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Federation of AAL& AHA systems through semantically interoperable framework

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Abstract— **Ambient Assisted Living (AAL) and Active and Healthy Ageing (AHA) immensely benefit from IoT application. The federation of IoT platforms can multiply the benefits obtained by the operation of those systems in an isolated way, as it enables important synergies (e.g., intelligent information sharing, system cooperation, service enhancement). This federation requires the enablement of interoperability between the IoT systems, which represents a major challenge, as systems typically follow very different standards, data formats, semantic models and manners of representing the information. We have provided a technical solution in the frame of ACTIVAGE, a project that aims to federate multiple heterogeneous IoT platforms and systems associated to clusters of AHA Smart Homes in 12 regions across Europe, with the goal to improve the AHA service provided and create the first European AHA ecosystem. Our technical solution allows the enablement of full semantic interoperability across heterogeneous platforms and it has been validated in a test scenario. It enables significant AHA service enhancement within the ACTIVAGE ecosystem, as native applications from one platform could be used indistinctly by all federated platforms. Our solution allows good scalability federating new platforms, with linear and relatively low effort.**

Keywords— AHA, AAL, platform interoperability, semantic interoperability, federation of systems, IoT

I. INTRODUCTION

One of the most critical societal problems in the present is the accelerated increase of elderly population, paired with their special caring needs. In order to overcome this problem, a variety of solutions that make use of modern technologies to increase the wellbeing of the elderly are being implemented. Many of these solutions come from two interrelated areas that aim to leverage the quality of life of people using technology, namely, Ambient Assisted Living (AAL) [2] and Active & Healthy Ageing (AHA) [3]. In particular, AHA is a field of AAL that aims to enhance the wellbeing of the elderly by exploiting opportunities for enhancing safety, physical activities and health aspects, promoting an active, independent and healthy life. Many AAL, e-Health and AHA systems rely on the Internet of Things (IoT), which is a recent technology paradigm that has proven an immense potential in solving problems on a wide variety of domains and easing modern life [1], including the improvement of the quality of life and health of the elderly population [4]. For example, remote monitoring systems based on IoT technologies would allow a very precise follow-up of body signals over time [5], as well as the development of associated services, such as an automatic intelligent analysis of this data, which would send an early warning notification to caregivers, doctors or family in case of abnormal situations. Moreover, Smart Home systems can be tailored for the specific needs of the elderly in order to increase their safety and comfort [6], while, at the same time, promoting a healthy lifestyle. At the present, the COVID-19 situation is highlighting the enormous advantages of these types of systems, which are remarkably useful to protect and ease the impact of social isolation on a collective as especially vulnerable as the aged population.

In addition to the great usefulness of these solutions, the federation of these systems can result in synergies that could produce a dramatic increase of the benefits of the application of IoT solutions. More concretely, the federation of several solutions would enable the enhancement of the current services based on the co-operation between different solutions and allow coordinated responses from different service providers. Moreover, the solutions based on machine learning or deep learning would benefit from the intelligent sharing of key information, as well as the enrichment of information (which includes both the increase of information sources and data enrichment).

However, nowadays there is a general lack of interoperability among different IoT systems and platforms, due to the high heterogeneity of this paradigm, in which the systems follow different standards. As a result, currently the majority of IoT systems are locked and isolated due to this inherent lack of interoperability. The market reality is that today every IoT device is installed within its own platform and ecosystem, and data integration is not possible outside of this IoT platform or any type of interoperation among external systems [7]. Thus, the potential of the IoT paradigm is significantly constrained due to this lack of interoperability. It is estimated that 40% of the potential benefits of IoT cannot be obtained without interoperability [7]. For these reasons, interoperability among different IoT Systems and IoT platforms, which is considered the key to unlock the full potential of IoT, represents a major challenge with an inherent high complexity, but its application can lead to massive benefits. To this respect, the existence of semantic interoperability would allow the different systems to share information in a way that can be understood and processed by all of them.

The European project ACTIVAGE [8] intends to multiply the benefits obtained from the use of AHA services in Smart Homes for the elderly by enabling semantic interoperability across a set of Smart Home clusters located in 12 different European cities and regions. Our solution for providing semantic interoperability is composed by a real-time semantic translator (Inter Platform Semantic Mediator or IPSM) [9] and a middleware component (Inter-MW) [10] that manages the communication between platforms and performs the syntactic transformation of data formats. In the context of ACTIVAGE, semantic interoperability would enable the co-operation among different Smart Home clusters regardless of their deployed IoT technologies, allowing each of them to incorporate services from other clusters. As a result, the number of available services would be significantly increased, current services could be enhanced with new data, and new services that make use of previously unavailable data sources or data processing services could be built. This would result in remarkable AHA service improvements, which can lead to a significant enhancement of the quality of life of the aged population living at their Smart Homes.

This paper is organized as follows. First, section 1 introduces this research. Section 2 explains the state-of-the-art. Third, section 3 describes the federation of interoperable systems and services from smart homes clusters for the elderly and the semantic interoperability framework deployed to make this possible. Section 4 shows one specific use case and the technical development and results obtained. Finally, section 5 draws conclusions and provides an outlook on the possible future benefits of semantic interoperability in AHA.

II. INTEROPERABILITY

A. *Types of interoperability*

Interoperability refers to the ability of systems to exchange information and correctly interpret and use it. Different types of interoperability between systems have been defined [7]:

- Technical interoperability: being able to exchange data across different networks.
- Syntactic interoperability: being able to interpret the format and encoding of the data.
- Semantic interoperability: being able to understand the meaning of the shared information. This is the highest type of interoperability and can only be achieved after the two previous types are provided.

Due to the high heterogeneity of the IoT paradigm at all levels, there is an inherent lack of interoperability as each IoT system follows very different standards. Typically, systems that have not been designed initially to work together are unable to interoperate among them, thus being incapable of exchanging data. For this reason, interoperability across systems is currently considered a major challenge in IoT.

B. *) Initiatives for semantic interoperability across systems*

There are two main approaches for the enablement of semantic interoperability in AAL-related systems: i) the use of common semantic ontologies, which enables a common representation of the information, and eases up to certain extent interoperation, and ii) the application of technical solutions between or over non-interoperable systems.

Some of the main ontologies specifically designed for IoT are: SSN [11], GOIoTP [12], M3-lite [13] and SAREF [14]. From an AHA perspective, relevant ontology initiatives for the areas of AAL and e-health are FHIR [15], HL7 [16], OpenEHR[17] and OBO[18].

Research efforts for the achievement of semantic interoperability are typically focused on the use of common ontologies among systems that are intended to interoperate [19]. However, this approach is not viable, in general, among systems that were not initially designed to interoperate [7][19] and, therefore, do not share common standards. The effort of changing the semantics in an established IoT platform is, in general, very costly in development terms, especially once an ecosystem of applications is built on top, since it would imply to adapt them to the new semantics. Moreover, in many cases, this is not even possible if the platform cannot support the target data format.

IoT systems are very heterogeneous in terms of semantics and information models, and due to this reason, they are generally non-interoperable among them [20][7]. Technical solutions for enabling interoperability across heterogenous

IoT systems are typically custom-made, hardly scalable requiring exponential effort for the inclusion of new platforms or systems and require a complex development [7]. Few technical initiatives have addressed the IoT interoperability issue among IoT platforms and systems intending to provide generic solutions, such as symbIoTe[1], bIoTope[2], VICINITY[3], BIG IoT[4] and INTER-IoT [20]. Among them, the most remarkable is the H2020 INTER-IoT project [21], which provides a generic framework to ease the enablement of interoperability at several levels in IoT systems. This framework contains the only existing real-time semantic translator for IoT [15].

III. FEDERATION OF AAL & AHA SYSTEMS THROUGH INTEROPERABILITY

The ACTIVAGE project aims to federate 12 different IoT platforms providing AHA services in order to enhance the AHA and aiming to boost the first AHA ecosystem in Europe. Specifically, each platform manages AHA sensors and services from a Smart Home cluster of around 500 users. This federation requires a semantic interoperability solution capable of overcoming the complex challenge of the inherent lack of interoperability across heterogeneous IoT platforms with different standards and information models. In addition, this solution should be generic and scalable.

A. Technical solution

The component of the ACTIVAGE architecture that enables semantic interoperability among the different platforms is the Semantic Interoperability Layer (SIL). The SIL consists of two blocks, named Inter-MW and Inter-Platform Semantic Mediator (IPSM), respectively. These components were developed in the INTER-IoT[5] project [18].

Inter-MW [10]: enables syntactic interoperability. Inter-MW communicates with the platforms through the corresponding bridges, which are developed as separate modules and then deployed along with Inter-MW. Bridges are specific for each IoT platform and perform the necessary syntactic translations between the specific format of the platform and a common data format (JSON-LD).

IPSM (Inter Platform Semantic Mediator) [9]: is the only known real-time semantic translator for IoT [15] at the time of writing this paper and provides semantic interoperability. This component receives the data in the common format and performs the semantic translations based on the specified semantic alignments. The semantic alignments are based on the semantic mappings between two ontologies or data models and define the rules for the translation, which are based on SPARQL operations. For its use with the IPSM, alignments are described using the IPSM-AF formalism [22].

The use of real-time semantic translations is a novel technique [15] for the achievement of semantic interoperability in IoT. It must face several challenges, such as the alignment of ontologies, which is not trivial and it is especially challenging among IoT data models that have non-RDF formalism (which is a very common case), the lack of effective tools to perform the translation, and the appropriate timing for enabling a real-time processing of data. To our knowledge, the achievement of semantic interoperability through streaming semantic translations is novel and has never been applied before to the AHA domain.

This translation framework makes use of a central ontology. Messages sent platform-to-platform through the SIL have a two-step sequential translation. First, messages from platforms are translated to this central ontology semantics. Second, the output messages are adapted to the receiver platform's semantics via a second translation. The ACTIVAGE AHA ontology [23] is employed as the central ontology. This ontology is capable of representing a wide variety of AHA concepts.

B. Application in specific use case

One application of the SIL in ACTIVAGE is the integration in an existing IoT infrastructure of new devices managed by a different platform. This integration is not directly possible due to the interoperability barriers existing among different platforms, as has been explained previously and, thus, the integration of devices from different platforms represents a complex technical challenge. First, the information collected by the sensor is expressed in a different syntactic and semantic format than the employed by the external platform, which requires a complex adaptation of the data to be understandable by the receiver platform. Second, sensor information must be received and used by the external platform in real time.

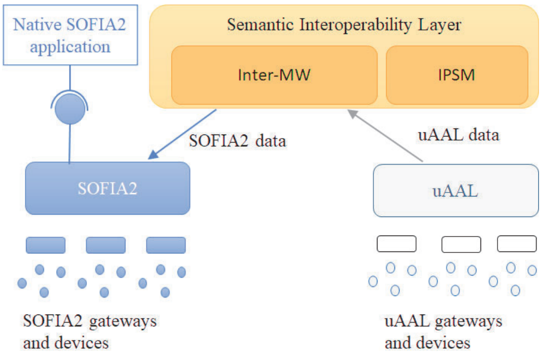

Fig. 1. Use of the SIL in the use case scenario

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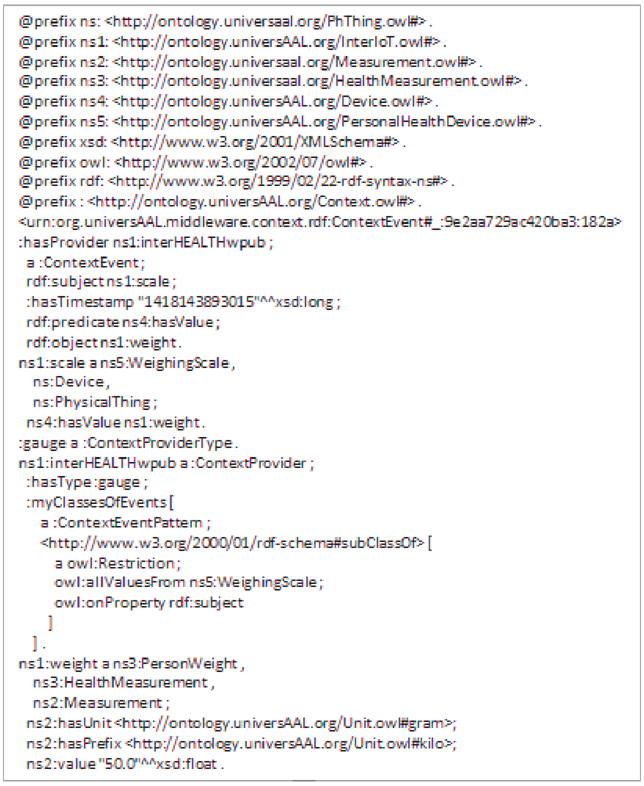
[1] https://www.symbiote-h2020.eu/
[2] https://biotope-project.eu/
[3] https://www.vicinity2020.eu/vicinity/
[4] https://biotope-project.eu/
[5] https://inter-iot.eu

Also, both platforms must be connected to this information flow, and the receiver should be able to process the data as if it came from one of its own devices. In the specific use case presented in this paper, a set of devices managed by universAAL (uAAL) were incorporated in a Smart Home cluster (Galicia SH) whose IoT infrastructure was based on SOFIA2. The use of the SIL allowed the integration of the new devices with the existing native SOFIA2 applications without having to make changes in these applications or developing new drivers to connect them to SOFIA2.

II. IMPLEMENTATION & RESULTS

A. Use case in AHA Smart Home cluster

In the proposed solution, the SIL communicates with both platforms through the corresponding bridges and translates the data coming from uAAL into the data model and syntactic format of SOFIA2 (see Figure 1). To enable the necessary syntactic interoperability in this exchange, the bridges for SOFIA2 and uAAL were installed in the SIL. To enable semantic translation, two different alignments were developed and used in this exchange. The first one was designed to translate the data from the uAAL ontology to the central ontology. The second one defined the translation between the central ontology and the Galicia SH SOFIA2 data model. The alignments contain matches between concepts from both ontologies from a semantic perspective, and the necessary steps for performing a semantic translation between them.



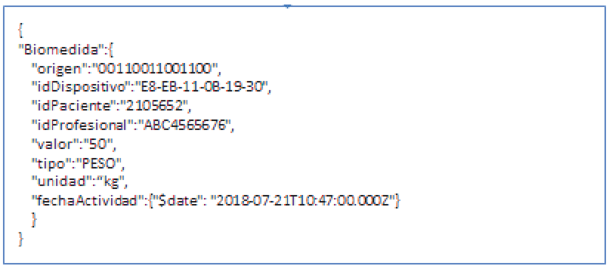
```
@prefix ns: <http://ontology.universaal.org/PhThing.owl#> .
@prefix ns1: <http://ontology.universAAL.org/InterIoT.owl#> .
@prefix ns2: <http://ontology.universaal.org/Measurement.owl#> .
@prefix ns3: <http://ontology.universaal.org/HealthMeasurement.owl#> .
@prefix ns4: <http://ontology.universAAL.org/Device.owl#> .
@prefix ns5: <http://ontology.universAAL.org/PersonalHealthDevice.owl#> .
@prefix xsd: <http://www.w3.org/2001/XMLSchema#> .
@prefix owl: <http://www.w3.org/2002/07/owl#> .
@prefix rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#> .
@prefix : <http://ontology.universAAL.org/Context.owl#> .
<urn:org.universAAL.middleware.context.rdf:ContextEvent#_:9e2aa729ac420ba3:182a>
:hasProvider ns1:interHEALTHwpub ;
  a :ContextEvent ;
  rdf:subject ns1:scale ;
  :hasTimestamp "1418143893015"^^xsd:long ;
  rdf:predicate ns4:hasValue ;
  rdf:object ns1:weight .
ns1:scale a ns5:WeighingScale ,
   ns:Device ,
   ns:PhysicalThing ;
  ns4:hasValue ns1:weight .
:gauge a :ContextProviderType .
ns1:interHEALTHwpub a :ContextProvider ;
  :hasType :gauge ;
  :myClassesOfEvents [
    a :ContextEventPattern ;
    <http://www.w3.org/2000/01/rdf-schema#subClassOf> [
      a owl:Restriction ;
      owl:allValuesFrom ns5:WeighingScale ;
      owl:onProperty rdf:subject
     ]
   ] .
ns1:weight a ns3:PersonWeight ,
   ns3:HealthMeasurement ,
   ns2:Measurement ;
  ns2:hasUnit <http://ontology.universAAL.org/Unit.owl#gram>;
  ns2:hasPrefix <http://ontology.universAAL.org/Unit.owl#kilo>;
  ns2:value "50.0"^^xsd:float .
```

Fig. 2. Example of syntactic and semantic translation from uAAL to SOFIA2 – Input universAAL message to be translated by the SIL

To make the data from the uAAL devices available for the client application, virtual representations of those devices were created in the SOFIA2 platform. These virtual devices are represented in SOFIA2 in the same way as the real ones and are managed by the SIL, which interacts with the platform making use of its API. When an event is sent by the devices in uAAL, the SIL translates the data in real time and sends it as an update for the corresponding virtual device. In a first step, the SIL translates the data from uAAL into the common semantics and format of the SIL using the uAAL alignment and bridge. Next, the message is translated into the syntax and data model of SOFIA2 making use of the SOFIA2 alignment and bridge and is sent to SOFIA2 as a new measurement of the virtual device. Figure 2 shows an example of the translation of a measurement from a weight scale in uAAL (RDF Turtle, following the uAAL ontology) into the data model and syntactic format of SOFIA2 (JSON, following a custom defined data model for the Galicia SH, which does not have an explicit RDF formalism) following the previously explained steps. The semantic and syntactic features of each translation step are summarized in Table 1 and the main semantic matches that are the base of the semantic translations performed in this scenario are shown in Table 2. Data obtained from other types of sensors connected in this scenario can be translated in the same way.

TABLE I. COMPONENT REPRESENTATION OF THE INFORMATION

	universAAL platform	***SIL***	***SOFIA2 platform***
Syntactic format	Turtle (RDF)	JSON-LD (RDF)	JSON
Semantic model	universAAL default ontology	ACTIVAGE AHA ontology	Galicia SH SOFIA2 data model



```
{
"Biomedida":{
  "origen":"00110011001100",
  "idDispositivo":"E8-EB-11-08-19-30",
  "idPaciente":"2105652",
  "idProfesional":"ABC4565676",
  "valor":"50",
  "tipo":"PESO",
  "unidad":"kg",
  "fechaActividad":{"$date": "2018-07-21T10:47:00.000Z"}
  }
}
```

Fig. 3. Example of syntactic and semantic translation from uAAL to SOFIA2 - Output SOFIA2 message translated by the SIL

TABLE II. SEMANTIC EQUIVALENCES BETWEEN TARGET AND SOURCE ONTOLOGIES

	universAAL default ontology (source ontology)		**Galicia SH SOFIA2 data model (target ontology)**	
	Tag	***Example value***	***Tag***	***Example value***
Device ID (different on each platform but inter-related internally in the SIL)	http://www.w3.org/1999/02/22-rdf-syntax-ns#subject	http://ontology.universAAL.org/InterIoT.owl#scale	idDispositivo	E8-EB-11-08-19-30
Date and time of measurement	http://ontology.universAAL.org/Context.owl#hasTimestamp	1418143893015	fechaActividad	2018-07-21T10:47:00.000Z
Magnitude measured	ns1:http://ontology.universAAL.org/InterIoT.owl#weight	50.0	PESO	50
Unit	ns2:hasPrefix ns2:hasUnit	http://ontology.universAAL.org/Unit.owl#kilo http://ontology.universAAL.org/Unit.owl#gram	unidad	kg

Once the measurements are available in SOFIA2, they can be retrieved by the client application through the SOFIA2 API. Thus, the client application obtains and processes the data from the virtual sensors in the same way as the data from the devices deployed in the original SOFIA2 infrastructure. This way, the AHA weight monitoring application, unable to read universAAL weight scale measurement messages, is able to retrieve data from a device and a user from another platform.

B. Real-time performance

The application of this interoperability through semantic translation must allow real-time performance, meaning that the delay induced by the use of the SIL must be reasonably low to allow a correct performance of AHA IoT systems and applications that monitor the elder physical condition and activity.

We measured the SIL processing time of messages containing sensor measurements in a testbed. In our testing scenario, the SIL runs on a desktop PC with an Intel Core i5-2400S processor running at 2.5GHz, with 8GB of RAM, and has connected a platform emulator that generates messages at a rate of 10 msg/s. The number and frequency of messages received is verified through a client application that retrieves translated messages through the SIL API. We executed a series of 5 experiments of 300 seconds. Table 3 presents the overall values obtained in all experiments. The performance behavior observed in all batches was very similar with no significant differences.

TABLE III. OVERALL RESULTS OF DELAY MEASUREMENT

Min latency (ms)	*Max Latency (ms)*	*Mean (ms)*	*Median (ms)*
16	148	21.429	20

We estimate that the measured rate of 600 msg/s cover the needs of a cluster of Smart Homes, in which the whole set of monitoring devices have a lower message rate in normal conditions (measured under 500 msg/s in the SH cluster studied). The processing time of the SIL only depends on the message rate, and not on the number of platforms or devices connected. Also, we found no difference in terms of performance measurement in the use of real platforms or emulators. Due to this reason, we chose to use a simplistic scenario with a platform emulator because it provides an accurate message rate generation.

The maximum latency value (worst case among all batches) is 148 ms, but as it can be seen in the mean and median values, it is not significant along time (it corresponds to a peak value at the beginning of the transmission). After then, we observed that the latency time stabilizes at around 20 ms and presents very slight variations.

We consider this latency acceptable for real-time applications on AHA Smart Home scenarios, on which even alarms triggered can afford significatively higher delays. To estimate the complete latency of the use of the SIL it should also be considered the transmission delay to the SIL server, which depends on the specific scenario deployment. In the same way as the IoT platform transmission delay is generally considered despicable in this type of systems, it would also be considered non-relevant this other server transmission delay, in most cases.

III. CONCLUSIONS & OUTLOOK

We have developed a technical solution for enabling interoperability across platforms in the frame of the ACTIVAGE project, with the aim of enabling a federation of AHA IoT platforms managing different AHA Smart Home clusters across 9 countries in Europe. Our open-source solution is based on the interoperability framework of the INTER-IoT project, particularized to our specific scenario. Although the interoperability barrier is one of the most complex challenges in IoT, we have demonstrated the effectiveness of our solution.

In this paper, we have presented one of the scenarios that were used in the validation of our solution, which is a simple interoperability scenario with 2 different platforms. Our SIL allows the correct exchange of information across them in real time, providing semantic interoperability among them despite the very different way of modelling information for each of those platforms. Furthermore, we demonstrated that it allows the use of native applications of a platform with devices connected to a different one by making the data sent by the sensors understandable by the applications while, at the same time, maintaining the latency of the measurements within an acceptable range for this type of services. Thus, the use of our solution can multiply the services available in one platform, as it allows the inclusion of native applications from the other platform, which are made available through interoperability. Similarly, an existing service can be easily extended to incorporate users that are making use of a different IoT platform. This feature can be especially useful for enhancing an AHA ecosystem and boosting its growth.

Furthermore, this interoperability solution can potentially enable AHA service improvement in other ways. For instance, new services based on interoperability could be defined, which could incorporate data and services from different IoT platforms.

Typically, solutions for interoperability across platforms are hardly scalable, but the one presented in this paper allows a modular approach. Thus, it will be possible to easily accommodate new platforms without adding extra complexity or affecting platforms already included. To this respect, the inclusion of a new platform does not imply making any changes to the existing bridges and alignments. Moreover, bridges are implemented in a generic way and, thus, the same bridge can be used to connect any new instances of an existing platform. In the specific case of the ACTIVAGE project, the adopted interoperability solution allows the inclusion of the 12 different platforms, as well as future platforms in the scope of this ecosystem.

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