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Use Cases, Applications and Implementation Aspects for IoT Interoperability

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Abstract

Interoperability in IoT is currently a very complex and difficult challenge in IoT. Lack of interoperability drastically constrains potential benefits from the interconnection of smart objects and hampers the incipient evolution of IoT (Ambient Intelligent Environments, natural transparent human-oriented interfaces, integration with machine learning mechanisms, blockchain security and Artificial intelligence). INTER-IoT solution for interoperability enables platform-to-platform interoperability, across any IoT layer and any application domains. In this chapter, INTER-IoT solution for platforms' integration is applied to relevant use cases in the domains of e-Health, AHA, AAL, Transport and Logistics. Furthermore, innovative aspects and elements of the INTER-IoT are explained, and the benefits of its implementation.

5.1 Introduction

This chapter is about the enablement of IoT interoperability though a novel framework provided by the INTER-IoT project [1, 2]. In particular, it is focused on the uses cases and applications of the INTER-IoT framework, and on the innovative aspects of its implementation.

Interoperability is one of the major challenges in IoT and has a vital importance in the exploitation of all the potential benefits that can be achieved through this new technology paradigm. Without interoperability, possibilities and benefits from the use of IoT are significantly constrained [3].

INTER-IoT project provides an open cross-layer framework with its own associated methodology and integration tools to enable interoperability among heterogeneous Internet of Things (IoT) platforms [2]. INTER-IoT will enable the quick and effective development of smart IoT applications and services, on top of heterogeneous IoT platforms interconnected, and independently from the domain (thus between one or several application domains).

This chapter explains relevant uses cases of the INTER-IoT framework, focused on different application domains (Transportation & Logistics, e-Health, Active & Healthy Ageing, and others). In addition, it provides a state-of-the-art of the current situation of interoperability in IoT, and an overview of new approaches employed in the INTER-IoT implementation.

5.2 Current Interoperability State of the Art

Regarding the implementation of IoT, insufficient interoperability among platforms tends to provoke major issues both at the technical and business levels [3, 4]. Typical problems are the impossibility of integrating non-interoperable IoT devices into non-homogeneous IoT platforms as well as the inability of developing applications and services over several platforms and different domains. Other important setbacks are the paucity of IoT technology penetration, avoidance of customers and companies in employing IoT technology, cost increases in general, impossibility of reusing of technical solutions and low user satisfaction.

Furthermore, lack of interoperability slows and even impedes the incipient evolution of IoT. Ambient Intelligent Environments require seamless interoperability among elements and interfaces. Also, interoperability is essential for the creation of natural transparent human-oriented interfaces of Smart Systems, and it has vital importance for the IoT integration with Artificial Intelligence and the inclusion of new mechanisms such as blockchain security.

In recent years, many solutions have been implemented at different levels, from the device layer to complete IoT platforms, due to a great interest of both business and research institutions in investigating and developing

IoT technology. However, there is no reference standard for IoT and the development of one is not expected in the foreseeable future [3]. Hence, IoT deployments present high heterogeneity at all layers (device, networking, middleware, application service, data/semantics), which restricts interoperability among their elements and among them. Though many projects have dealt with the development of IoT architectures in diversified application domains, not many projects have addressed interoperability and integration issues among platforms (a clear exception are Butler and iCore [29]). Furthermore, no proposals up to the date of the INTER-IoT project approval have been put forward to deliver a general, fully reusable and systematic approach to solve multiple interoperability problems existing in the IoT platforms technology.

The main goal of the INTER-IoT project is to offer a solution for the lack of interoperability in the Internet of Things by providing an open framework that facilitates “voluntary interoperability” among heterogeneous IoT platforms, at any level an IoT deployment (device, network, middleware, application or data & semantics), and across any IoT application domain [2, 6]. Therefore, INTER-IoT guarantees a transparent and effective integration of heterogeneous IoT technology [2, 5].

By using the proposed approach, IoT platform heterogeneity can be turned from a crucial problem to a great advantage, as there will be no need to wait for a unique standard for an interoperable IoT. Instead, interoperable IoT, even on a very large scale, can be created through a bottom-up approach.

The majority of current existing sensor networks and IoT deployments work as standalone entities, and represent isolated islands of information, unable to communicate, interoperate and share information with other IoT systems and platforms due to the use of different standards and to their high inner heterogeneity. In the infrequent cases in which there is an integration effort of IoT elements, it is generally performed at the device or data layer, seeking only the collection of data from smart devices. However, there are many other levels of an IoT deployment, in which it is very beneficial to have interoperability, and many other relevant objectives. Differently from current interoperability approaches, INTER-IoT uses a layer-oriented approach to exploit in depth functionalities of each different layer (device, networking, middleware, application services, data & semantics) [1].

Among the different types and levels of interoperability, a main challenge is inter-platform interoperability, which is addressed on the INTER-IoT project.

5.3 Inter-IoT New Approaches for Implementation

5.3.1 Multilayer Approach

Differently from current interoperability solutions, that typically follow a global approach, INTER-IoT uses a layer-oriented approach for performing a complete exploitation of each different layer functions [2]. Despite of the research and development challenge that the design of a layer-oriented approach represents, in comparison to a global approach, it can potentially provide a very tight and superior bidirectional integration between different IoT platforms. Therefore, a multilayer-oriented approach can potentially offer improved performance, adaptability, flexibility, modularity, reliability, privacy, trust and security.

This layer-oriented approach is composed by several interoperability solutions, addressed specifically to each level or layer of an IoT deployment: Device-to-Device (D2D), Networking-to-Networking (N2N), Middleware-to-Middleware (MW2MW), Application & Services-to-Application & Services (AS2AS), Data & Semantics-to-Data & Semantics (DS2DS).

Each interoperability infrastructure layer has a strong coupling with adjacent layers and provides an interface. Interfaces are controlled by a meta-level framework to provide unrestricted interoperability. Every interoperability mechanism can be accessed through an API. The interoperability infrastructure layers can communicate and interoperate through the interfaces. This cross-layering allows to achieve a deeper and more complete integration. Next, the different layers and associated tools are detailed:

Device layer (D2D): Currently applications and platforms are tightly coupled, preventing their interaction with other applications and platforms, sensors and actuators communicate only within one system, certain platforms do not implement some important services (i.e. discovery), or do so in an incompatible way. Roaming elements can be missing or inaccessible. IoT Device software is never platform independent as companies create proprietary software. These facts present enormous difficulties for the achievement of interoperability. At the device level, D2D solution will allow the transparent inclusion of new IoT devices and the device-to-device interoperation with other smart objects (legacy). D2D interoperability will allow boosting the growth of IoT ecosystems. As a potential solution, INTER-IoT proposes a D2D gateway that allows any type of data forwarding, making the device layer flexible by decoupling the gateway into two independent parts: a physical part that only handles network access and communication protocols, and a virtual part that handles all other gateway operations and services. When connection is lost, the virtual part remains functional and will answer the API and Middleware requests. The gateway will follow a modular approach to allow the addition of optional service blocks, to adapt to the specific case.

Network layer (N2N): Currently the immense amount of traffic flows generated by smart devices is extremely hard to handle. The scalability of the IoT systems is difficult. Also creating the interconnections between gateways and platforms is a complex task. N2N solution aims to provide transparent roaming (support for smart devices mobility) and their associated mobility information. It will also allow offloading and roaming, what implies the interconnection of gateways and platforms through the network. INTER-IoT solution at network level uses paradigms such as SDN and NFV, and achieves interoperability through the creation of a virtual network, with the support of the N2N API. The N2N solution will allow the design and implementation of fully interconnected ecosystems.

Middleware layer (MW2MW): At the middleware level, INTER-IoT solution will enable seamless resource discovery and management of IoT smart objects in heterogeneous IoT platforms. Interoperability at the middleware layer is achieved through the establishment of an abstraction layer and the attachment of IoT platforms to it. Different modules included at this level will provide services to manage the virtual representation of the objects, creating the abstraction layer to access all their features and information. Among the offered services, there are component-based interoperability solutions within the middleware based on communication using mediators, bridges and brokers. Brokers are accessible through a general API. Interoperability at this layer will allow a global exploitation of smart objects in large-scale multi-platform IoT systems [7].

Application & Services layer (AS2AS): INTER-IoT allows the use of various services among different IoT platforms. Our approach enables discovery, catalogue and composition of services from different platforms. AS2AS will also provide an API as an integration toolbox to facilitate the development of new applications that integrate existing heterogeneous IoT services.

Semantics & Data layer (DS2DS): INTER-IoT solution for the DS2DS layer will allow a common meaning of data and information among different IoT systems and heterogeneous data sources, thus providing semantic interoperability. It is based on semantic translation of IoT platforms' ontologies to/from a common IPSM modular ontology. The Inter Platform Semantic

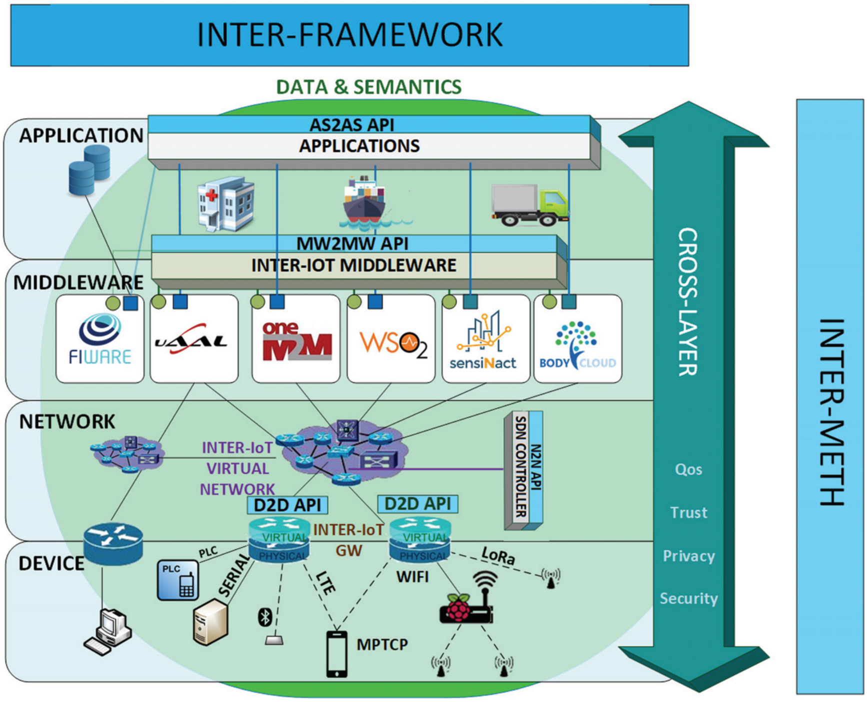

Figure 5.1 INTER-IoT multi-layered architecture.

Mediator (IPSM) component will be responsible for performing ontology-to-ontology translations of the information using ontology alignments. It will be necessary to define explicit OWL-demarcated semantics for each IoT artifact that would like to interoperate, communicate and collaborate [8, 9].

Cross-Layer guarantees non-functional aspects that are required across all layers, such as privacy, security, quality of service (QoS) and trust.

5.3.2 Virtualization of each INTER-IoT Layer Interoperability Solution

In order of providing the option of a quick set-up of each of the layers of the INTER-IoT framework, it is given the option of running a virtualized instance of each of them for rapidly implementing the INTER-IoT interoperability solution. This virtualization is performed by means of Docker [30] engine. Through the creation of Docker containers, the software layer components are separated from each other and from the underlying hardware and operating system. Despite of the virtualization, APIs to access to specific layers functionalities are secured, and protected through the use of security tokens and certificates, and by the assignment of specific permissions to each user or type of user.

Each layer solution can be deployed and implemented standalone, as far as they are independent from other layers' solutions. Thus, there is no need for a complete implementation to achieve interoperability on a specific layer. Though, the combined use of adjacent layers' solutions multiplies benefits, as enables some functionalities among them related to multiple layers.

5.3.3 Universal Semantic Translation

INTER-IoT offers a novel solution to provide automatic semantic translation among any pair of platforms [2]. DS2DS solution performs an ontology-to-ontology translation between two platforms, and thus it is able to provide universal semantic interoperability. The INTER-IoT approach for achieving semantic interoperability among heterogeneous IoT platforms is based on:

- The definition of explicit, OWL-demarcated, semantics for each IoT platform or artifact that is to interoperate, communicate and collaborate.
- An infrastructure that translates messages/data/communication from its native format to the common format used across the INTER-IoT infrastructure: an IoT Platform Semantic Mediator (IPSM) component that will be responsible for translating incoming information, representing semantics of artifact X to semantics of artifact Y. The IPSM will use ontological alignments to perform ontology-to-ontology translations.
- The existence of a common modular ontology of INTER-IoT, called GOIoTP [26].

The IoT Platform Semantic Mediator (IPSM) is a software component that performs semantic translation of data. In the context of the INTER-IoT, it is used to translate semantics of messages exchanged by IoT artifacts (platforms, gateways, applications, etc.) within the INTER-IoT software. It is composed of the IPSM Core and auxiliary components, i.e. Semantic Annotators, and exposes a REST API (for configuration). An additional Communication Infrastructure is required to enable communication between the IPSM and all other "artifacts" that are to use its semantic translation services.

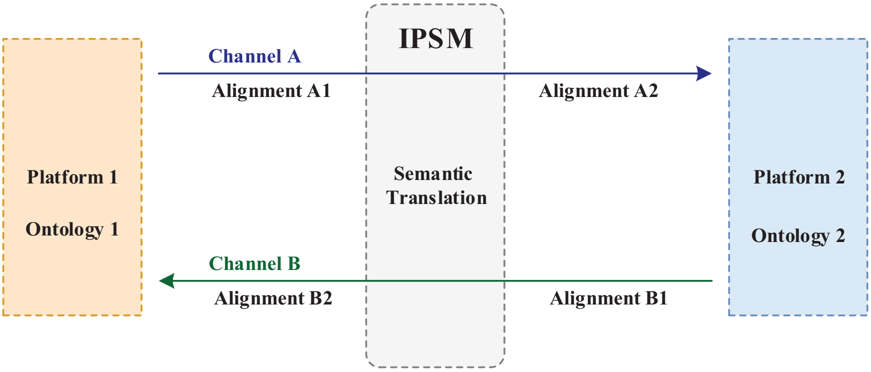

Figure 5.2 Semantic Inter-Platform Ontology-to-Ontology translation through IPSM.

The Semantic Annotators are located between the "outside world" and the IPSM. Their role is to produce RDF triples from data that they receive, e.g. from Bridges (component of MW2MW layer and the INTER-IoT middleware), and forward them to the IPSM Core through the Communication Channels, instantiated within the Communication Infrastructure. The IPSM Core performs the semantic translation of the RDF data, by applying pre-stored alignments (representing relationships between input and output ontologies). An instance of the IPSM can concurrently "service" multiple "conversations" taking place in separate Communication Channels. To achieve this goal, it can communicate with multiple instances of Semantic Annotators at the same time. Furthermore, each Alignment Applicator services a single Communication Channel and applies a separate alignment within the context of such channel.

Communication Channels work in publish-subscribe mode, which allows a single channel to serve both, one-to-one and one-to-many communication.

5.3.4 Methodology and Tools for Guiding the Implementation

A novel aspect of INTER-IoT is that provides a methodology to guide and ease the INTER-IoT framework implementation.

The INTER-METH methodology eases and offers guidance on the implementation of INTER-IoT in order to integrate different heterogeneous IoT platforms [10]. This makes it possible to achieve interoperability among the aforementioned IoT platforms and thus it enables to deploy fully functional IoT applications on top of them. There are currently no methodological approaches that might enable platform integration in a systematic and comprehensive way. It is a well-known truism that the utilization of an engineering methodology is of foremost importance at any domain (e.g. civil engineering, software engineering), maximizes, and ensures the effectiveness of the processes and actions to be performed. In sharp contrast with that, trying to manually apply complex techniques and methods in order to achieve platform integration would of necessity result in an unacceptably high rate of errors and bugs, which may instead be precluded via systematization and automation. The structure of the INTER-METH process can be seen in Figure 5.3. It is iterative in nature and comprises six successive stages: Analysis, Design, Implementation, Deployment, Testing and Maintenance. In principle, the output of each stage is the input of the following one. But in practice and depending on the particular circumstances being dealt with, is it possible to loop only specific steps of the process or else sets of successive ones, facilitating the adaptation to new components, and providing flexibility to this technique.

Additionally, INTER-IoT provides a set of tools, named INTER-CASE, that guide the implementation of the INTER-IoT framework, explaining the methodology for each specific implementation case. This set of programs offer step-to-step assessment and guidance in this process.

5.3.5 Middleware for the Interconnection of Platforms

This interoperability middleware has syntactic translators (bridges) that are able to convert the specific data format employed by an IoT platform to the INTER-IoT data format (JSON-LD), and vice versa. Thus, INTER-IoT middleware can provide syntactic interoperability among different IoT platforms. Platforms are therefore able to send or receive flows of information

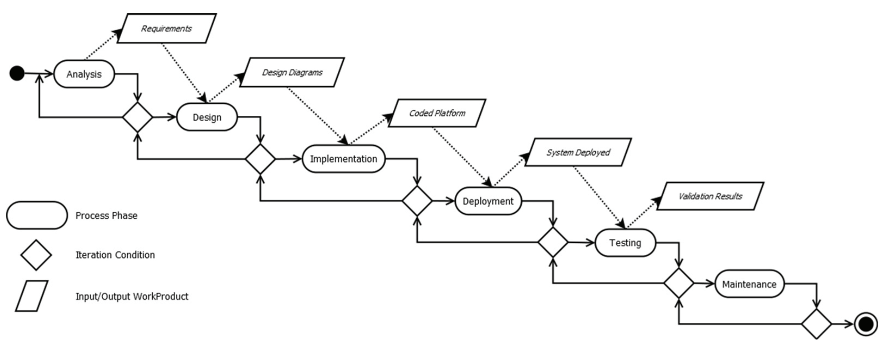

Figure 5.3 Process schema of INTER-METH.

in a data format understandable for them. INTER-IoT MW2MW represents a solution for interconnecting platforms at middleware level, and to enable interoperability among them [7].

In regard to the middleware structure (Figure 5.4), south from the Communication and Control block, the bridges manage the communication with the underlying platforms by translating requests and answers from and into messages for the queue. Different bridges might need to use HTTP, REST, sockets or other technologies to talk to the platforms, but these will be translated northwards into messages.They also pass the message content to the

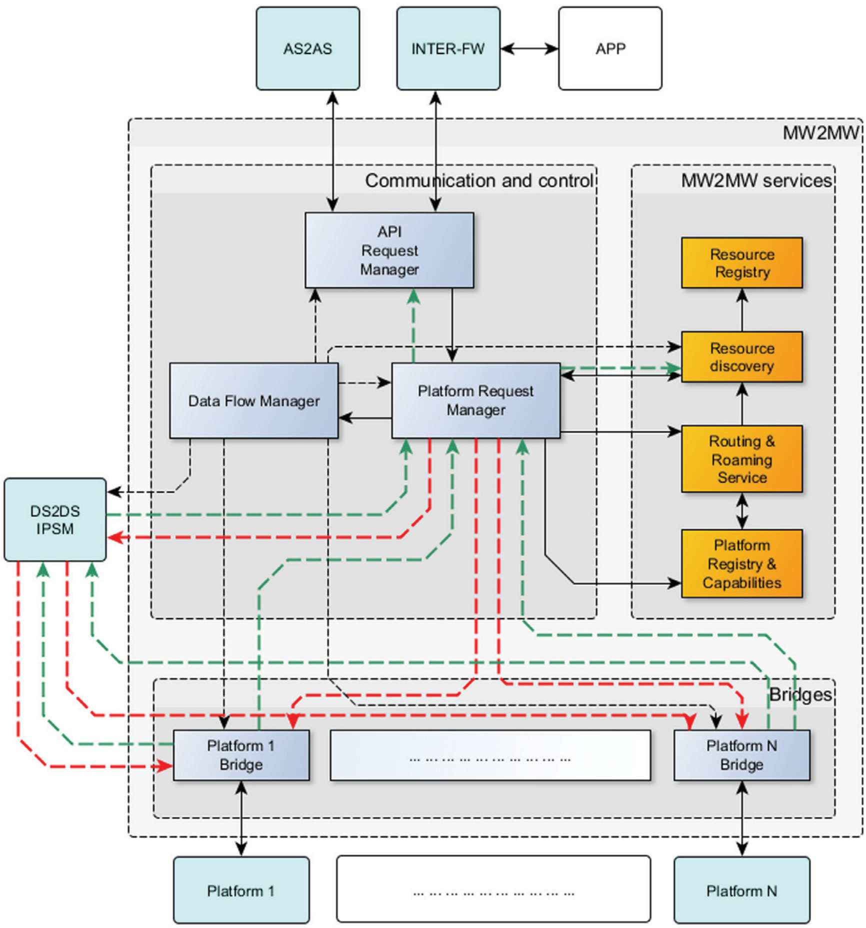

Figure 5.4 MW2MW structure.

IPSM, which is a service external to MW2MW that will allow for ontological and format translation between the platforms and a common language.

In the services group of components, the most important are the Platform Registry and Capabilities, that contains the information of all connected Platforms including their type and service capabilities, the Resource Discovery that creates requests to obtain the necessary information from the platforms, and the Resource Registry, that contains a list of resources (e.g. devices) and their properties that can be quickly consulted. In the second phase, the Routing and Roaming Service will be expected to allow the communication with a particular device independently of the platform it is currently connected to, while Authentication and Accountability (not shown) would provide services for the security and monitoring of all the actions.

5.3.6 Virtual Gateway

INTER-IoT provides a smart gateway that has the particularity that is partially virtual. This gateway provides IoT interoperability at the device level and has a modular design. Modularity in protocols and access networks is optimal. Any access network, protocol or middleware module can be inserted into the structure as long as its interface matches with the controller.

The device is build up in a way that once the system structure is functional a split-up can be realized. Part of the device gateway can be placed in the virtual world to allow device activity to higher level at all time. The device dispatcher will take care of connecting or simulating the actual platform. When connection is lost, the virtual part remains functional and will answer to requests of API and INTER-IoT middleware.

At the lowest level there are sensors and actuators. These are connected to the different input modules. These modules take care of connectivity with wireless smart objects.

This smart software gateway provides interoperability among very different network technologies and protocols. In addition to Wi-Fi and Bluetooth, INTER-IoT gateway supports network protocols and technologies specifically designed for IoT, such as CoAP, MQTT, LoRa and IQRF, as well as advanced techniques for offloading. Moreover, it is able to support the recent network protocol Multipath TCP [11], which is thought to be the successor of TCP in the Future Internet [12, 13], and it is massively used in smartphones due to its capability of bandwidth aggregation from different networks [13, 14] (e.g. such as 3G and Wi-Fi networks).

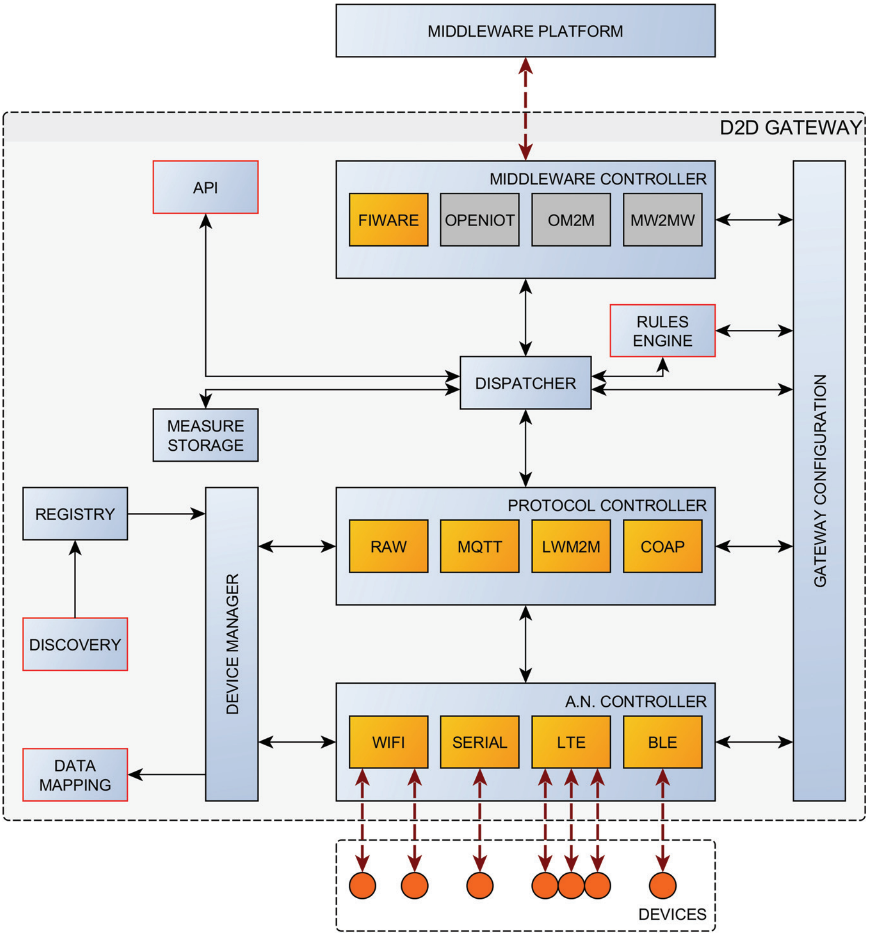

Figure 5.5 Gateway structure and inner components.

5.4 Inter-Iot Use Cases and Applications

INTER-IoT has two pilots INTER-LogP, as an interoperable solution in the seaport scenario, for port management, and INTER-Health, associated with the domain of e-Health.

5.4.1 e-Health (INTER-Health)

The INTER-IoT approach is case-driven, and it is implemented and tested in realistic large-scale pilots. One of its pilots, INTER-Health, is focused on the use case of INTER-IoT on e-Health [10], and it is tested on an Italian National Health Centre for m-health, involving 200 patients equipped with body sensor networks, wearable sensors and mobile smart devices for health monitoring.

This use case is based on the integration of two e-Health IoT platforms, and its goal is the development of an e-Health system through the integration of several IoT platforms and medical sensors. This system aims to monitor people's lifestyle in a decentralized and mobile manner for the prevention of health issues such obesity, caused by unappropriated diet and lack of physical activity [15]. These monitoring processes are meant to be decentralized from the healthcare centre to the monitored subjects' homes and supported in mobility by using on-body physical activity monitors. It is worth noting that, the strategic importance of such complete use case, is largely motivated by the fact that unhealthy lifestyles such as improper and hypercaloric diet and insufficient physical activity, are at the base of main chronic diseases [16, 17]. During the use case experimentation, the effectiveness of the novel system,

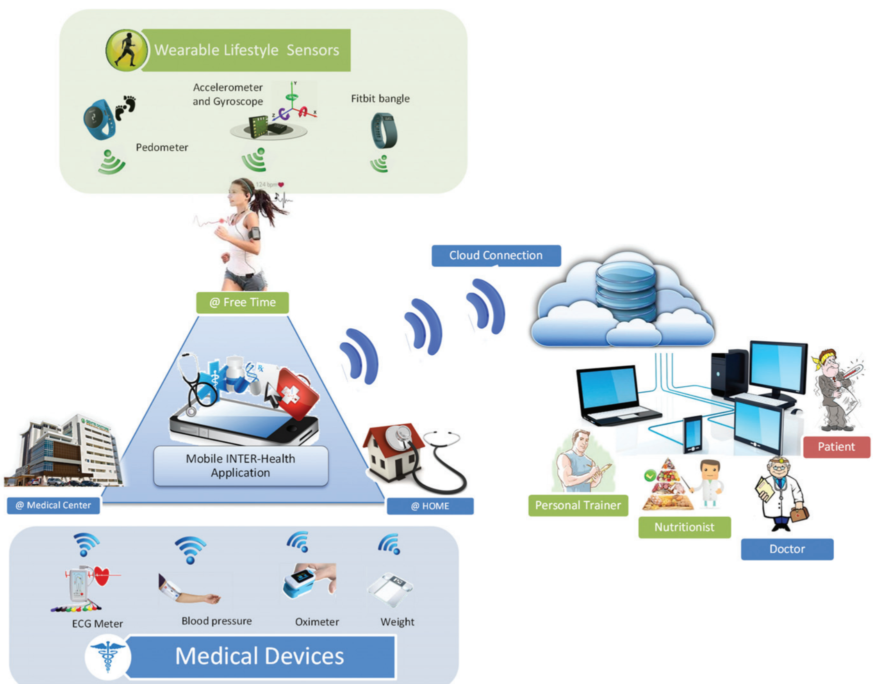

Figure 5.6 INTER-Health pilot.

in terms of lifestyle improvement indices, will be evaluated with respect to the current "manual" monitoring performed by conventional Healthcare Centres.

5.4.1.1 Lifestyle monitor: Medical perspective

There are a variety of indicators to measure and observe for preventing and/or detecting obesity, following the medical protocol given by the World Health Organisation (WHO) [16, 17]. Through these indicators, it is possible to determine the health status in terms of appropriate or inappropriate weight (levels vary from underweight, normal weight, overweight to obesity). These measurements can be collected in health centres by a healthcare worker (dietist or doctor). These include objective measurements (body mass index, blood pressure, weight, height, waist circumference) and subjective indices (eating habits and the practise of physical activity) [15]. For these reasons, the goal of this use case is to monitor a person's lifestyle in a decentralized manner with mobile sensors in order to prevent health issues. Specifically, the use case requires the monitoring of the following health indicators:

- The Body Mass Index (BMI) (weight/height^2) is an objective indicator of the health state of the patient (underweight, normal weight, overweight, first level obesity, second level obesity and 3rd level obesity) of subjects, also allowing to make the diagnosis of overweight and obesity.
- The waist circumference is an objective indicator for the diagnosis of overweight and obesity; values over 80 cm in women and 94 cm in men are considered pathological.
- The physical activity practice is a subjective indicator that detect the amount (hours/daily and hours/week) and the type of physical activity (no activity; light, moderate and intense activity). This measure is used to detect a poor lifestyle with physical inactivity.
- The eating habits is a subjective indicator for measuring the quality and quantity of the diet. This measure is used to detect a poor lifestyle due to improper diet and high-calories.

This use case will be deployed over the integrated system composed through the joint of the IoT e-Health platforms UniversAAL and BodyCloud. This will enable the computerized monitoring at the healthcare centre coupled with the monitoring at the patients' homes [19], which would be supported by the UniversAAL remote services, while BodyCloud will allow to monitor subjects' physical activity through BodyCloud mobile BSN services.

5.4.1.2 Platforms to integrate

BodyCloud

BodyCloud [18] is an IoT platform specifically addressed to the creation and management of Body Sensor Networks (BSNs). It has a Software-as-a-Service architecture, and it is capable of creating a smart gateway on smart phone devices that are able to receive and monitor health rates from medical wearable sensors. BodyCloud supports the management and storage of body sensor data streams and the offline and online analysis, of the stored data using software services hosted in the Cloud in order to enable large-scale data sharing and collaborations among users and applications in the Cloud and deliver Cloud services via sensor-rich mobile devices. BodyCloud endeavours to support a variety of specialized processing tasks and multi-domain applications and offers decision support services to take further actions based on the analysed BSN data.

The BodyCloud approach is based on four main components:

- The Body-side refers to an Android-based element for the monitoring of assisted living by means of smart wearable medical sensors, and the collection and upload of data to the Cloud through a smart phone that acts as a mobile gateway.
- The Cloud-side is a Software-as-a-Service element that provides Cloud services, such as storage.
- The Viewer-side refers to the Web browser-enabled component for the visualization of data.
- The Analyst side facilitates the analysis of data and the creation of BodyCloud applications.

UniversAAL

The IoT platform UniversAAL[1] (Universal Ambient Assisted Living) is specifically designed for the domain of Ambient Assisted Living and medical environments. UniversAAL is a platform that enables the creation of assistive systems by connecting different, heterogeneous technical devices to a single, unified network. UniversAAL also delivers the means to control this distributed system. Well-defined semantics is an important concern in medical and AAL environments, to lead to no ambiguity in measurements, units and terms employed [13]. In this regard, UniversAAL utilizes semantics

[1] http://www.universaal.info

in a very strict and well-defined manner, unlike many other IoT platforms, and employs W3C SSN ontology for IoT and smart devices.

Complementary Platforms

The aforementioned IoT platforms (i.e. BodyCloud and UniversAAL) have several high-level characteristics in common and differing aims and technology. Both are e-Health platforms that employ Bluetooth technology to interact with sensors. Moreover, both platforms employ Cloud data storage, cloud big data analysis and data visualization. Though, the two platforms have different specific objectives and are not interoperable from a technological point of view.

Their specific objectives are complementary: UniversAAL is focused on non-mobile remote monitoring based on non-wearable measurement devices, whereas BodyCloud provides monitoring of subjects in mobility through wearable devices organized as body sensor networks (BSN). Thus, their integration would produce a full-fledged m-Health platform atop of which multitudes of m-Health services could be developed and furnished.

5.4.1.3 INTER-IoT integration of health platforms

The integration of UniversAAL and BodyCloud is achieved through their interconnection through INTER-IoT, as can be seen on Figure 5.7. This integration is done across three layers (device, application and semantics). The middleware layer of the resulting integrated IoT system is based entirely on UniversAAL thus no interconnection is required across different platforms.

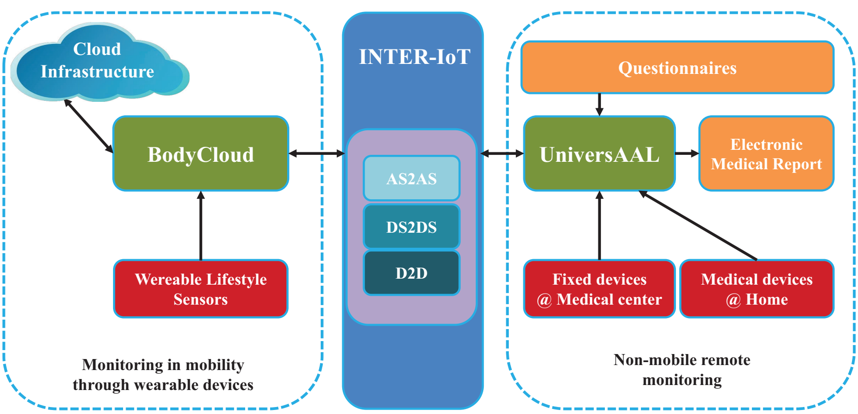

Figure 5.7 INTER-Health: BodyCloud and UniversAAL integration.

Therefore, INTER-IoT provides integration and transparent interconnection at the following levels:

- at device layer (D2D), enabling the new IoT system to communicate with the wireless medical devices supported by BodyCloud and with the fixed e-Health devices from the health centre or from the patients' houses.
- at the application and services layer (AS2AS), the applications for handling patients' reports the reports from UniversAAL are integrated in the overall systems in such a way that reports can be complemented with additional data from BodyCloud measurement applications.
- at the data and semantics layer (DS2DS), enabling semantic and syntactic interoperability among all platforms and systems.

The integration scheme of the aforementioned IoT platforms by means of INTER-IoT can be seen on Figure 5.10.

5.4.1.4 INTER-Health technical functionalities

The integrated IoT system has the following main functionalities:

- collection of objective (weight, height, body mass index, blood pressure or waist circumference) and subjective (questionnaires concerning the eating habits and the practice of physical activity) measures during the visits at the healthcare centre (based on UniversAAL);
- telemonitoring at the healthcare centre of subjective (questionnaires) and objective (weight, blood pressure, etc...) measures sent by the patients at home (based on UniversAAL platform);
- telemonitoring at the healthcare centre of the physical activities performed by patient at home with wearable devices (based on BodyCloud platform) report and visualization of all the measurements collected for analysis and interaction on treatments.

5.4.1.5 INTER-Health pilot

The main goal of the INTER-Health pilot is demonstrating how to foster a healthy lifestyle and how to prevent chronic diseases by monitoring subjects' physical characteristics, nutritional behaviour and activity [15, 19, 20].

The pilot consists of 200 test subjects: 100 subjects following traditional monitoring without IoT devices and 100 subjects with devices. The latter use the INTER-IoT solution. They attended a nutritional counseling session a medical and nutritional centre where their initial physical characteristics are measured, using IoT Devices on the premises (BMI, waist circumference, weight, blood pressure…). Each subject received a management program. Then at home, while they follow the program, they measure their characteristics using their phone and IoT devices.

The subjects will visit the medical and nutritional centre each 6 month for check-ups. The healthcare professional in charge of monitoring each user will have access to the history of all the measurements through a dedicated web application.

The assisted living environment created for INTER-Health enables the remote measurement of different physiological parameters by means of medical IoT devices such as weigh scale, blood pressure monitor and physical activity rate monitor [21, 22]. The aforementioned sensors interact with an IoT platform (BodyCloud or UniversAAL), and provide measurements through the connection with a smart gateway employing Bluetooth communication [23]. This smart gateway receives the measures from the devices and sends them to the platform via 2G/3G/4G/Wi-Fi/ADSL connectivity. The platform BodyCloud creates a smart gateway on a mobile phone, thus enables a smartphone to become an IoT gateway for the medical sensors. Doctors have access to a web medical application that allows them to follow up the

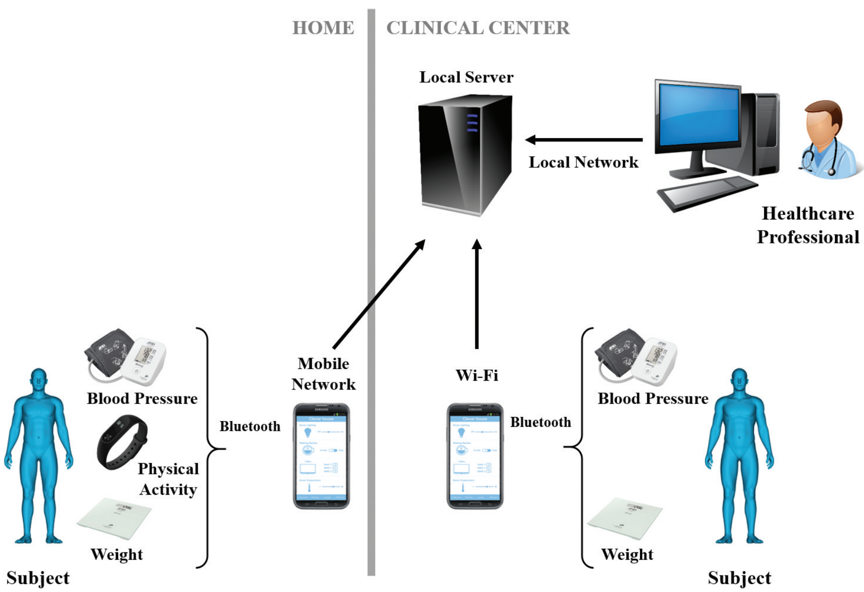

Figure 5.8 INTER- Health System overview.

monitoring of patients remotely at any moment, as well as to contact them via ITC communication tools (SMS, e-mail, telephone, and teleconference) and give medical assessment.

5.4.1.6 Benefits

INTER-IoT integration guarantees an effective and efficient interoperability between heterogeneous IoT platforms such as the two described e-Health IoT Platforms (i.e., UniversAAL and BodyCloud). The proposed interoperable approach will enable the development of new cross-platform services. Thus, the main benefit of the proposed approach consists of the availability of a more powerful IoT healthcare platform for lifestyle monitoring to implement new applications and services that the individual platforms could not support. Finally, the aforementioned monitoring process can be decentralized from the healthcare centre to the monitored subjects' homes, and supported in mobility by using on-body physical activity monitors connected to the novel fully integrated IoT environment. This approach, would reduce both the transfer costs of patients at medical centres and the waiting times, also obtaining constantly updated results to make the necessary adjustments in a faster and precise manner.

From a final user perspective, INTER-Health use case significantly benefits from INTER-IoT solutions:

- For outpatients subjects: improving the survey quality of their health status; improve the definition of risk behaviour; provide information on diets and physical activity more relevant with the health status and with the risks of the subject compared to the traditional methods; increasing the sensitivity of the screening of subjects who need intervention from the local doctor or of the hospitals (second and third level obesity, diabetes, etc); reduce the time spent in face-to-face contact with the nutritional outpatient and the number of travels.
- For public health services: increase efficiency with the same resources used; increase effectiveness through standardization of objective and subjective measurements; turning subjective ones, such as activity practice, into objective ones (by exploiting IoT wearable systems); enlarge the number and type of subjects that appeal to nutritional outpatient.
- For local doctors: lighten the taking charge of healthy subjects by the local doctor for guaranteeing greater availability toward pathological subjects; overall, the local doctor becomes a vehicle from a lower general incidence of healthcare costs on the income of citizens, improve

the care and diagnostics efficiency making directly available on the computer system of the local doctor, the data present on the platform used from the nutritional ambulatory.

5.4.2 Smart Transport & Logistics (INTER-LogP)

INTER-IoT has a pilot, called INTER-LogP, focused on a use case of Smart Transport & Logistics. INTER-IoT offers an interoperable solution in the seaport scenario for port management [7, 24]. The main objective of this pilot is to provide a service to control port access, monitor traffic and assist the operations at the port. Several systems will be able to identify trucks and drivers using different devices. This information can be shared under certain predefined rules through interoperability between the platforms involved; it can be used to monitor trucks inside the port by the Port Authority platform (due to security and safety purposes), and to manage more efficiently resources in the terminal. Moreover, this information is employed to avoid queues in the access gates to the port and the terminal.

The use IoT platforms in ports can potentially enable traffic and container monitoring, geolocation of cargo and vehicles, management of storage and cargo processes and improvement of services. These benefits can be multiplied through appropriate sharing of valuable information and cooperation among the different IoT platforms in port environments, creating synergies. This use case addresses the need of IoT platforms interoperation within port actors: such as container terminals, transport companies (road and maritime transportation), the port authority, and customers.

This pilot has been deployed in the port of Valencia, the most important port of the Mediterranean. The pilot is mainly composed by an Access Control System, and a Health Emergency System, which are possible fruit of the interoperability among platforms provided by INTER-IoT.

The platforms integrated through INTER-IoT belong to the main actors of the port: IoT platforms of the Port Authority, of one of the Port Container Terminal (NOATUM Valencia), and Intelligent Transportation Systems of several Road Haulier Companies. This interconnection is set at middleware level, employing the INTER-IoT MW2MW solution [7].

Important platforms and systems involved are:

- In the Container Terminal :
    - SEAMS : IoT platform for controlling container terminal machinery

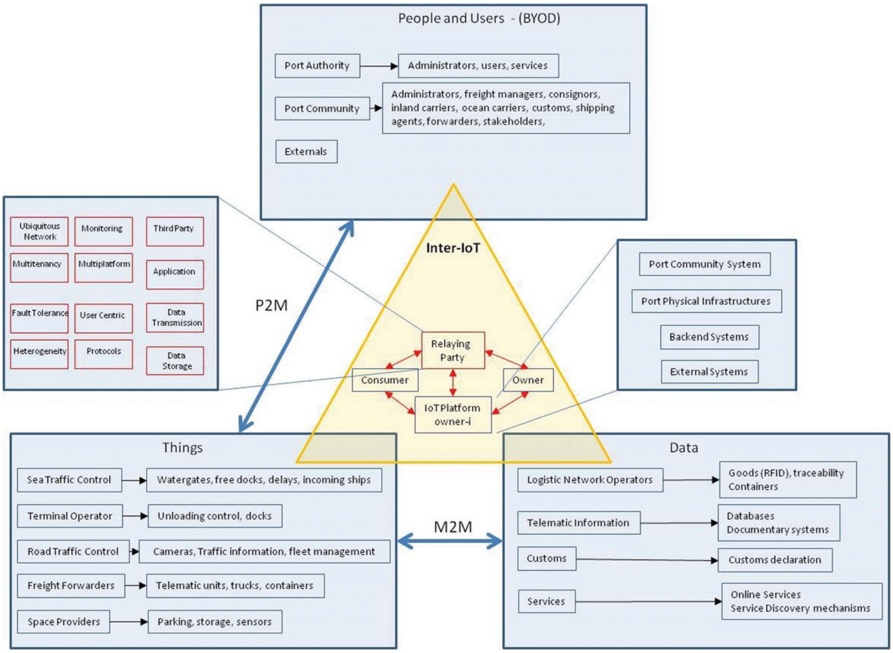

Figure 5.9 INTER-LogP use case approach.

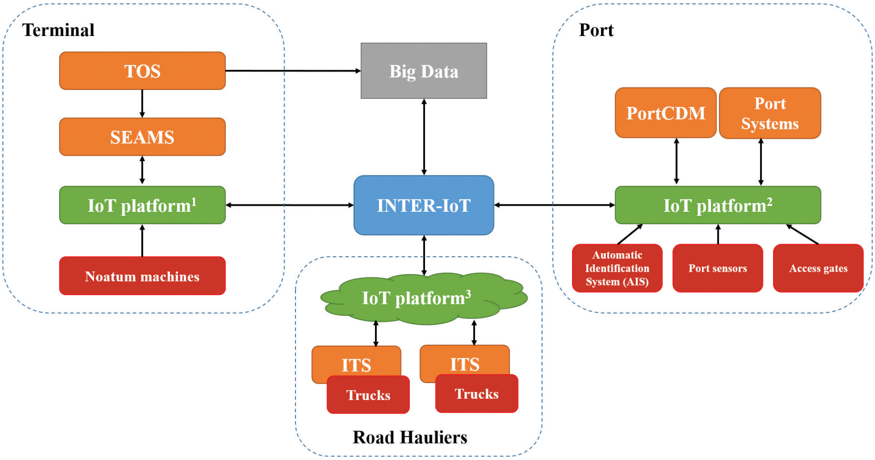

Figure 5.10 Integration of IoT platforms of different port stakeholders through INTER-IoT.

  - TOS : Terminal Operating System that controls and handles data associated to any terminal operation (Big Data)
- From the Port of Valencia :
  - PORTCDM : Intelligent transportation system for the management of ships arrivals to the port
- From the Road Haulier Companies
  - Different Intelligent Transportation Systems (ITS)

This interconnection provides interoperability at middleware level, and flows of relevant information can be shared among platforms to enhance services and processes in the port. The enhancement of the access control to the port facilities is explained in the next subsection. Also, a new service combining e-Health emergencies and port transportation is described in this section.

5.4.2.1 Pilot for access control at the port area

The interoperation of the platforms of main port stakeholders can bring very significant enhancement to the services related with the access control to the port facilities. Appropriate sharing of information and interoperation among them lead to a more efficient access control in terms of time and cost efficiency, security, safety, minor waiting times and improved management. Platforms integrated through INTER-IoT are from diverse entities from the port environment: the port, a container terminal (NOATUM) and several road haulier transportation companies. Relevant information shared among platforms are the location of trucks inside the port, information regarding load and unload operations, and access controls.

The main benefits from these services are the collection and analysis of data regarding queues, congestion and temporary distribution of traffic, and to manage efficiently the resources. Relevant information obtained is the position of the trucks inside the port facilities, and its use it is important in the sake of safety and security. All these data can be shared between the port authority and the port terminals to improve operations.

5.4.2.2 Pilot for health accident at the port area

Starting from the access control pilot, trucks will be monitored once they enter in the port facilities. The Emergency Warning System (EWS) will be monitoring the data coming from the truck and the driver. In case it detects an accident or a medical problem, EWS will publish a notification to the port

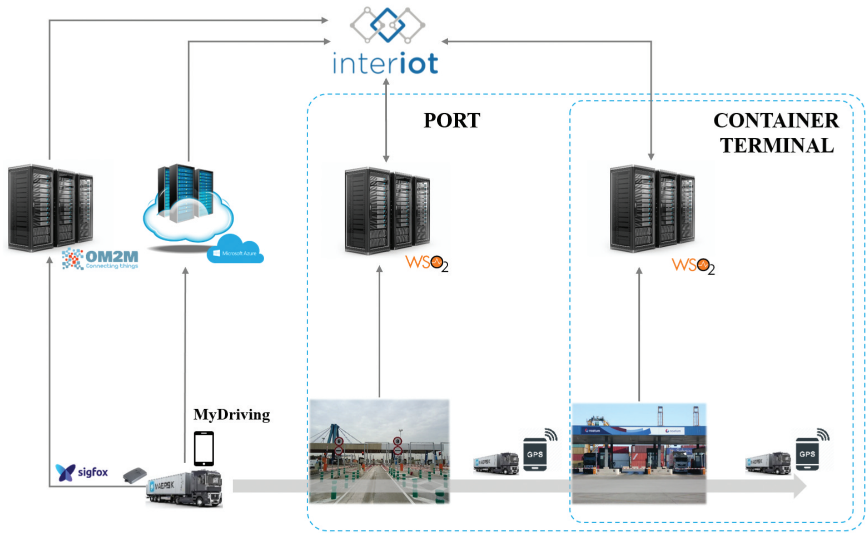

Figure 5.11 High-level view of the access control pilot.

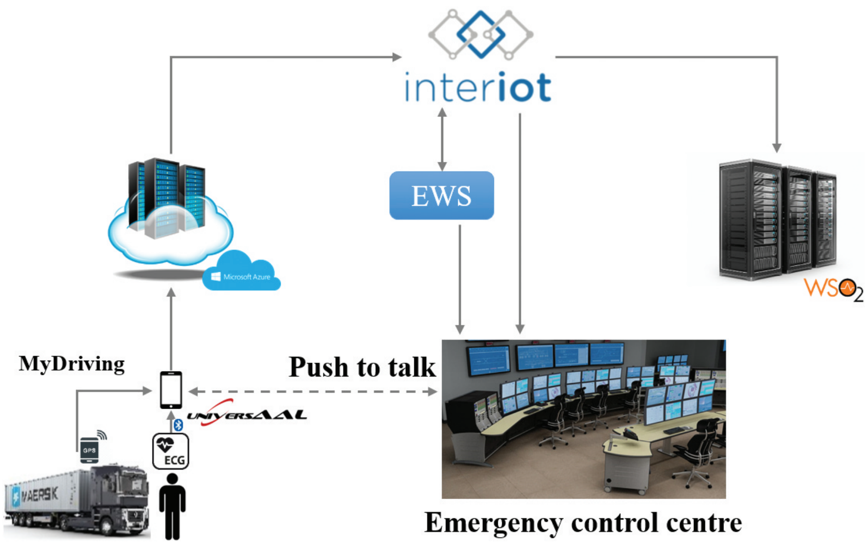

Figure 5.12 High-level scheme of the pilot for health accident assistance in port areas.

authority in a standard format (EDXL). Once the emergence control centre receives the notification, it will be possible to communicate with the driver through a push to talk protocol in the driver's mobile.

The main benefits we can get from this scenario are: apply in the port communications a standard format in accident reporting like EDXL, real-time identification of the location of the accident, direct communication with the closest control centre when an accident occurs and monitoring driver's health if it is necessary.

5.4.3 Active and Healhy Ageing (ACTIVAGE)

ACTIVAGE [27] is a H2020 LSP project that addresses the use of IoT technologies in the Active & Healthy Ageing (AHA) domain [25]. INTER-IoT framework is a core element in the ACTIVAGE system that enables interoperability at different levels and fulfills the ACTIVAGE's needs of interoperability.

5.4.3.1 ACTIVAGE: Active and healthy ageing initiative

ACTIVAGE project addresses the use of IoT technologies in the Active & Healthy Ageing (AHA) domain [25]. The objective of this project is to prolong and support the independent living of older adults in their cities and homes and responding to real needs of caregivers, service providers and public authorities. Hence, this project aims to improve the autonomy and quality of life of older adults and contribute to the sustainability of the health and care systems. The ACTIVAGE project has been designed as a Multi Centric Large-Scale Pilot consisting of nine interconnected Deployment Sites (DS) distributed over seven European countries. A DS can be defined as a cluster of stakeholders in the AHA value network, working together within a geographical space. Therefore, a DS includes users (elderly people, formal and informal caregivers), service providers, AHA services, health care/social care administration and technological infrastructures and technology providers. The DS make use of existing open and proprietary IoT platforms. Each DS utilizes a specific IoT platform, or two. The different IoT platforms employed in ACTIVAGE DS are FIWARE, SOFIA2, UniversAAL, SensiNact, OpenIoT, IoTivity and SENIORSOME.

The following DS have been defined in the ACTIVAGE project:

- DS1: Galicia (Spain) will make use of the SOFIA2 platform.
- DS2: Valencia (Spain) will provide services based on a combination of data from UniversAAL and Fiware platforms.
- DS3: Madrid (Spain) will deploy services based on UniversAAL.
- DS4: Region Emilia Romagna (Italy) will make use of the Fiware platform.

- DS5: Greece will offer services based on the IoTivity platform
- DS6: Isére (France) will provide services based on the SensiNact platform.
- DS7: Woqaz (Germany) will develop services based on the UniversAAL platform.
- DS8: Leeds (UK) will deploy services based on the IoTivity platform.
- DS9: Finland will make use of the proprietary IoT platform SENIOR-SOME.

Due to the lack of interoperability among IoT platforms, the definition of an interoperability framework is needed in order to create a European AHA ecosystem.

With this aim, ACTIVAGE will develop the ACTIVAGE IoT Ecosystem Suite (AIoTES), which is defined as a set of tools, techniques and methodology for interoperability between existing IoT platforms. The AIoTES Framework will provide interoperability among IoT platforms and ensure security and privacy. The different DS will connect to AIoTES and AHA applications will be deployed over this framework, thus allowing the integration of remote health-care services and wearable systems-based health-care

Figure 5.13 AHA Interoperable DS (Smart Home Clusters).

services in mobility, which will include remote medical measurements, local mobile physical detection and processing, and on-line and off-line analysis of lifestyle data.

ACTIVAGE aims to achieve interoperability at three stages:

- **Intra-deployment site interoperability,** which means that the services provided at each DS must be interoperable to each other. In order to achieve this, any the application should be able to access all the application data within the same DS. Moreover, the applications within a DS should support multiple IoT platforms and be able to be transferred between different platforms within s DS.
- **Inter-deployment site interoperability**: enables new services to be automatically incorporated into the ecosystem of the DS. This means that different DS should be able to exchange application data. Moreover, it should be possible to transfer an application that was designed for a DS to a different DS and new applications could be developed for multiple DS instead of being designed for a particular DS.
- **Interoperable external adopted solutions**: according to the needs of each specific DS, new solutions will be implemented within the DS. They will be interoperable according to the ACTIVAGE interoperability framework.

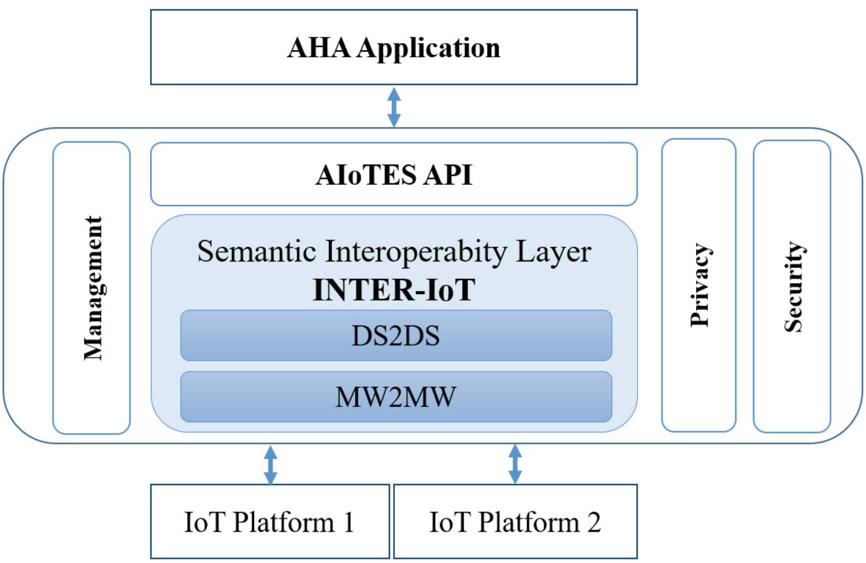

Figure 5.14 AHA Architecture for Interoperability.

These goals imply that the same data format must be used by the applications regardless of the IoT platforms being used in the DSs so as the applications can access any platform's data. Moreover, applications initially development for a DS can be extended for any other DS only by adapting them to AIoTES instead of making an adaptation for each individual platform. Overall, multiple AHA applications and IoT platforms may coexist in the same DS, thus contributing to fulfil the main goal of a DS. Therefore, it is required inter-platform and intra-platform interoperability among the different IoT platforms of the DS of this AHA intiative (FIWARE, UniversAAL, SOFIA2, OpenIoT, IoTivity and Seniorsome). Furthermore, this interoperability must be both syntactic and semantic, to allow the understandability of the information across platforms and a common interpretation of data shared among them. In this regard, INTER-IoT is the key component that makes it possible for the ACTIVAGE deployment to enable and ensure platform interoperability in DSs.

The required interoperability among IoT platforms is provided by the Semantic Interoperability Layer (SIL), which is a component of the AIoTES framework. INTER-IoT is the key component that provides inter-platform interoperability in this AHA deployment. Two components of INTER-IoT, namely, the MW2MW layer and the DS2DS layer (composed by the IPSM), have been incorporated in the SIL. The MW2MW layer connects to all the IoT platforms and provides a common abstraction layer to provide access to platform's features and information. An important function of the MW2MW is to convert the data to a common syntax, which is based on JSON-LD. Once the data is in the common format, the IPSM performs semantic translations. As a result, AIoTES provides semantic and syntactic interoperability among the different platforms, and enables information sharing and interoperation among them. This data shared will be understandable for the receiver platform, not only in terms of data format but also regarding the meaning of the received information.

In addition to these INTER-IoT components, the AIoTES framework includes an API, security and privacy protection components management functions. Security and privacy span across all the components of AIoTES in order to ensure the protection of sensitive data against unauthorized access. AIoTES management provides a set of tools that allow access to the information of a DS, such as platforms and devices, and mechanisms to facilitate the integration of the framework. Finally, AIoTES will provide a common API, which will allow a homogeneous access to the components of AIoTES in order to develop services and applications able to exchange data from different IoT platforms and produce new added value services. Hence, the AIoTES API will make possible the development of and ecosystem based on applications and services compatible with AIoTES.

5.4.3.2 Use Cases of ACTIVAGE

AAL and AHA systems can very significantly benefit from interoperability [31, 32]. The following Reference Use Cases respond to specific user needs (senior people and caregivers), to improve their quality of life and autonomy, in a AHA context, that require IoT interoperability:

Daily activity monitoring at home for informal caregivers support and for formal caregivers follow up in order to alert them about deviations of the elderly persons' habits, allowing early interventions while extending independency. Wireless sensors like presence, magnetic contact, power measurement, proximity, are deployed at the home of the elderly. A gateway transmits the information to a Cloud where calculation on activities, trends and risks is performed.

Integrated care for older adults under chronic conditions. This use case combines daily activity monitoring at home and the use of medical devices for health monitoring. The combination of IoT technologies with eHealth solutions in one single integrated IT system, and the integration of care protocols from entities traditionally working separately will promote the coordination among care providers, joint response to emergencies, better planning of resources and more effective interventions. This will lead to economic savings and a better quality of life for people with chronic disease.

Monitoring assisted persons outside home and controlling risky situations. This use case combines wearable devices or smartphones and the Smart City infrastructure in order to promote socialization and activity. The Smart City infrastructure tracks the wearable devices and request for help if certain rules are met in order to help persons at risk.

Emergency trigger. The system automatically reports an emergency when a critical situation is detected. Wireless or wired sensors and "panic" buttons distributed in the home environment in strategic situations linked to a gateway that forwards the emergency to a call-centre system. Other complex scenarios might involve the processing of data in the private or hybrid cloud and then the emergency is triggered. Compared to state-of-the-art systems at home, emergency works when the user requests for help, but also when the environment detects the emergency and the person cannot (unconsciousness, fall, gas).

Exercise promotion for fall prevention and physical activeness using wearable and ambient sensors.

Cognitive stimulation for mental decline prevention in order to extend the time elderly people live independently. This use case combines behavioural monitoring at home and outside, and interventions, such as the promotion of mental and physical exercises and gaming, making use of apps in tablets or smartphones and peripheral connected devices.

Prevention of social isolation by means of communication tools at home. This use case promotes social interaction and mobility though the use of video-based system and apps connected to the Smart City infrastructure, which provides data about events, and linking to other peers. In addition, continuity between home (home sensors) and outdoors scenarios (smart phone as a sensor) provides seamless information about users' social activity. Social engagement keeps depression and decline away.

Comfort and safety at home. This use case includes climate and light control, perimeter safety, energy control and home automation.

Support for transportation and mobility. This use case includes adapted route planning for elderly persons both in cities and between different cities. Routes can be computed making use of the Smart City data about traffic conditions and other mobility aspects and personalized according to goals such as exercise promotions or finding the easiest/fastest route.

5.4.4 Other Potential Use Cases

INTER-IoT can be employed in any domain or across domains where there is a need of IoT interoperability. Thus, its use is not limited to the aforementioned use cases and can be utilized in the most various IoT environments, allowing very different aims that are enabled or partially enabled through interoperability.

A clear example is the Smart Cities use case, which greatly benefits from the synergies and cooperation among different systems and platforms that provide different city services. In this case, there is an enormous need of interconnection that is limited by the typical interoperability problems in the IoT realm. The application of the INTER-IoT framework is able to solve the integration of heterogeneous platforms and systems within a Smart City, provide numerous benefits to the citizens and enable the creation of new useful services fruit of this interoperability.

5.5 Conclusions and Outlook

In this chapter, it has been described the current problem of lack of interoperability in the heterogeneous Internet of Things realm, and the usefulness of INTER-IoT for solving this important problem and enabling the integration and interoperation of heterogeneous IoT platforms at all layers and across multiple domains.

The effective application of INTER-IoT for solving the lack of interoperability among platforms has been explained and demonstrated in several use cases associated to different application domains. First, the usefulness of INTER-IoT has been analysed in a e-Health and AAL use case, in which the interoperability framework is implemented. In this regard, INTER-IoT enables the integration and interoperability of IoT platforms and provides a more powerful solution that the individual solution provided by each one of those platforms. These advantages are a consequence of the enablement of synergies and the sum of capabilities of all the integrated platforms.

Second, INTER-IoT has been a key integrator element in an interoperable solution for efficient port management. This use case is focused on the domain of Transportation and Logistics. INTER-IoT enables the interconnection of several platforms at middleware level, and the syntactic and semantic interoperability of any information shared among them, despite of the different data formats, standards, message structure and semantics. Because of this interconnection of platforms and sharing of relevant data among key entities, several management processes in the port can be very significantly improved. Also, the interoperability provided by INTER-IoT demonstrates that enables the existence of new services, fruit of the new information sharing and the possibilities of cooperation among platforms.

Third, INTER-IoT interoperability framework is employed in an AHA and AAL use case for enabling an assisted living environment in elder homes, to allow ancient people to live at home in a safe and autonomous way. INTER-IoT allows different IoT platforms to interoperate with the ACTIVAGE system around Europe, to enable this autonomous life of elderly people.

Finally, other potential use cases are mentioned, as far as INTER-IoT framework can be successfully employed in any domain and use case that has a need of IoT interoperability at any level (e.g. Smart Cities).

Regarding implementation aspects, INTER-IoT employs several innovative elements to provide enhanced functionality and has clear positive differentiators from other interoperability approaches. First, INTER-IoT has a layered approach to guarantee tight interoperability on each of the different layers (device, network, middleware, application, data and semantics), compared to a more global approach. Also, due to this multilayer approach, any of the INTER-IoT layer solutions can be employed in a standalone way, providing more flexibility and adaptation to specific IoT cases. Additionally, to guarantee a quick and easy implementation, INTER-IoT gives the option of running virtualized interoperability solutions for each layer through Docker. This virtualization enormously facilitates the deployment of the INTER-IoT solutions. Moreover, INTER-IoT has a huge concern on security, and layer solutions and APIs are securitized.

The INTER-IoT interoperability framework provides innovative elements, such as a universal semantic platform-to-platforms translator, a middleware that enables the interconnection and interoperation of any platform at middleware level, despite of the standards and formats employed, and a partially virtualized gateway. Furthermore, INTER-IoT implementation is guided and eased through a novel methodology (INTER-METH) specifically designed with this aim.

Interoperability in IoT, and more specifically among platforms, represents one of the most important challenges in IoT, and interoperability solutions such as INTER-IoT can potentially unlock immense benefits from the use of smart technology, and a huge integrator and enabler of services on top of IoT deployments. INTER-IoT can be used in the middle future to enable interoperability solutions among the most diverse use cases and domains in which IoT interoperability is required, solving modern society problems to let technology improve people's daily life, and propel European economy. Also, INTER-IoT facilitates a key element for the evolution of IoT; interoperability is essential for the creation of natural human interfaces in IoT systems, the existence of Ambient Intelligent Environments or the integration of IoT with Artifical Intelligence.

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List of Notations and Abbreviations:

Notations	Abbreviations
API	Application Programming Interface
IoT	Internet of Things
BSN	Body Sensor Network
AAL	Ambient Assisted Living
SaaS	Software as a Service
ITS	Intelligent Transportation System
EWS	Emergency Warning System
AHA	Active and Healthy Ageing
LSP	Large Scale Pilot
DS	Deployment Site

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