Integrating the AAL CasAware platform within an IoT ecosystem, leveraging the INTER-IoT approach

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Abstract. *CasAware* is an Ambient Assisted Living platform, which aims at improving level of comfort and well-being of inhabitants, while optimizing energy consumption. A key feature for a successful realization of such a platform is its integration with other available/deployed IoT solutions. Indeed, this integration has to facilitate smooth communication between the CasAware platform and devices, and other IoT devices, in particular to enable exchange of data sets among them. In this paper, we introduce an approach, followed in CasAware, to realize such integration. Specifically, the proposed solution exploits guidelines of the INTER-IoT project, which proposed a framework for the inter-platform communication. So far, various existing IoT platforms have been plugged into this framework, originating from multiple application fields, thus demonstrating the advantages of such integration, capable of disregarding the specific application context. The idea behind the herein presented study, is that an INTER-IoT based approach can guarantee enhancement of interoperability between CasAware and other platforms, thus promoting a unified view of the data, from client's perspective, within the complete IoT ecosystem.

Keywords: INTER-IoT, Internet-of-Things (IoT), CasAware, Smart Home, IoT Platforms, Semantic Interoperability.

1 Introduction

With the rapidly growing number of devices that produce and consume data, Internet-of-Things (IoT) is not just a matter of connecting things to the Internet. The real challenge, in exploiting IoT to its full potential, is to link *things/IoT artifacts* into synergistic networks, endowed with virtual and physical components, which work together with a high degree of interoperability [5,11]. In order to enable such interoperability, it is crucial to identify valid methods of making things more cooperative and collaborative, providing them with capabilities to exchange information in a meaningful way (i.e. making it semantically understood by communicating parties) [32].

Here, we focus on integration, within an IoT ecosystem, of the CasAware platform [36], which is the main outcome of an Italian research project funded by the Lombardy region. CasAware is an Ambient Assisted Living solution, which aims at optimizing energy consumption within a household, exploiting cooperation and collaboration among domestic devices, enabled by the IoT paradigm.

Success of the CasAware platform depends on its capability to interoperate with other existing IoT solutions. Since these, typically, come from various vendors, lack of interoperability can be caused by adoption of different (not directly compatible) communication interfaces, software stacks, operating systems, and hardware [31]. Moreover, lack of widely accepted IoT interoperability standards further worsens the problem. One example of a possible CasAware integration, involves meteorological observation platform, allowing to adjust the living environment parameters (e.g., indoor temperature, brightness, etc.) in response to the available meteorological data. Obviously, also many other usage scenarios of the CasAware solution require interoperability [27].

The paper describes our experience in integrating CasAware with other IoT platforms leveraging methodology, tools, and framework of the European research project INTER-IoT [2,15]. INTER-IoT aims at designing, implementing and testing a set of tools, along with a methodology that helps to achieve interoperability among IoT artifacts (platforms/systems/applications) on different layers (device, network, middleware, applications and services, data and semantics). So far, various IoT platforms, from multiple application domains, have been plugged into the INTER-IoT ecosystem, demonstrating advantages of the proposed approach, which, in particular, allows disregarding the specific application context. In what follows, we discuss how the CasAware platform can utilize advantages brought by the INTER-IoT project, i.e.: (1) exchange of meaningful information between plugged platforms in a seamless and smart way; (2) simplified communication between client and CasAware back-end services, by exploiting tested, robust communication mechanisms provided within INTER-IoT implementation.

The remainder of the paper is structured as follows. Section 2 outlines state of the art of interoperability between IoT platforms. Next, in Section 3 the CasAware system, with its architectural levels paired with a usage scenario that will guide presentation of the application of the INTER-IoT methodology, is described. Section 4 presents the INTER-IoT approach. We follow, in Section 5 with the description of integration of the CasAware system with INTER-IoT components/products. Finally, Section 6 draws conclusions and discusses future research directions.

2 Interoperability of IoT artifacts

The concept and approaches to interoperability of IoT artifacts evolved over time. According to [13], the first wave of IoT application emphasized on connecting sensors interfacing with physical-world using lightweight communication protocols such as CoAP (Constrained Application Protocol) [10], and XMPP (Extensible Messaging and Presence Protocol) [34], mainly within *smart city* domain. Subsequently, traditional Internet representational state transfer protocol (REST) idea has been used for similar applications, where event-centric approaches had been implemented to reduce number of transmitted messages [14].

Later on, the second wave has come, together with the idea of "smart objects", i.e., devices that incorporate certain degree of intelligence, making them able to "understand" the *environment* and react to external stimuli it provides. With growing real-world awareness, smart objects provide support for increasingly complex solutions [25]. In industrial applications, for example, existing physical objects like containers and tools, as well as procedures, like, e.g., quality control, have been converted into smart objects equipped with embedded sensors, wireless connectivity, and computational capabilities, so they could communicate, interpret sensor data, make decisions, and cooperate with each other. With the introduction of smart objects the Internet of Things vision became reality [9,28].

Finally, the third wave has involved use of *semantically-enriched* data, acquired from *heterogeneous* sources in a, possibly, *multi-domain/cross-domain* environment. The need for semantic techniques/technologies became obvious once the IoT domain started getting congested with multiple platforms/applications using different (essentially incompatible) communication protocols and data models [7]. Because of the proliferation of vendors-specific solutions, many organizations are attempting to promote standardization in order to enable/guarantee interoperability between applications. For example, the OpenIoT and AllSeen alliances, have developed the OpenIoT platform and an IoT framework. The Internet Engineering Task Force (IETF) and XMPP standards foundation are trying to align their messaging protocols, CoAP and XMPP, with other protocols [13]. Numerous approaches have also been used to align and integrate different communication protocols or data models instead of focusing on creating a *single* standardized one [12,26].

By leveraging theoretical and technological approaches developed within the *Semantic Web*, data produced and processed by IoT artifacts progressively becomes semantically-enriched or even semantics-based. In the case of raw sensor data, for instance, the enrichment usually refers to contextual information, compliant with corresponding data models. To facilitate the "semantic-enrichment" a number of standards/proposals for data formats and IoT-related *ontologies* emerged [21]. For instance, for sensor data we can mention: i) OGC Sensor Web Enablement (SWE), established by the Open Geospatial Consortium, and including following important specifications: Observation & Measurement (O&M), Sensor Model Language (SensorML) and Sensor Observation Service (SOS); ii) Semantic Sensor Network (SSN) ontology, developed by W3C provides a standard for modeling sensor devices, sensor platforms, knowledge of the environment and observations; and iii) Semantic Sensor Observation Service (SemSOS).

Although the utilization of these standards supports integration of Semantic Web with sensor-based applications, the IoT interoperability challenge is far from being solved. A real, semantic-based, IoT-specific architecture is required to provide *semantic interoperability* between IoT artifacts [13,19,22]. One of the first initiatives, in this direction was the already mentioned OpenIoT project, funded by Europe Union's framework program. OpenIoT focuses on developing open source middleware for IoT interoperability using linked sensor data. At the heart of OpenIoT lies the old revision of W3C Semantic Sensor Networks (SSNX) ontology, which provides a common standards-based model for representing physical and virtual sensors [35]. It also uses several well-known vocabularies and relations (e.g. PROVO provenance ontology, LinkedGeoData and basic geo vocabulary, LSM live sensor data management vocabulary, etc.), as well as custom pilot-specific ontologies to model the necessary concepts [16]. FI-WARE [33] is another EU sponsored platform for IoT, enabling a market-ready open source solution, which combines components that enable the connection of IoT with Context Information Management and Big Data services in the Cloud.

Another IoT solution developed by the AllSeen Alliance, in conjunction with the Open Connectivity Foundation (OCF), is AllJoyn [6], an open source software framework that makes it easy for devices and applications to discover and communicate with each other, freeing developers from the details of the transport layer, the manufacturer-specific differences, and so forth, when they develop IoT applications.

3 CasAware project overview

The CasAware project aims at improving inhabitants level of comfort and well-being, while optimizing energy consumption and enforcing security. Specifically, it provides a context-aware system, which monitors the dwellers' behaviour in order to provide customized services related to their safety in the house, appliance management and energy consumption management [36]. Customized services are also enabled by integration of CasAware with other IoT platforms, external to CasAware, which provide further information to the CasAware ecosystem.

3.1 CasAware architecture

The proposed system leverages combined exploitation of various technologies, ranging from Big Data to the Semantic Web. In particular, it takes advantage of ontological modeling techniques to formalize and represent knowledge of different domestic concepts (house, appliances, and the information they share and exchange). Furthermore, the ontology-based approach enables use of reasoning to infer new insights from already known facts. The system is currently being developed at the STIIMA CNR's IoT Living Lab in Lecco and is to be tested with real inhabitants (both able-bodied and impaired). Specifically, the CasAware system is structured into five layers, depicted in Figure 1 (see, also [36]).

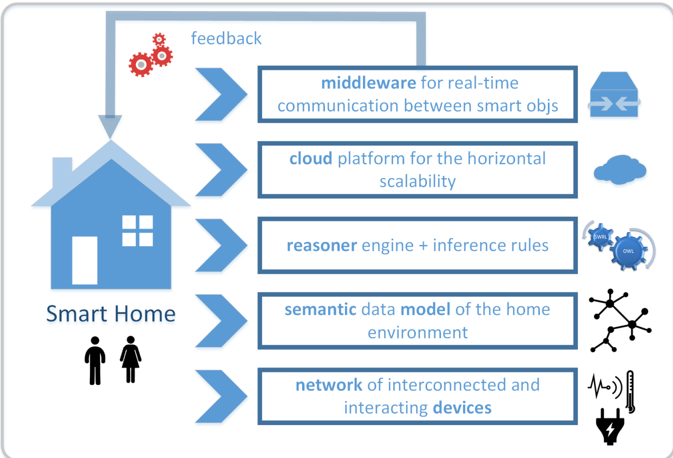

Fig. 1. A layered-based architecture for CasAware project

The first layer is a physical network of interconnected and interacting devices. Connection between these devices and people can be realized leveraging active transponders that are suitably equipped with sensors connected to various receivers to transmit acquired home telemetry. Second layer is a semantic data model that formally represents knowledge of home environment and behaviors of its inhabitants. The semantic model can be expressed as a set of ontologies, which are "formal, explicit specifications of a shared conceptualization" [23]. For their formalization, Resource Description Framework (RDF) [4], Web Ontology Language (OWL) [3] and Semantic Web Rule Language (SWRL) [24] (standard languages, endorsed by the W3C) are used. Since CasAware's main purpose is to enhance the dwellers' comfort, semantic models represent (i) interactions among household devices, and (ii) dwellers' behaviors. A good starting point for the development of needed ontologies consists of data models developed within research projects PEGASO [30] and Apps4aME [29]. The third layer contains a reasoner and a set of inference rules that, together, allow to entail and extract new knowledge, by exploiting data already acquired by the sensors. The fourth layer is a cloud platform that guarantees horizontal scalability of the whole infrastructure. The cloud hosts the semantic database, where the semantic model is persisted (both instances and corresponding meta-model), leveraging the exposed SPARQL engine [31, 32]. Finally, the fifth layer is a Semantic Middleware (SM) that allows near real-time communication among devices. It is based on the semantic model of the Third Layer. In addition, integration with INTER-IoT components takes place in this (SM) layer. Specifically, thanks to the SM, the CasAware platform exposes two types of requests: *publish* and *subscribe*, through a publisher/subscriber mechanism, implemented by the SM component [31] (see, Figure 2), leveraging the MQTT protocol [8].

3.2 CasAware integration – motivating scenario

In [27], authors describe a typical scenarios involving CasAware IoT platform. The first described use case highlights the benefits of connecting the CasAware platform to other IoT solutions. Let us summarize it here.

Let us consider Antonio, who is 41 years old and suffering from hypotension. CasAware system is aware that Antonio gets up every morning at 7:00 and leaves home to work at 7:45. It also knows that in regular conditions, it takes Antonio about 45 minutes to reach work, by walking 800 meters to the nearest train station, and then taking a train that stops at a station that is right next to the building where he works. CasAware processes real-time information regarding train and weather conditions acquired from two other IoT platforms (*Viaggiatreno*[1] for train information, and *Openweather*[2] for weather conditions). Thus, CasAware can estimate potential slowdowns on Antonio's usual path to work (e.g. due to heavy rain, delay of the train, etc.), which in turn can cause a delay of N minutes in his arrival at work. In this case, according to acquired information, CasAware sends information to the alarm clock and wakes Antonio M minutes earlier than usual (to catch train that leaves M minutes earlier). Similarly, the coffee machine starts M minutes earlier and the coffee is ready as soon as Antonio enters the kitchen. In addition, earlier ignition of the heating system is needed, to ensure a warm environment when Antonio rises. The system will then be switched off, as soon as Antonio leaves the house, thus optimizing gas consumption. When Antonio tries to open the door to leave the house, the door does not open if he has not taken the medicine for the hypotension. Finally, in case of rain or snow, the umbrella stand near the door blinks, reminding Antonio to take the umbrella with him.

It should be highlighted that, compared to CasAware, Viaggiatreno and Meteo.com use completely different data model representation. Thus, the need for translation to a data model used within the CasAware platform.

[1] http://www.viaggiatreno.it
[2] http://openweather.com

4 INTER-IoT project overview

The EU H2020 INTER-IoT project [2] aims at design and implementation of a set of tools and a methodology, dedicated to achieving interoperability between heterogeneous IoT artifacts. Interoperability mechanisms work at the various layers of the hardware/software stack, i.e. devices (D2D), network (N2N), middleware (MW2MW), application and services (AS2AS), data and semantics (DS2DS). The INTER-IoT solution enables creation of IoT ecosystems, in which uni- or bi-directional communication can be established at any layer of the hardware-software stack. Additionally, the solution offers INTER-API that allows to configure and interact with each layer's components. In the context of CasAware, (semantic) integration is performed at MW2MW (Middleware to Middleware) layer, where INTER-IoT component INTER-MW enables the data exchange among CasAware and the other platforms – *Viaggiatreno* and *Openweather*.

INTER-MW, internally, uses IPSM (Inter-Platform Semantic Mediator) component [18, 20, 22] that performs (streaming) semantic translation. It should be stressed that the INTER-IoT interoperability approach does not require changes to the connected platforms/artifacts (e.g. the CaseAware platform). To achieve interoperability, a connector (Bridge) needs to be constructed from a provided template that specifies interfaces to be implemented. Part of the Bridge functionality is to perform syntactic translation – a two-way change of data formats. As an internal message format, INTER-IoT uses RDF in JSON-LD serialization. Every message consists of two graphs *metadata* and *payload*, where payload represents the "core content" of the message. Therefore, for instance, if source platform uses XML based on XSD, then Bridge should translate the message to JSON-LD, where the *payload* is expressed in source platform's ontology/vocabulary (if the platform natively uses RDF then no syntactic translation is necessary). The semantic translation to/from a *central ontology* (INTER-IoT model, extendable for specific deployments) and source/target artifact's ontology is performed by the IPSM (Inter-Platform Semantic Mediator) component. The translation is based on *alignments*, i.e. mappings between structures in source/target ontology and the central ontology. The central ontology is, in most part, deployment specific, but always extends the common "core" – the Generic Ontology for IoT Platforms (GOIoTP) [1, 17, 37].

5 Integrating CasAware into INTER-IoT

Let us now describe, in some detail, how the CasAware architecture has been integrated with INTER-IoT components and products. The main idea consists of interfacing CasAware platform through creation of a corresponding *Bridge*, and installing it into the INTER-IoT infrastructure. The Bridge component acts as a mediator that is able to handle the connection of CasAware platform with all other platforms, connected to the INTER-IoT ecosystem at the middleware layer. Its realization is based on a generic interface, which provides a structured

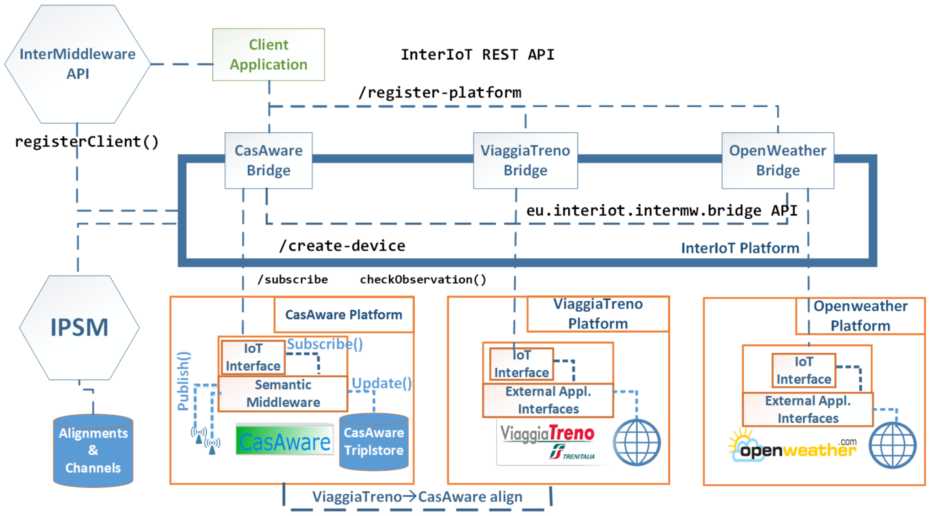

Fig. 2. The integration architecture of CasAware within Inter-IoT

template that enables to easily develop a new platform-specific instances. Once the CasAware Bridge is created, the CasAware platform is able to register in the INTER-IoT ecosystem by calling the *registerPlatform* method, and subsequently operate with the other interface methods such as: *registerDevice*, *observe*, *actuate*, and so forth.

The methods implemented within the Bridge include logic that is platform-specific and requires bidirectional communication with INTER-IoT middleware components. In this way, on the one hand, a client application or devices deployed on a platform can request information originating in CasAware via the REST services provided by the INTER-MW API. On the other hand, any device connected to CasAware can request information updates coming from any other of the INTER-MW connected IoT platforms/artifacts. For example, when a device of any IoT platform (e.g., a temperature sensor) intends to write a new value in the repository, it makes an *update* call to the Semantic Middleware (SM), which will result in a *publish* call to the SM and then in turn in a *a SPARQL update* operation in the underlying Triple Store (Figure 4). Conversely, when a client intends to be acknowledged about specific CasAware device values update, it expresses it by calling the *observe* directive via INTER-MW bridge API, which gets translated into a *subscribe* request to the SM (Figure **??**). As soon as the CasAware receives the answer, it elaborates the received information.

In figure 3 is shown the projects tree related to the CasAware Dashboard Demo Client and the underlying platforms such as, CasAware Emulator, ViaggiaTreno and OpenWeather. In order for the proposed demo to demonstrate the integration of the mentioned platforms through the INTER-IoT layers, diverse Java Maven modules have been created, the main one being the CasAware Dashboard. This latter is in charge of registering itself and all the platforms to

Fig. 3. The Eclipse projects tree of CasAware Dashboard Demo Client

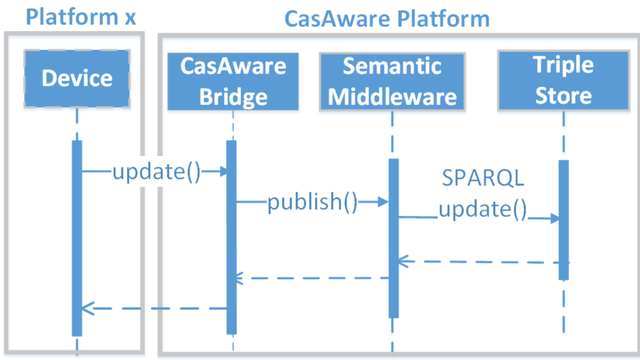

Fig. 4. Sequence Diagram to write a value into CasAware

the INTER-IoT middleware and creating the devices from which data will be observed, by exploiting the interfaces exposed by the platform's Bridge (each platform is equipped with a specific bridge as a separated jar module). Thus, the client is able to smoothly collect and integrate data coming from the various platforms at application level disregarding the different levels of heterogeneity characterizing them.

In addition to the Bridge, another INTER-IoT product that CasAware uses is the IPSM. Indeed, since CasAware and other IoT artifacts have to exchange data, an interoperability at the semantic layer is required. For this reason, it is essential to reconcile and mediate the ontology handled by applications and devices connected to CasAware and the data models behind the other IoT platforms integrated within the INTER-IoT deployment. For this purpose, GOIoTPex, a more specific version of GOIoTP offered by INTER-IoT, is used as the central ontology. The alignments (or pairs of alignments) between GOIoTPex and the involved platforms data models are part of the configuration required to establish communication with INTER-MW. Specifically, they are internally used by the IPSM, which is used to translate and align the commonalities (overlapping concepts and expressions) between the CasAware application ontology with

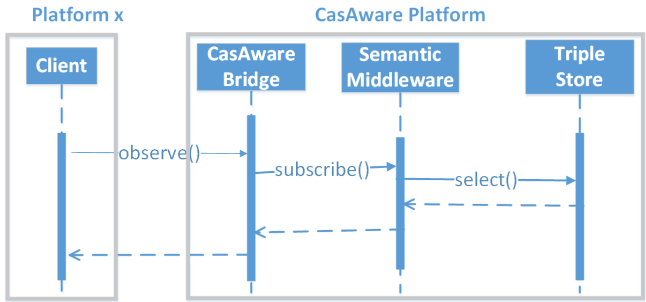

Fig. 5. Sequence Diagram representing an observation request

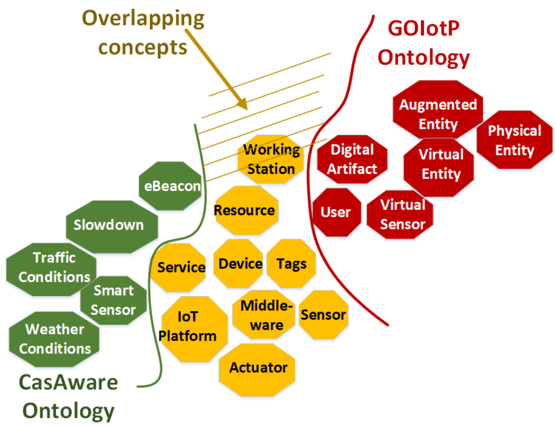

Fig. 6. Overlapping between GOIoTP and CasAware ontology

GOIoTPex and vice-versa (Figure 6). In order to define the alignments, it was necessary to formally represent the corresponding mappings. A simple example of such a representation, using the IPSM Alignment Format (IPSM-AF) is given in the listing below:

```
<Alignment
              xmlns="http://www.inter-iot.eu/sripas#"
       xmlns:rdf="http://www.w3.org/1999/02/22-rdf-syntax-ns#"
       xmlns:sripas="http://www.inter-iot.eu/sripas#"
       xmlns:sosa="http://www.w3.org/ns/sosa/"
       xmlns:iiot="http://inter-iot.eu/GOIoTP#"
       xmlns:iiotex="http://inter-iot.eu/GOIoTPex#"
       xmlns:cas="http://itia.cnr.it/CasAwareOntology#"
       name="CasAware_CO_align" version="1.0.11" creator="ITIA-
           ↪ CNR" description="Alignment between CasAware
```

```
        ↪ application ontology and INTER-IoT central ontology
        ↪ .">
  <onto1>
    <Ontology about="http://itia.cnr.it/CasAwareOntology#">
      <formalism>
        <Formalism name="OWL2.0" uri="http://www.w3.org/2002/07/
        ↪ owl#"/>
      </formalism>
    </Ontology>
  </onto1>
  <onto2>
    <Ontology about="http://inter-iot.eu/GOIoTPex#">
      <formalism>
        <Formalism name="OWL2.0" uri="http://www.w3.org/2002/07/
        ↪ owl#"/>
      </formalism>
    </Ontology>
  </onto2>
  <steps>
    <step order="1" cell="1_device"/>
  </steps>
  <map>
    <Cell id="1_device">
      <entity1>
        <sripas:node_CTX>
          <rdf:type rdf:resource="&cas;Sensor" />
        </sripas:node_CTX>
      </entity1>
      <entity2>
        <sripas:node_CTX>
          <rdf:type rdf:resource="&iiot;IoTDevice" />
        </sripas:node_CTX>
      </entity2>
      <relation>=</relation>
    </Cell>
  </map>
</Alignment>
```

In the example, two concepts from relevant ontologies (CasAwareOntology and GOIoTP) are aligned. The *cells* of the alignment represent (possible) single *steps* in the corresponding translation process. In the listing a single example step is defined through which `entity1`:

http://itia.cnr.it/CasAwareOntology#Sensor

is postulated to be equivalent to `entity2`:

http://inter-iot.eu/GOIoTP#IoTDevice.

The actual alignment is comprised of much more cells that describe mappings with varying degree of complexity.

In Figure 7, an excerpt of the CasAware Dashboard Panel, i.e., a GUI-based tool able to implement the motivating scenario previously described, thanks to the integration of three different IoT platforms is shown. In the figure the graphical widgets whose activation follows what described in the scenario, are shown: a) the external temperature, humidity percentage and precipitation forecast (information received from *Openweather* platform); b) the next available train (information received from *Viaggiatreno* platform; c) the alarm clock with the set time, the coffee machine with a time indicator set to the activation time, the indoor temperature indicator, two alarms alerting the inhabitant in case of rain and if he/she forgetss to take the daily prescribed pill (information handled by the CasAware platform).

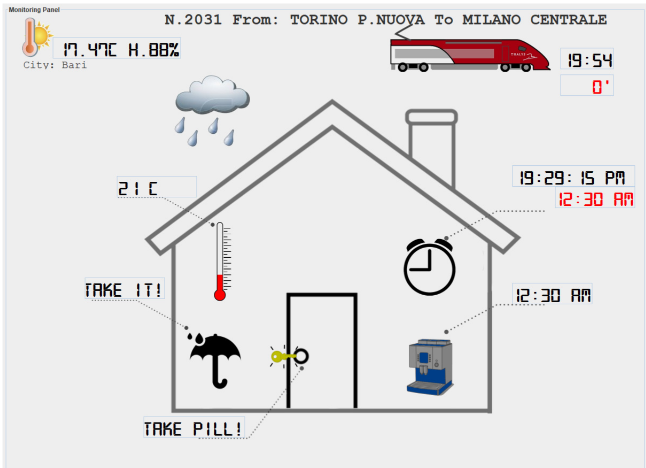

Fig. 7. A screenshot from the CasAware Dashboard Panel

The proposed approach has been initially implemented and is currently being tested. It has been established that the translation works, as expected, for all connected artifacts.

6 Concluding remarks

The paper presents and discusses the use of INTER-IoT approach and software to integrate the CasAware platform with other IoT artifacts (platforms and devices). The integration was explained within a domain specific (Ambient Assisted Living) application. To achieve interoperability, appropriate Bridges have been implemented and alignments between data representations created. Prototype implementation has been completed and is being tested across a number of scenarios outlined in [27]. While the tests are successful for a single deployment, one of the interesting open questions is that of scalability. In other words, how will the proposed approach behave in the case of multiple CasAWARE households being connected to various artifacts (including the two external platforms) via INTER-IoT middleware/services. Will the current approach scale, nad if it does not, how will it have to be adapted to obtain sufficient scalability. We plan to investigate this question in the near future.

Separately, upon reflections based on the initial implementation, we came to the following conclusions. (1) Instantiation of a Bridge, which connects an artifact to the INTER-IoT environment, is not very difficult and can be achieved by following templates provided by the INTER-IoT project. (2) Creation of alignments is more complex and requires, at least basic, knowledge about ontologies and semantic technologies. Without such knowledge/understanding what is an ontology, how it is represented and how it is used in practical applications, creation of correct alignments is a relatively complex and time consuming process, even if appropriate documentation and examples are provided. Here, let us observe that it is a well-known fact that semantic technologies are not very popular, even though they hold a lot of promise. This is, at least in part, because they require knowledge that is not easily available (e.g. few universities include semantic technologies in their CS/CE curriculum). Nevertheless, there must be a way to help alignment developers; for instance, by development of appropriate tools. Here, the AFE tool, proposed within the scope of INTER-IoT is a step in the right direction.

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