IV describes the use case scenario and implementation; the conclusion follows.

II. Towards an Open IoT Ecosystem

Establishing a open IoT ecosystem, e.g. for smart cities, requires a joint effort of administrative, academic and industrial institutions. In the following the EU initiatives and relevant background for semantic interoperability in the IoT will be presented.

A. *EU Vision and Initiatives*

EU projects [4] Horizontal integration Convergence Partners (cities, academic, BMW)

B. *Semantic Interoperability in the IoT*

Interoperability in the IoT needs to be achieved at different levels. These levels can be decomposed via the terms *Internet of Things*, *Web of Things* and *Semantic Web of Things* which respectively relates to interoperability of the network layer, of the application layer, and to a common description of things [5]. Semantic interoperability relates to the payload of the messages in this communication stack in order to achieve a universal understanding of the message content. As the underlying network and application layers mainly moved towards web technologies, leveraging semantic web technologies for IoT is a promising approach to converge heterogeneous data sources in a smart ecosystem [6].

The Resource Description Format (RDF) [7] is the major technology supporting the movement to a Semantic Web of Things. RDF allows to describe entities and their relationships in a structured form, which can be referenced via URIs. Linked Data [8], for example, is based on RDF and allows to define, link and query concepts. The main motivation to move towards the Semantic Web of Things is to be achieve a common understanding of the labels which are annotated to the data that is exchanged.

To achieve this universal understanding of semantics of data, all parties involved in the communication must be able to interpret the used vocabulary. RDF provides a flexible approach in which defined terms can be easily referenced via URIs, it allows the development of domain-dependent and independent vocabularies, and to define relations between terms from different vocabularies [5]. However, even though the vocabulary can be easily accessed, consumers need to be able to understand the used vocabulary by the publisher, by either using the same or an *aligned* vocabulary. This is a known issue in the semantic web community [9] and is also being investigated for the Semantic Web of Things.

Linked Open Vocabularies (LOV) [10], for example, is a RDF-based repository in which data publishers and consumers can lookup vocabularies in order to annotate and parse messages. Several initiatives to define domain-dependent and independent vocabularies can be found. Schema.org[1] and the Semantic Sensor Network ontology (SSN)[2] are prominent examples of domain-independent RDF vocabularies. MobiVoc[3], for example, is an initiative for a domain-dependent RDF vocabulary for mobility.

The Figure 1 illustrates how these vocabularies are related to the IoT application layer. The open messaging standards called Open-Messaging Interface (O-MI)[4] and Open-Data Format (O-DF)[5] are used in the ecosystem to achieve interoperability on the application layer and the message payload. These will be discussed in more detail in the following section. RDF-based vocabularies are then used to annotate the data in the message payload.

TODO related work

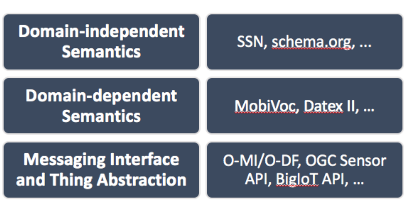

Figure 1. Positioning of Semantic Techniques in IoT Communication Stack

The proof-of-concept of this paper combines the MobiVoc vocabulary for the mobility domain with O-DF to benefit the development of connected vehicle services.

[1]Schema.org vocabulary: http://schema.org/
[2]SSN ontology: https://www.w3.org/2005/Incubator/ssn/ssnx/ssn
[3]MobiVoc vocabulary: http://www.mobivoc.org/
[4]O-MI standard: https://www2.opengroup.org/ogsys/catalog/C14B
[5]O-DF standard: https://www2.opengroup.org/ogsys/catalog/C14A

III. bIoTope Ecosystem Foundation

The building blocks in the bIoTope ecosystem, as illustrated in Figure 2, are O-MI (i), O-DF (ii), publishers (iii) and consumers (iv), as well as a service description repository (v). Furthermore, the figure presents the typical interactions between these components and technologies.

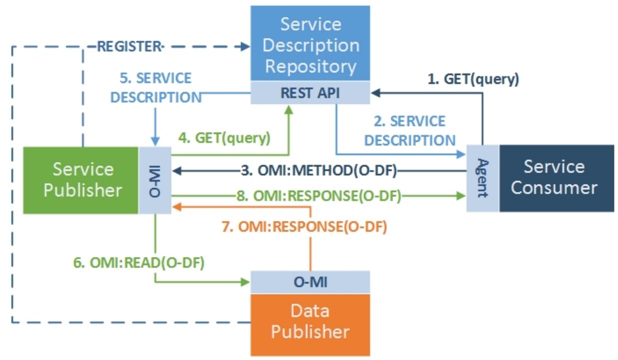

Figure 2. Building Blocks and Interactions in the bIoTope Ecosystem

The bIoTope ecosystem relies on the O-MI standard (i) as a messaging interface between data/service publishers/consumers in the IoT. An agent is responsible to push the data from any kind of source (sensor network gateways, APIs, local files, databases, UI etc.) to an O-MI node. The interface includes operations to read, write and subscribe to values, as well as invoking methods with parameters.

The O-DF standard (ii) defines the structure of the message payload. O-DF provides a tree structure of *objects* which are comprised of *infoitems* with *values* and *meta-data*. An example of O-MI/O-DF messaging will be presented in section IV. Both standards have been thoroughly discussed and designed to meet the requirements of all involved stakeholders in an IoT ecosystem as presented in [11].

Publishers (iii) can be differentiated in those exposing data and those offering more complex services. Data publishers in the bIoTope ecosystem refer to exposing low-level data via the O-MI operations *read*, *write* and *subscribe*. Service publishers compose high-level services by gathering low-level data, processing it and exposing the results via the O-MI operation *method*. Consumers (iv) are calling service methods or reading low-level data to compose smart services for the ecosystem.

The service description repository (v) provides an index of available O-MI nodes and their exposed O-DF tree. Publisher register their services in the repository and consumers use the repository as an entry point to discover relevant services. The repository provides a REST API that allows to search and filter available O-MI nodes and returns the data required to access the matching services in a peer-to-peer manner.

O-DF was designed to provide a general message format without restricting involved actors in their width of information that can be exchanged. Thus, the goal is to achieve semantic interoperability with between the presented consumers, publishers and the service description repository on top of O-DF payload.

IV. Pilot Description

For demonstration purposes of the presented smart ecosystem components, it is assumed that vehicles are connected to infrastructure (V2I). The vehicles expose their data (location, car profile, etc.) to a back end server. Moreover, the vehicle is capable of receiving remotely computed information and able to integrate the data into the services that are offered to the driver in the connected vehicle.

The scenario involves the following implementations: A back end agent which acts as a service consumer and gateways to the connected vehicles, three service publishers (*find parking*, *find charging station* and *predict free parking*), one data publisher (*real time parking data*), and the service description repository.

The selected pilot setting that is considered is the Lyon Greater Region. The goal is to demonstrate how the consumer is able to dynamically discover and request relevant services, as well as to process the results, due to the usage of a standardized vocabulary. Figure 3 shows an instantiated execution flow of this scenario involving the *find parking* service.

The data publishing component is realised by accessing real time parking data via the open data platform of Lyon[6]. The agent requests every minute the parking data from the open data platform API and transforms the received JSON object into an MobiVoc annotated O-DF tree, which is then pushed to the O-MI node. A fragment of the O-DF tree is show in Listing 1 that integrates terms of the MobiVoc and schema.org vocabulary.

Listing 1. O-DF Tree with Semantic Annotations for Parking Data

```
<Object type=”mv:ParkingFacility”>
    <id>7</id>
    <InfoItem name=”mv:placeName”>
        <value type=”xs:string”>Parking Hotel de Ville</value>
    </InfoItem>
    <InfoItem name=”mv:vehicleType”>
        <value type=”xs:string”>mv:Car</value>
    </InfoItem>
    <InfoItem name=”mv:totalCapacity”>
        <value type=”xs:integer”>202</value>
    </InfoItem>
    <InfoItem name=”mv:numberOfVacantParkingSpaces”>
        <value type=”xs:integer”>5</value>
    </InfoItem>
    <InfoItem name=”schema:longitude”>
        <value type=”xs:double”>45.768505</value>
    </InfoItem>
    <InfoItem name=”schema:latitude”>
        <value type=”xs:double”>4.837461</value>
    </InfoItem>
    <InfoItem name=”mv:isConnectedTo”>
        <value type=”xs:string”>mv:Carpooling</value>
    </InfoItem>
</Object>
```

[6]Data Grand Lyon: https://data.grandlyon.com/

The service publishers are realised as individual implementations based on the flow that was presented in Figure 2. Upon a method call, service publishers request the service descriptions from the repository by using terms from the MobiVoc vocabulary (and a geo-filter) to discover relevant service and data publishers. The service descriptions are used to establish peer-to-peer connections to these nodes. The collected data is used to calculate the results of the service implementation and to be sent as the response to the consumer. In case of the *find parking* service, the MobiVoc term *ParkingFacility* is used to discover publishers with parking information. The service algorithm takes the *numberOfVacantParkingSpaces*. The location and profile of the vehicle, as well as the location of the parking facilities into account to send the data of the best parking facility as response to the initial request of the vehicle gateway.

All publishers are indexed in the service description repository with respective URLs and other meta-data taken from the O-DF tree. Furthermore, service publishers are assigned with a geographic service area in which the service is valid. Upon service description requests with a location parameter, only service descriptions for services the are assigned for this location are returned.

A web interface is used to monitor the execution flow and visualise the service results, as shown in Figure 4. The location of the vehicles are simulated by an agent that update the values every second via an O-MI node. The execution flow is initiated by the vehicle gateway by reading the location and initiating the service discover, selection and execution process.

The eventual result of the *find parking* service contains the semantic annotated data for the best parking facility. In the described scenario, this data is used by the vehicle gateway to calculate a route to the location of this parking facility. The route is sent to the vehicle and displayed to the router via the vehicle's user interface.

V. Conclusion

This paper presented ongoing initiatives for open IoT ecosystems and challenges for semantic interoperability. Based on the building blocks of the bIoTope ecosystem the integration of semantic web technologies was discussed to approach the aforementioned challenges. A proof-of-concept demonstrated the application of this approach for a smart city pilot for a parking scenario with connected vehicles.

Efforts are ongoing to extend the implementations for the large-scale city pilots. This includes the further integration of contextual data in the ecosystem, fully harness the potential of semantic technologies and developing advanced services.

Mentioning CoaaS?

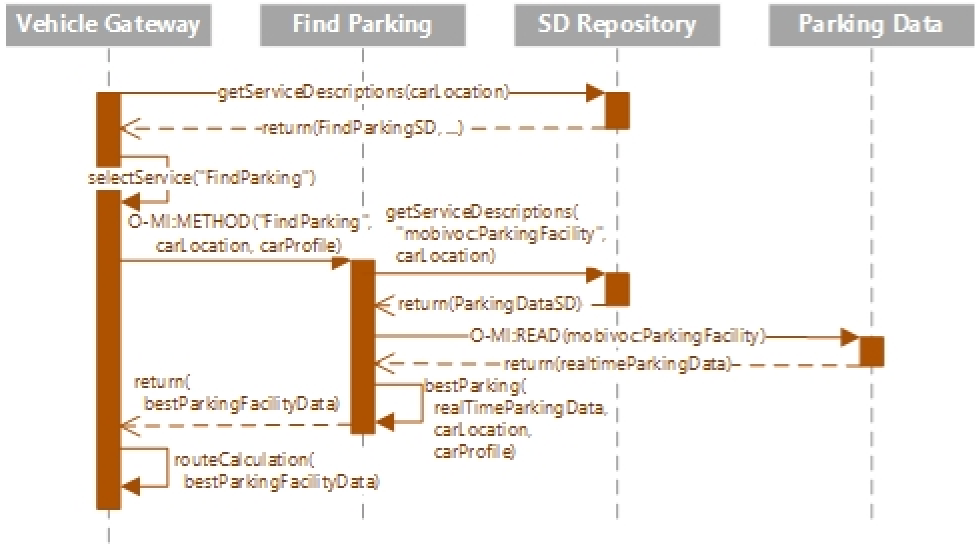

Figure 3. Sequence Diagram for Smart Parking Scenario

Request sent by	FunctionCall	Executing Component	Return
Agent	OMI:READ(car location)	O-MI node	4.93457, 45.71912
Agent	getServiceDescriptions(car location)	IoTBnB	PredictFreeParkingSpace FindParkingFacility
ConnectedDrive	selectService("Find Parking Lyon")	ConnectedDrive	No service selected.
Agent	OMI:METHOD("findParking", car location, car profile)	Find Parking Lyon	Method call received
Find Parking Lyon	getServiceDescriptions(car location, mobivoc:ParkingFacility)	IoTBnB	http://localhost:9001/ ParkingFacilitiesLyonRealtime/109 /mv:numberOfVacantParkingSpaces ParkingFacilitiesLyonRealtime/56 /mv:numberOfVacantParkingSpaces
Find Parking Lyon	OMI:READ(mobivoc:ParkingFacility)	Parking Data Lyon	ID: 109 schema:latitude: 4.945893483960178 schema:longitude: 45.735155208299155 mv:numberOfVacantParkingSpaces: 0 ID: 41

Figure 4. Proof-of-concept UI to observe Function Calls and Results

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(Copied from Sylvain's smart parking paper)

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