Internet of Things

Carlos E. Palau · Giancarlo Fortino ·
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Pablo Giménez · Garik Markarian · Valérie Castay ·
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Interoperability of Heterogeneous IoT Platforms

A Layered Approach

Springer

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Preface

In recent years, due to a great interest of both Industry and Academy in researching and developing IoT technology, many solutions at different levels (from the IoT device-level to full-fledged IoT platforms) have been implemented. However, there is no reference standard for IoT platform technology, and we do not foresee one in the near future. Hence, IoT scenarios will be characterized by a high degree of heterogeneity at all levels (device, networking, middleware, application service, data/semantics), preventing interoperability of IoT solutions. Although many research actions and projects have dealt and/or are dealing with developing IoT architectures in diversified application domains, not many of them have addressed interoperability/integration issues. Furthermore, no proposals (to date) have been put forward to deliver a general, application domain agnostic, fully reusable and systematic approach to solve multiple interoperability problems existing in the IoT platforms technology.

Lack of interoperability causes major technological and business issues such as impossibility to plug non-interoperable IoT devices into heterogeneous IoT platforms, impossibility to develop IoT applications exploiting multiple platforms in homogeneous and/or cross domains, slowness of IoT technology introduction at a large-scale, discouragement in adopting IoT technology, increase of costs, scarce reusability of technical solutions, user dissatisfaction. In contrast, interoperability among platforms will provide numerous benefits such as new market opportunities, the disappearance of vertical silos, and vertically oriented closed systems, architectures and application areas, to move towards open systems and platforms. Comprehensively addressing lack of interoperability in the IoT realm by proposing a full-fledged approach facilitating "voluntary interoperability" at any level of IoT platforms and across any IoT application domain, thus guaranteeing a seamless integration of heterogeneous IoT technology.

Most current existing sensor networks and IoT device deployments work as independent entities of homogeneous elements that serve a specific purpose, and are isolated from "the rest of the world". In a few cases where heterogeneous elements are integrated, this is done either at device or network level, and focused mostly on unidirectional gathering of information. A multi-layered approach to integrating heterogeneous IoT devices, networks, platforms, services and applications will allow heterogeneous elements to cooperate seamlessly to share data, infrastructures and services as in a homogeneous scenario.

INTER-IoT is a solution proposed to the above problem, and has aimed at the design, implementation and experimentation of an open cross-layer framework, an associated methodology and tools to enable voluntary interoperability among heterogeneous Internet of Things (IoT) platforms. INTER-IoT is the supporting environment for this book. It has been conceived and created among other potential solutions in the framework of IoT-EPI (IoT European Platforms Initiative), and has allowed effective and efficient development of adaptive, smart IoT applications and services, atop different heterogeneous IoT platforms, spanning single and/or multiple application domains, creating also its own ecosystem.

This book investigates on the multi-layered approach to achieve semantic interoperability, presenting innovative solutions for the architecture and the individual layers so as management and the methodological approach. Readers are offered with new issues and challenges in a continuously moving environment like IoT platform interoperability. In particular, the book spans the following scenarios: (1) port transportation and logistics; (2) mobile healthcare and (3) different application domains related with the INTER-IoT ecosystem. All the areas covered by the interoperability solution and its application correspond to ten authored chapters briefly introduced below.

Chapter "Introduction to Interoperability for Heterogeneous IoT Platforms" by Carlos E. Palau, et al., presents an overview of the needs, potential solutions and advances regarding IoT platforms interoperability. The chapter in particular starts reviewing the existing solutions and state of the art associated with platform interoperability and discuses the benefits of a multi-layered approach solution analysing the layers selected for the INTER-IoT solution and the potential application to two selected use cases, identifying the uniqueness of the provided approach.

Chapter "INTER-IoT Requirements" by Pablo Giménez, Miguel Llop, Regel Gonzalez-Usach, and Miguel A. Llorente proposes the main requirements and the process to gather them to achieve interoperability between IoT platforms. The chapter considers the Volere methodology as the mechanism to define, gather, select and prioritize the functional and non-functional requirements to develop an interoperable solution. Requirements are analysed following different approaches and can be used as support for potential developers that may need to perform a similar analysis for the same or different application domains.

Chapter "INTER-IoT Architecture for Platform Interoperability" by Alessandro Bassi, Miguel A. Llorente, Miguel Montesinos, and Raffaele Gravina analyses the need of a meta-architecture with a specific domain model to define the different building blocks for an interoperable solution. The chapter illustrates the contribution of INTER-IoT for the definition of a reference architecture, using IoT-A as a starting point and the link with further developments related with the IoT community. The chapter includes the software vision of the architecture and supports the multi-layered approach which is the current approach required from the market.

Chapter "INTER-Layer: A Layered Approach for IoT Platform Interoperability" by Andreu Belsa et al., describes the different solutions for each of the layers that compose the architecture. The chapter starts with a detailed state-of-the-art analysis and describes the different technologies that can be used to provide interoperability at each layer of the architecture. The technical aspects of the developments and integration are based on the requirements gathered and described in Chapter "INTER-IoT Requirements". The cross-layer needs of the architecture are also analysed in the chapter with a specific focus on security, privacy, reliability and management.

Chapter "Semantic Interoperability" by Maria Ganzha, et al., concerns modern trends in IoT semantic interoperability, in particular the different methods to be used, with a specific focus on semantic alignment. After an overview of current literature, the chapter defines the different semantic interoperability patterns, a global ontology (GOIoTP) for platform interoperability, that agnostically address any domain. The chapter describes a key component of the architecture as the IoT Platform Semantic Mediator (IPSM) that support semantic interoperability functions at any layer but mainly at middleware and application and service layers.

Chapter "INTER-Framework: An Interoperability Framework to Support IoT Platform Interoperability" by Clara I. Valero et al., considers the different tools required to manage, secure and provide global access to the APIs of the architecture. After a brief discussion on related work the chapter describes INTER-API and the global API of the INTER-IoT architecture as a relevant contribution and innovation in the area of IoT interoperability; the management functions that allow fast configuration of the interoperability parameters at any layer and the security measures in order to achieve and guarantee interoperability highlighting scalability, flexibility and sustainability.

Chapter "INTER-Meth: A Methodological Approach for the Integration of Heterogeneous IoT Systems" by Giancarlo Fortino et al., provides support for the integration of heterogeneous IoT platforms from the analysis to the maintenance phase, something that is required due to the lack of proper interoperability standards. The chapter provides a description using software engineering of a methodological approach to achieve and manage interoperability among IoT platforms avoiding dependency on the application domain. The proposed methodology is supported by software tools that help the different actors, following their different profile in configuring every required enabler and component.

Chapter "Interoperability Application in e-Health" by Gema Ibáñez-Sánchez, Alvaro Fides-Valero, Jose-Luis Bayo-Monton, Margherita Gulino, and Pasquale Pace is a chapter where the different proposals of the previous chapters, from requirements elicitation till interoperability achievement, are analysed and deployed in the application domain of mobile health. INTER-HEALTH provides a solution that allows health experts to prevent and reduce obesity, which is one of the main causes of chronic diseases. Through INTER-IoT, two different platforms (i.e. UniversAAL and BodyCloud) are able to interoperate to exchange information and so, to provide aggregated information to health experts. The results show a clear improvement in the health of the participants compared to those not using it.

Chapter "INTER-LogP: INTER-IoT for Smart Port Transportation" by Pablo Giménez, Miguel Llop, Joan Meseguer, Fernando Martin, and Antonio Broseta explores the application of the methodology, including requirements gathering and implementation of the different components in a complex environment like a port. The chapter considers the interaction of several IoT platforms with the goal of sharing data and services, provided by the port authority of Valencia, the NOATUM container terminal and other IoT platforms provided by third parties. With the data provided, three different scenarios were defined, and showed the benefits of sharing data in the port and the logistic sector: access control and traffic, dynamic lighting and wind gusts detection.

Chapter "IoT Ecosystem Building" by Regel Gonzalez-Usach, Carlos E. Palau, Miguel A. Llorente, Roel Vossen, Rafael Vaño, and Joao Pita analyses the mechanism to extend the developments of an IoT Open Source project. The chapter describes the methodology and new actors associated with the interoperability framework defined in the previous chapters. A detailed description of different projects is associated with INTER-IoT that validated different enablers, components and methods of the proposed interoperability approach with the aim of sustainability and extendibility.

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Abstract INTER-IoT presents a novel layer-oriented solution for interoperability, to provide interoperability at any layer and across layers among different IoT systems and platforms. Contrary to a more general global approach, the INTER-IoT layered approach has a higher potential in order to provide interoperability. It facilitates a tight bidirectional integration, higher performance, complete modularity, high adaptability and flexibility, and presents increased reliability. This layer-oriented solution is achieved through INTER-LAYER, several interoperability solutions dedicated to specific layers. Each interoperability infrastructure layer has a strong coupling with adjacent layers and provides an interface. Interfaces will be controlled by a meta-level framework to provide global 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.

1 Introduction

The connection of intelligent devices, equipped with a growing number of electronic sensors and/or actuators, via the Internet, is known as the Internet of Things (IoT). With the IoT, every physical and virtual object can be connected to other objects and to the Internet, creating a fabric of connectivity between things and between humans and things [1, 2]. The IoT is now widely recognised as the next step of disruptive digital innovation.

The International Communications Union (ITU) and the European Research Cluster on the Internet of Things (IERC) provide the following definition: IoT is a dynamic global network infrastructure, with self-configuring capabilities based on standard and interoperable communication protocols, where physical and virtual things have identities, physical attributes and virtual personalities and use intelligent interfaces. All of them seamlessly integrated into the information network [3].

The design of the Internet and specifically the extension of the Internet to the IoT, rely on the convergence of the infrastructure with software and services. A common practice is required to think/design cross solutions between software and infrastructure in order to provide integrated solutions for some of the complex problems in the current and future systems. In the IoT environment this convergence is evident, and the continuous evolution generates more and more smart connected objects and platforms that are embedded with sensors and their respective associated services, in some cases considering virtualization.

IoT is the network or overlay associations between smart connected objects (physical and virtual), that are able to exchange information by using an agreed method (including protocols) and a data schema. IoT deployments are increasing, the same applies to standards, alliances and interest for homogenization. All of this is giving a strong push to the IoT domain to be considered as one of the most promising emerging technologies. As an example, Gartner (one of the world's leading information technology research and advisory company) estimates the number of web-connected devices will reach 25 billion by 2020. In other words, more devices, appliances, cars, artefacts, and accessories will be connected and will communicate with each other, and with other objects, thus bringing amplified connectivity and better supply chain visibility. The applications of the IoT are numerous i.e. every object could be transformed into a smart object that sends several valuable information to other devices. As an example, in the port industry IoT could be applied to shipping containers, the equipment that handles them, the trucks that carry them and, even, the ships that move them around the globe [4].

According to the European Commission (EC) the IoT represents the next step towards the digitisation of our society and economy, where objects and people are interconnected through communication networks, and report about their status and/or the surrounding environment. Furthermore, IoT can also benefit the European economy generating economic growth and employment; according to a recent European Commission study revenues in the EU28 will increase from more than €307 billion in 2013 to more than €1,181 billion in 2020 [3, 4].

IoT is an emerging area that not only requires development of infrastructure but also deployment of new services capable of supporting multiple, scalable and interoperable applications. The focus is today associated with cloud deployments, virtualizations and the elimination of silos avoiding the existence of application domain specific developments, AIOTI and EC are pressing in this line. IoT has evolved from sensor networks and wireless sensor networks to a most clear description and definition referring to objects and the virtual representations of these objects on the Internet and associated infrastructures. It defines how the physical things and virtual objects will be connected through the Internet and their interaction, and how they communicate with other systems and platforms, in order to expose their capabilities and functionalities in terms of services and accessibility through open APIs and frameworks. IoT is not only linking connected devices by the Internet; it is also web-enabled data exchange in order to enable systems with more capacities to become smart and accessible, creating webs of objects and allowing integration of data, services and components [5].

There are several challenges associated with IoT and its evolution, but one major issue is related with interoperability [6–8]. IoT is mainly supported by continuous progress in wireless sensor and actuator networks and by manufacturing low cost and energy efficient hardware for sensor and device communications. However, heterogeneity of underlying devices and communication technologies and interoperability in different layers, from communication and seamless integration of devices to interoperability of data generated by the IoT resources, is a challenge for expanding generic IoT solutions to a global scale, with the further aim of avoiding silos and provide solutions that are application domain agnostic, like those proposed in INTER-IoT and that will be reflected in the rest of the book [9].

2 INTER-IoT at a Glance

Achieving interoperability is one of the main objectives of the IoT. It is all about connecting things and make them easily accessible just like the Internet today. Broadly speaking, interoperability can be defined as a measure of the degree to which diverse systems, organizations, and/or individuals are able to work together to achieve a common goal" [6]. However, interoperability is a complex thing and there are many aspects to it. In literature, there exists quite a lot of different classifications of these aspects of interoperability, often also called levels of interoperability. One of the most important classification of levels of interoperability for technical systems is called Levels of Conceptual Interoperability Model (LCIM). It defines six levels of interoperability: technical, syntactic, semantic, pragmatic, dynamic and conceptual interoperability. INTER-IoT follows a similar layered structure, however the approach has been different in terms of identification of the layers.

INTER-IoT as a whole has been the result of a Research and Innovation Action under H2020 EC Framework Programme. The project has designed, implemented and experimented with an open cross-layer framework, an associated methodology and tools to enable voluntary interoperability among heterogeneous Internet of Things (IoT) platforms (all these components will be reflected in the next chapters of this book) [10]. The proposal has allowed effective and efficient development of adaptive, smart IoT applications and services, atop different heterogeneous IoT platforms, spanning single and/or multiple application domains. The project will be tested in two application domains: transport and logistics in a port environment and mobile health, additionally it will be validated in a cross-domain use case supported by the integration in the project of twelve third parties. The INTER-IoT approach is general-purpose and may be applied to any application domain and across domains, in which there is a need to interconnect IoT systems already deployed or add new ones. Additionally, INTER-IoT is one of the seven RIAs and two CSA composing IoT-EPI, supporting the creation of a European common space for IoT interoperability [11–13].

INTER-IoT is based on three main building blocks, with different subcomponents that have been identified and classified in different exploitable products adequate to the needs of the different stakeholders involved in the project and also addressing the main needs of the potential customers of the entities participating in INTER-IoT. This three main building blocks, that will be further explained in the following chapters of the book are:

- INTER-LAYER: methods and tools for providing interoperability among and across each layer (virtual gateways/devices, network, middleware, application services, data and semantics) of IoT platforms. Specifically, we will explore real/virtual gateways, for device-to-device communication, virtual switches based on SDN for network-to-network interconnection, super middleware for middleware-to-middleware integration, service broker for the orchestration of the service layer and a semantics mediator for data and semantics interoperability [11].

- INTER-FW: a global framework (based on an interoperable meta-architecture and meta-data model) for programming and managing interoperable IoT platforms, including an API to access INTER-LAYER components and allow the creation of an ecosystem of IoT applications and services. INTER-FW will provide management functions specifically devoted to the interconnection between layers. The provided API includes security and privacy features and will support the creation of a community of users and developers [14].
- INTER-METH: an engineering methodology based on CASE (Computer Aided Software Engineering) tool for systematically driving the integration and interconnection of heterogeneous non-interoperable IoT platforms [15, 16].

INTER-IoT provides an interoperable mediation component (i.e. INTER-LAYER to enable the discovery and sharing of connected devices across existing and future IoT platforms for rapid development of cross-platform IoT applications. INTER-IoT allows flexible and voluntary interoperability at different layers. This layered approach can be achieved by introducing an incremental deployment of INTER-IoT functionality across the platform's space, which will in effect influence the level of platform collaboration and cooperation with other platforms. INTER-IoT does not pretend to create a new IoT platform but an interoperability structure to interconnect different IoT platforms, devices, applications and other IoT artifacts [11, 17].

Syntactic and semantic interoperability represent the essential interoperability mechanisms in the future INTER-IoT ecosystem, while organizational/enterprise interoperability has different structures/layers to enable platform providers to choose an adequate interoperability model for their business needs. It will be supported by INTER-FW that may allow the development of new applications and services atop INTER-LAYER and INTER-METH, to provide a methodology in order to coordinate interoperability supported by the definition of different interoperability patterns and a CASE tool [16] (Fig. 1).

INTER-LAYER, which will be addressed in detail in Chap. 4, is composed by five layers, supported by cross-layer components as needed for the interaction of the different layers:

- Device layer (D2D): At the device level, D2D solution will allow the seamless inclusion of novel IoT devices and their interoperation with already existing ones. D2D solution is a modular gateway that supports a vast range of protocols as well as raw forwarding. It is composed on a physical part that only handles network access and communication protocols, and a virtual part that handles all other gateway operations and services (gw virtualization). When connection is lost, the virtual part remains functional and is capable to answer the API and Middleware requests. The gateway follows a modular approach to allow the addition of optional service blocks to adapt to the specific case, allowing a fast growth of smart objects ecosystems [18, 19].
- Network layer (N2N): N2N solution enables seamless Network-to-Network interoperability, allowing transparent smart object mobility, and information routing support. It will also allow offloading and roaming, what implies the interconnection of gateways and platforms through the network. Interoperability is achieved

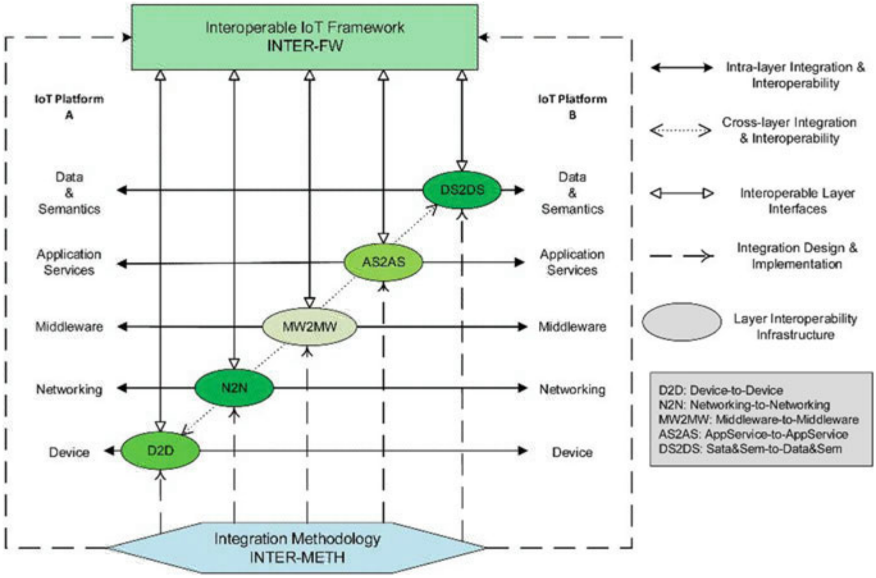

Fig. 1 INTER-IoT concept and vision

through the creation of a virtual network, using SDN and NFV paradigms, with the support of the N2N API. The N2N solution will allow the design and implementation of fully interconnected ecosystems, and solve the smart object mobility problem [20].

- Middleware layer (MW2MW): At the middleware level INTER-IoT solution will enable seamless resource discovery and management system for the IoT devices 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 provide services to manage the virtual representation of the objects, creating the abstraction layer to access all their features and information. Those services 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 [21].
- Application and Services layer (AS2AS): INTER-IoT will enable the use of heterogeneous services among different IoT platforms. Our approach will allow the discovery, catalogue, use and even 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 [22].
- Data and Semantics level (DS2DS): INTER-IoT guarantees a common interpretation of data and information among different IoT platforms and heterogeneous data sources that typically employ different data formats and ontologies, and are unable to directly share information among them. INTER-IoT DS2DS approach

is the first solution that provides universal semantic and syntactic interoperability among heterogeneous IoT platforms. It is based on a novel approach, a semantic translation of IoT platforms' ontologies to/from a common Central Ontology that INTER-IoT employs, instead of direct platform-to-platform translations. This technique reduces dramatically the number of potential combinations of semantic translations required for universal semantic interoperability. INTER-IoT semantic interoperability tools work with any vocabulary, or ontology. INTER-IoT own modular Central Ontology, called GOIoTP, for all IoT platforms, devices and services, is available at http://docs.inter-iot.eu/ontology. Also, syntactic translators allow interoperability between different data formats, such as JSON, XML, and others. Although the pilot deployments of INTER-IoT realize the Core Information Model with Extensions approach to semantic interoperability, INTER-IoT supports any solutions between its pilot approach and Core Information Model [23, 24].

- Cross-Layer: INTER-IoT also guarantees non-functional aspects that must be present across all layers: trust, security, privacy, and quality of service (QoS). As well, INTER-IoT provides a virtualized version of the solution for each layer, to offer the possibility of a quick and easy deployment. Security is guaranteed inside each individual layer, and the external API access is securitized through encrypted communication, authentication and security tokens. INTER-IoT accomplishes the new European Data Privacy Law, and in the specific case of e-Health, in which information is highly sensitive, the Medical Device Regulation law [11, 25].

And INTER-FW which provides the wrapping environment for INTER-LAYER component coordination and new services development using INTER-API. Open interoperability delivers on the promise of enabling vendors and developers to interact and interoperate, without interfering with anyone's ability to compete by delivering a superior product and experience. In the absence of global IoT standards, the INTER-IoT project will support and make it easy for any company to design IoT devices, smart objects, or services and get them to market quickly, and create new IoT interoperable ecosystems. INTER-IoT may provide a solution to any potential interoperability problem within the IoT landscape [13] (Fig. 2).

3 INTER-IoT Use Case-Driven

The INTER-IoT approach is use case-driven, implemented and tested in three realistic large-scale pilots: (i) Port of Valencia transportation and logistics involving heterogeneous platforms with 400 smart objects; (ii) an Italian National Health Center for m-health involving 200 patients, equipped with body sensor networks with wearable sensors and mobile smart devices and (iii) a cross domain pilot involving IoT platforms from different application domains and enlarged by the collaboration of the solutions associated to the different layers and sublayers from the third parties that have attended the open call. The use cases are:

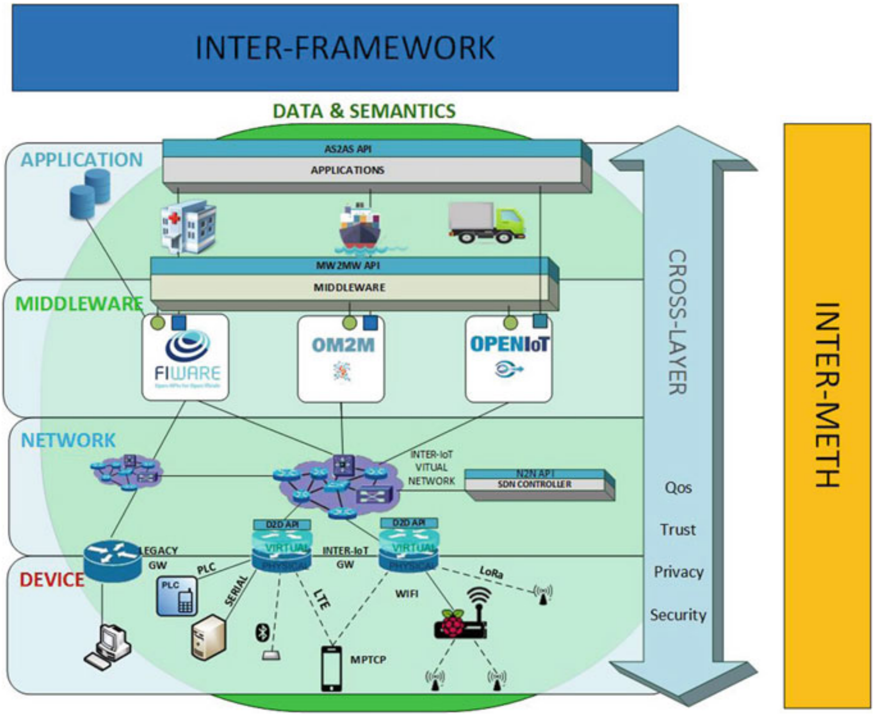

Fig. 2 INTER-IoT layered approach

- INTER-LogP: The use of IoT platforms in the ports of the future will enable locating, monitoring, and handling different transport and cargo equipment and storage areas. This use case will address the need to seamlessly handle IoT platforms interoperation within port premises: container terminal, transportation companies, warehouses, road hauliers, port authorities, customs, and outside the port [26].
- INTER-Health: The Decentralized and Mobile Monitoring of Assisted Livings' Lifestyle use case, aims to develop an integrated IoT system for monitoring humans' lifestyle in a decentralized mobile way to prevent chronic diseases. The aforementioned monitoring process can be decentralized from the healthcare center to the monitored subjects' homes, and supported in mobility by using on-body physical activity monitors [27].
- INTER-DOMAIN, composed by IoT platforms from the two application domain oriented pilots and the IoT platforms and the specific layer-oriented solutions from different application domains selected in the open call. SENSINACT and OM2M platforms with Smart Cities orientation have been selected, and contributions from the different layers may complement INTER-IoT [28, 29].

The project has analyzed requirements provided by the stakeholders of the project and usability of the provided solutions from the perspective of IoT platform creators, IoT platform owners, IoT application programmers and users investigating business perspectives and creating new business models. These results have allowed to start INTER-IoT ecosystem and new features and components: methodologies, tools, protocols and API. The variety and cross availability of the results could be used to build and integrate services and platforms at different layers according to the needs of the stakeholders and developers. The availability of more and new data will stimulate the creation of new opportunities and products.

3.1 INTER-LogP: Interoperability for Transport and Logistics in a Port Environment

In the ports of the future, port users, equipment and infrastructures will achieve a zero distance interaction offering more sustainable transport solutions. The use of IoT platforms will enable locating, monitoring, and handling different transport and cargo equipment and storage areas. The requirements for a better management of equipment and resources and the huge complexity of interactions involving large quantity of simultaneous transport movements around big logistics nodes (e.g., container terminals, ports, warehouses and dry ports) originates the need to introduce IoT platforms with multiple sensors in all logistics elements to control and monitor the several operations like energy consumption, gas emissions, or machine status. With these platforms, logistics service providers will be able to monitor and control in real time all the operations and movements of freight, equipment, vehicles and drivers on logistics nodes.

The Port of Valencia premises extend for several square kilometres. It is the largest Mediterranean port in terms of container handling. The port contains five container terminals (e.g., NOATUM and MSC), and several other facilities (e.g., train freight station, warehouses, and parking spaces). The port includes several kilometres of road within the premises. The Port Authority has several deployed IoT platforms connected to different HMI and SCADA with different goals (e.g., traffic management, security, safety and environmental protection, or vessels identification). Some of these platforms provide selected data to the Port Community System (PCS) like tamper proof RFID tags and e-seals that are installed on trucks and semi-trailers. In particular, A Port Community System is an electronic platform that connects the multiple systems operated by a variety of organisations that make up a seaport, airport or inland port community. It is shared in the sense that it is set up, organised and used by firms in the same sector—in this case, a port community. There is an increasing need that trucks, vehicles and drivers seamlessly interoperate with the port infrastructures and vice versa. All deployed IoT platforms do not interoperate as they are based on different standards, and remain isolated with a clear lack of interoperability at all layers.

NOATUM Container Terminal is one of the biggest container terminals in the Mediterranean located at the port of Valencia. It is the fifth largest European port in container handling, i.e. it deals with more than 50,000 movements per day, produced by more than 200 container handling units (e.g., cranes, forklifts, RTGs, internally owned tractors and trailers, etc.); more than 4,000 trucks and other vehicles visit terminal premises; with more than 10,000 containers involved in these movements. These values show the complexity of this environment and the opportunities that the information compiled by the sensors installed on the equipment, trucks and containers; and the IoT interconnected architectures can bring to the terminal (e.g., in terms of optimization in the operations, safety, security or cost and energy savings). Container terminals like the one managed by the NOATUM have a huge number of sensors, CPS (Cyber Physical Systems) and smart objects; fixed and mobile deployed and exchanging information within one or between several platforms deployed in their premises. The sensors from the internal equipment (i.e., container terminal IoT ecosystem), constitute 5% of total vehicles moving daily within terminal premises, and they generate more than 8,000 data units per second. The other 95% of the vehicles are external trucks and other vehicles, with sensors belonging to other IoT ecosystems, currently unable to interact with the terminal IoT solution. Additionally, containers (mainly used to transport controlled temperature cargoes) have their own IoT architecture, which cannot be accessed by the terminal, when the container is stored in the yard or moved across it. This lack of interoperability of outdoor ambulatory IoT things based on heterogeneous architectures represents a big barrier that INTER-IoT aims at removing.

This use case illustrates the need to seamlessly IoT platforms interoperation within port premises, e.g., container terminal, transportation companies, warehouses, road hauliers, port authorities, customs, border protection agencies, and outside the port. Port IoT ecosystems use to be operated by a large number of stakeholders, and typically require high security and trust, due to mobility and seamless connectivity requirements, that currently are not available with the exception of proprietary and isolated solutions. Introduction of interoperability mechanisms and tools will therefore bring about new solutions and services leading to developments of the ports of the future.

3.1.1 INTER-IoT Approach to INTER-LogP

INTER-LogP will be an INTER-IoT outcome to facilitate interoperability of heterogeneous Port Transport and Logistics-oriented IoT platforms already in place, i.e., VPF and NOATUM and other components that will be brought to the use case in order to achieve the INTER-IoT proposed goals, e.g., I3WSN from UPV and other IoT platforms from companies operating in the Port managed premises.

The Port Authority of Valencia will provide its own IoT platform ecosystem to the project, including (i) the climate and weather forecast infrastructures, which monitor the environmental conditions in real-time and maintain historical data; (ii) beacon data acquisition system, which monitors and controls whenever necessary all the buoys distributed on the sea side; (iii) PCS-IoT platform, developed to cover different transportation and logistics components throughout the port premises, integrates an internal communication network and connects (more than 400) operating companies in the port.

NOATUM provides the SEAMS platform to be included in the INTER-LogP use case. SEAMS is an outcome from the Sea Terminals action (Smart, Energy Efficient and Adaptive Port Terminals) co-funded by the Trans-European Transport Network (TEN-T). It is an operational tool based on the reception of real-time energy and operative data coming from the whole machinery and vehicle fleets of NOATUM Container Terminal Valencia (NCTV). SEAMS integrates the whole set of machines (including Rubber Tyre Gantry cranes (RTG), Ship-To-Shore cranes (STS), Terminal Tractors (TT), Reach Stackers (RS) and Empty Container Handlers (ECH)) and vehicles deployed and available in the terminal premises.

INTER-IoT will help to expand the possibilities offered by not only SEAMS and the sensors installed on its own container terminal vehicles and container handling equipment units, but also sensors available on third party equipment (i.e., reefer containers) and vehicles (i.e., external trucks picking up and delivering containers). Finally, it will allow installation of sensors on legacy equipment that does not have them available. Moreover, INTER-IoT will allow to seamlessly connecting the container terminal IoT ecosystem with other ecosystems owned by other parties, e.g., the port authority, road hauliers, the individual trucks, vehicles, containers and vessels through intelligent objects offered by different vendors, some of them managed by the PCS [30].

On the other hand, UPV provided I3WSN, semantic IoT methodology and platform deployed in application domains like factories, automotive and defence. This generic architecture was developed within a large Spanish National project FASyS and has been extended to be used in different areas like port transportation and m-health. The framework provides interoperability at different layers and includes reliability, privacy and security by design. Additionally, devices from the partners will be added to the trials and devices from the users (e.g., truck drivers or terminal operators) like smart phones will be added to the system following BYOD (Bring Your Own Device) philosophy, allowing the integration of COTS devices in the large scale trials.

Although the different platforms that the transport and logistics use case integrates (in particular, IoT-PCS from VPF, NOATUM TOS, I3WSN UPV and the IoT platforms from other stakeholders) share some characteristics, they have different aims (i.e., focused on the particular benefits of the administrator/operator and use different technologies). All of them gather data, using different M2M and P2M protocols; some of them are cloud-based and others will be, but the most important thing is that they lack interoperability in terms of the five identified layers. There is a potential integration using one of the platforms (i.e., IoT-PCS) as a matrix architecture; however interoperability and integration will not profit the power of the proposed approach neither the capabilities of interoperable architectures rather than interconnected architectures. The use case, mainly focused in the transportation of containers, as it is the most sensorized in port transportation (especially reefer and International Maritime Organization—IMO safe containers), may improve efficiency, security and benefits to the whole transport chain. Additionally, INTER-IoT will provide the pos-

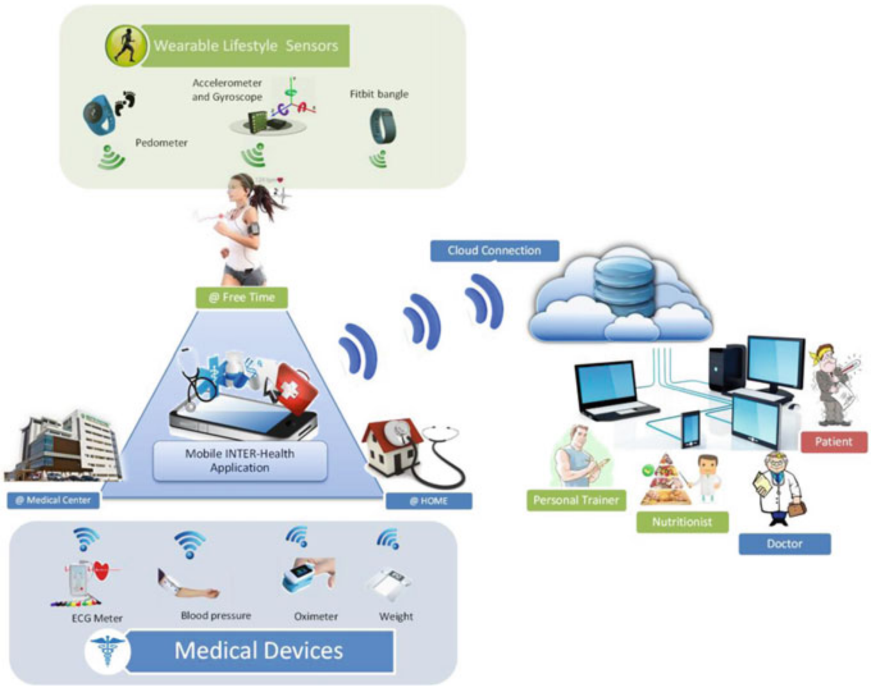

Fig. 3 INTER-IoT interconnection for m-Health (INTER-Health)

sibility to interact with other IoT platforms available in the port surroundings like Valencia City FIWARE infrastructure (i.e., VLCi) that is an open platform that will provide contextual information for different services and interactions at data and services layers [31–33] (Fig. 3).

3.2 INTER-Health: Interoperability for Mobile Health for Chronic Patients

The Decentralized and Mobile Monitoring of Assisted Livings' Lifestyle use case, aims at developing an integrated IoT system for monitoring humans' lifestyle in a decentralized way and in mobility, to prevent health issues mainly resulting from food and physical activity disorders. Users that attend nutritional out-patient care centres are healthy subjects with different risk degrees (normal weight, overweight, obese) that could develop chronic diseases. Only the obese (in case of second and third level obesity) need, at times, hospital care and get into a clinical and therapeutic route. The medical environment in which the pilot will be developed and deployed is the Dept. of Prevention/Hygiene Nutrition Unit at ASLTO5.

The use case will focus in the fact that in main chronic diseases, such as cardiovascular diseases, stroke, cancer, chronic respiratory diseases and diabetes, there are common and modifiable risk factors that are the cause of the majority of deaths (and of new diseases). Between the common and modifiable risk factors there are wrong lifestyles such as improper and hyper caloric diet and, in particular, the lack of physical activity. Every year in the world (World Health Organization and others, 2013): 2.8 million people die for obesity or overweight; 2.6 million people die for high cholesterol levels; 7.5 million people die for hypertension; 3.2 million people die for physical inactivity. These wrong lifestyles are expressed through the intermediate risk factors of raised blood pressure, raised glucose levels, abnormal blood lipids, particularly Low Density Lipoprotein (LDL cholesterol) and obesity (body mass index superior to 30 kg/m2).

According to the reference standard medical protocol for the global prevention and management of obesity, written by the World Health Organization, in order to assess the health status (underweight, normal weight, overweight, obesity) of the subject (of a given age) during the visit at the healthcare center, objective and subjective measurements should be collected (and/or computed) by a health-care team (doctor, biologist nutritionist, dietician, etc.). The objective measurements are: weight, height, body mass index (enabling diagnosis of overweight and obesity), blood pressure or waist circumference. The subjective measurements reported by the subject, are collected through computerized questionnaires, and concern the eating habits: quality and quantity of food consumed daily and weekly, daily consumption of main meals (breakfast, lunch, dinner and snacks) and the practice of physical activity (quality and quantity of physical activity daily and weekly). The physical activity degree is detected subjectively during the first visit and could be objectively monitored through wearable monitoring devices. On the basis of these measurements, the caloric needs are automatically calculated, and the diet of the subject is defined. From this point forward, the subject must be monitored periodically (for example, every three months) for a period of at least one year. Usually monitoring is carried out at the health-care center, where the objective and subjective measurements are cyclically repeated. Based on the results, and depending on the health status reached by the subject (improved or worsened), the possibility of redefining his diet and his physical activity is analyzed.

By exploiting an integrated IoT environment, the aforementioned monitoring process can be decentralized from the healthcare center to the monitored subjects' homes, and supported in mobility by using on-body physical activity monitors. Specifically, the system will be created by using a new IoT platform, named INTER-Health, obtained by integrating two already-existing heterogeneous, non-interoperable IoT platforms for e-Health according to the approach proposed in the INTER-IoT project, based on the INTER-FW and its associated methodology INTER-METH: (i) UniversAAL, developed by UPV, and (ii) BodyCloud [34], developed by UNICAL.

3.2.1 INTER-IoT Approach to INTER-Health

There is a need of integrating different IoT platforms as proposed in the INTER-Health use case. The effective and efficient integration of heterogeneous e-Health IoT Platforms will provide an appropriate answer to the challenges described in INTER-IoT proposal. The two platforms considered are UniversAAL and BodyCloud, and the result of the integration will allow developing a novel IoT m-Health system for Lifestyle Monitoring [27].

This flexibility allows deploying universAAL-based solutions in multiple configurations, such as local-only nodes, mobile nodes connected to server instances, or non-universAAL nodes connecting to a multi-tenant server. Communication between applications and/or sensors happens through three different buses. Messages and members are always described semantically using the domain ontologies at hand: (i) Context bus—An event-based bus for sharing contextual information from context publishers to context subscribers; (ii) Service bus—A request-based bus for on-demand execution and information retrieval from service callers to service providers and (iii) User Interface bus—A centrally-managed bus that allows applications to define abstract interfaces to be rendered by different User Interface (UI) modalities. In each bus, semantic reasoning is used to match the transferred messages to the appropriate destination. This way, applications and sensors only need to describe what they provide and what they require from others. There is no need to specify recipients, connections nor addresses explicitly [30].

BodyCloud is a SaaS architecture that supports the storage and management of body sensor data streams and the processing (online and offline analysis) of the stored data using software services hosted in the Cloud. In particular, BodyCloud endeavours to support several cross-disciplinary applications and specialized processing tasks. It enables large-scale data sharing and collaborations among users and applications in the Cloud, and delivers Cloud services via sensor-rich mobile devices. BodyCloud also offers decision support services to take further actions based on the analyzed BSN data [34].

The BodyCloud approach is centered around four main decentralized components (or sides), namely Body, Cloud, Viewer, Analyst: (i) Body-side is the component, currently based on the SPINE Android, that monitors an assisted living through wearable sensors and stores the collected data in the Cloud by means of a mobile device; (ii) Cloud-side is the component, based on SaaS paradigm, being the first general-purpose software engineering approach for Cloud-assisted community BSNs; (iii) Viewer-side is the Web browser-enabled component able to visualize data analysis through advanced graphical reporting; and (iv) e Analyst-side is the component that supports the development of BodyCloud applications.

The two platforms, UniversAAL and BodyCloud, share some high-level characteristics while differ in objectives and technology. Specifically, they are both e-Health platforms, based on Bluetooth technology to interact with measurement devices, and based on Cloud infrastructures to enable data storing, off-line analysis, and data visualization. However, they have different specific objectives and are not interoperable from a technological point of view (at each layer and at the global level). Their spe-

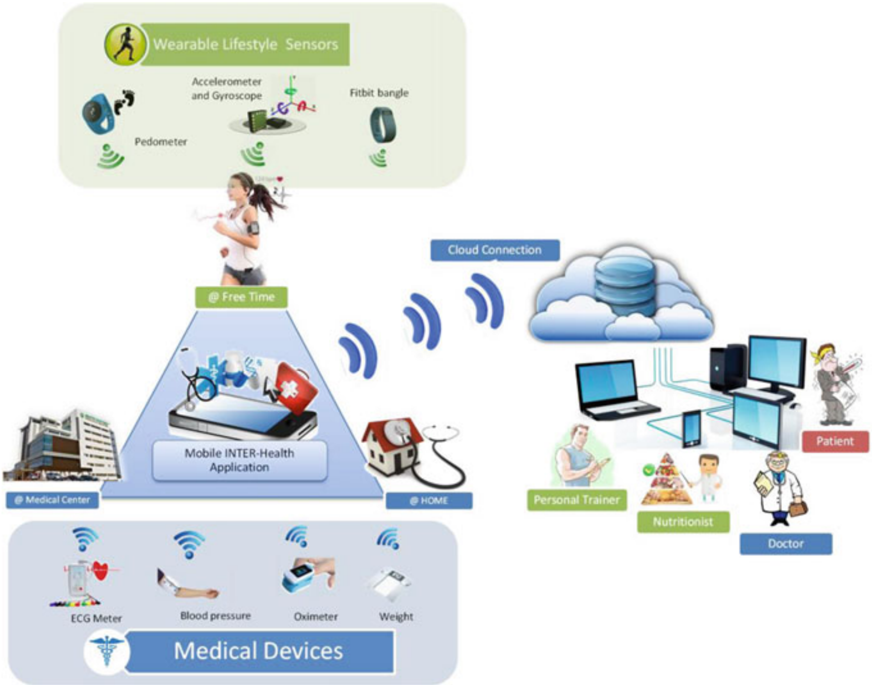

Fig. 4 INTER-IoT interconnection for m-Health (INTER-Health)

cific objectives are complementary: UniversAAL is focused mainly on non-mobile remote monitoring based on non-wearable measurement devices, whereas Body-Cloud provides monitoring of mobile subjects through wearable devices organized as body sensor networks. Thus, their integration will produce a full-fledged m-Health integrated platform on top of which multitudes of m-Health services could be developed and furnished. The use case will be fully deployable atop the integration of UniversAAL and BodyCloud: (i) the automated monitoring at the health-care center and the decentralization of the monitoring at the patients' homes will be supported by UniversAAL remote services; (ii) the monitoring of mobile assisted livings would be enabled by the BodyCloud mobile services; (iii) new cross-platform services will be developed for enabling complete analysis of the measurement streams coming from assisted livings [28, 35] (Fig. 4).

4 INTER-IoT Progress Beyond the State of Art

The overall concept of the INTER-IoT project targets a full-fledged robust approach for seamless integration of different IoT platforms within and across different application domains. Interoperability will be achieved at different layers, depending on the requirements of the specific scenario or the use case. The main outcomes of the project will be infrastructures for layer-oriented interoperability and a reference interoperable meta-architecture; an interoperability framework and an API along with an engineering methodology driven by a toolbox to be used by third parties to integrate heterogeneous IoT platforms and thus implement interoperable IoT applications. INTER-IoT will focus on two application domains (m-health and port transportation and logistics) and on their integration. The project outcome will optimize different operations in these two domains and in their integration. However, the INTER-IoT approach will be easily reused in any application domain, in which there is a need to interconnect already deployed (heterogeneous) IoT platforms. Or even in cross application domains, where IoT platforms and smart objects from different application domains will require co-operation or interoperability between them. Based on these principles, INTER-IoT targets the following innovations [5, 6].

4.1 Global Platform Interoperability

Global interoperability of hardware/software infrastructures is usually based on standards. However, as IoT is an evolving technology without specific central technical coordination and control, it is foreseen that many solutions and (pseudo) standards will be developed and proposed in the coming years. This will lead to massive heterogeneity. Indeed, currently many different (quasi) standards do exist in the IoT arena addressing: communications, hardware, software, and data. However, they mainly refer to specific IoT objects (sensors, sensor networks, RFID, nanocomputers, etc.) or contexts (smart grid, health-care, logistics, etc.). From the communications viewpoint, standards protocols at different level (MAC, network, application) are available: IEEE 802.11—WiFi, IEEE 802.16—WiMax, IEEE 802.15.4—LR-WPAN, 2G/3G/4G—Mobile Communication, Zigbee, Bluetooth, ANT+, NFC, M2M communications (M-Bus, WM-Bus, UWB, ModBus, Z-Wave), M2M ETSI, IPv4, IPv6, 6LowPAN, TCP, UDP, ISO/IEEE 11073 for medical devices, CoAP, HTTP, MQTT, XMPP, DDS, AMQP, Websocket, etc. From the hardware perspective, the technological state of the art is also heterogeneous: Arduino, BeagleBoard, TelosB sensor mote, RaspberryPI, pcDuino, Cubieboard, Libelium sensor/gateway, etc. The software realm is even richer including many base software technology (TinyOS, Contiki, FreeRTOS, eCos, Android, Ubuntu, Java, WebRTC, REST, WAMP, Django, etc.) and middleware solutions (FedNet, Ubicomp, SmartProducts, ACOSO, SkyNet, etc.), including cloud computing-based infrastructures (Amazon EC2, Google App Engine, Xively, MS Windows Azure). Also the data (and semantics) level presents high heterogeneity: XML (and XML-based like WSDL), JSON, UDCAP, uCode Relational Model, RDF, OWL, W3C SSN (Semantic Sensor Network) [4, 11].

It is worth noting that, when we consider a complete IoT platform, the complexity of technologies used to build up the platform further arises as each defined layer (device, networking, middleware, application service, data and semantics) exploits specific solutions that need to be holistically adapted to form the final platform. For instance, several available platforms, each of which was designed and deployed to fulfil quasi similar goals but exploiting heterogeneous IoT technological solutions, or providing any (or even limited) interoperability [36]. Thus, it is critical to provide bottom-up "voluntary" approaches able to integrate, interconnect, merge, heterogeneous IoT platforms to build up extreme-scale interoperable ecosystems on top of which large-scale applications can be designed, implemented, executed and managed [37].

INTER-IoT will provide the first full-fledged methodological and technological suite to completely address the fundamental issue of "voluntary interoperability". The suite will be composed of three main building blocks: (i) Layer-oriented infrastructures to adapt heterogeneous peer layers (device-to-device, networking-to-networking, middleware-to-middleware, application services-to-application services, data-to-data, and semantics-to-semantics); (ii) Interoperable open framework to program and manage integrated IoT platforms; (iii) Engineering methodology and tools to drive the integration process of heterogeneous IoT platforms. By using INTER-IoT, IoT heterogeneity will be turned from the most limiting factor for IoT technology diffusion to its greatest advantage due to the exploitation of specific benefits and characteristics derived from multiple heterogeneous IoT platforms [15, 38, 39].

4.2 Gateway and Device Interoperability

As sensors, actuators and smart devices become smaller, more versatile, lower cost and more power efficient, they are being deployed in greater numbers, either as special-purpose devices or embedded into other products. The unification and convergence of the vast number of platforms already deployed, the accessibility (API and interfaces) of the platform to app developers, requires interoperability. Smartphones are key components in Device-to-Device (D2D) communication and interoperability, however there are many other types of devices that are currently deployed, both independently (e.g. smart watches and other wearables) and as part of other devices and platforms (e.g. consumer electronics or Cyber-Physical Systems). Different communication protocols are used at device level. Here, Cellular and WiFi that are ubiquitous; they are evolving to support higher bandwidths and lower cost. Bluetooth is also becoming lower cost. New communication technologies like Bluetooth low energy (Bluetooth LE) and NFC are opening new possibilities for IoT. However, also traditional communication protocols and mechanisms for sensors, actuators and smart objects have to be considered (e.g. ZigBee, ISA100, WirelessHart), in addition to other non-standard proprietary protocols developed by individual vendors, or even to new emerging protocols, e.g. [40, 41]. Different classes of IoT objects need different communication supports: e.g. 'deterministic' communication protocols (MAC and Routing layers) are not possible using current Internet protocols, but may be needed by some application. Standardization on these topics is just starting (e.g., detnet working group in IETF). Yet, deterministic communications will hardly meet the interoperability requirements of all IoT objects. Typically device-level interconnection of IoT architectures has been performed using gateway-based solutions. FP7 Butler project proposed a device-centric architecture where a SmartGateway allows interconnection between smart objects (sensors, actuators, gateways) using IPv6 as communication protocol. Different approaches have been developed to integrate and interoperate devices in IoT architectures. Basic devices (e.g. sensors, tags, actuators) are virtualized and can be composed in more complex smart systems. The idea has been to create virtual objects, allowing object composition, considering a virtual object as a counterpart of existing smart objects [19, 42, 43].

INTER-IoT will provide fundamental benefits and competitiveness improvements in the way IoT devices will communicate with each other and will interface with different IoT platforms and subsystems. One of the proposed progresses regarding D2D interaction is to complement standardized communication protocols (which are mostly deterministic and reactive) with an ability for objects to make sense of their surroundings in order to understand how to best interplay with their neighbours. This requires new 'proactive' and 'predictive' communications capabilities, whereby a node can determine its communication requirements and those of its neighbours well before communication is required. It has recently been proven that machine learning capabilities can run even on small sensors (with as little as 20 KB of RAM). INTER-IoT will develop an interoperable communication layer, even based on lightweight machine learning that also accommodate for opportunistic communications among heterogeneous nodes/devices, based on prediction mechanisms [21, 44].

4.3 Networking Mobility and Interoperability

IoT products will encompass different data communication scenarios. Some may involve sensors that send small data packets infrequently and do not prioritize timely delivery. Others may involve storage in order to sustain periods when the communication link is down (e.g. Delay Tolerant Networks). Others may need high bandwidth but be able to accept high latency. And others may need high quality, high bandwidth, and low latency. Large amounts of traffic with relatively short packet sizes will require sophisticated traffic management. More efficient protocols can help reduce overhead but may present challenges to system integrity, reliability and scalability. Interface standardization is desirable so that IoT objects can communicate quickly and efficiently, and allow mobility between interoperable IoT platforms. IoT objects will need a way to quickly and easily discover each other and learn their neighbour's capabilities [28, 45].

At networking and communications layer different protocols can be used like 6LowPAN, TCP/HTTP, UDP/CoAP. Communication between real objects and the gateway can be based on universal plug and play (UPnP) or DLNA. Use of buses based on MQTT protocol can also be used to implement asynchronous communications between entities. The most promoted networking protocol in IoT environments is IPv6 and its version for constrained devices 6LoWPAN, even though its adoption is slow, and without global adoption it will be impossible for IoT to proliferate. IPv6 provides the following benefits to IoT configurations: (i) IPv6 auto-configuration; (ii) Scalable address space (sufficiently large for the enormous numbers of IoT objects envisioned); (iii) Redefined headers that enable header compression formats; (iv) Easy control of the system of things: (v) Open/Standard communications; (vi) IPv6 to IPv4 transition methods; (vii) IPv6 over constrained node networks (6LO, 6LoWPAN [11, 46].

IoT platforms have usually mechanisms for integrating with external systems, but they are all based on specific point to point connections, usually with legacy systems in the area of interest of the IoT platform (city, neighbourhood, factory, hospital, port, house, etc.). The integration between IoT platforms will allow tracking the behaviour of these objects when they move outside the intrinsic area of interest and get into the area of interest of another IoT platform. The pub/sub mechanism usually available in the communication buses at the core of these IoT platforms and the possible object context sharing allow a powerful and easy way to track the behaviour of these objects among different IoTs scope areas.

INTER-IoT will provide support for as many networks as possible, including as many networks as possible in the INTER-FW definition. Main contributions of the project will be focused to multihoming capabilities among the different IoT objects in order to provide network offloading connectivity and seamless mobility between different IoT platforms of moving objects. INTER-IoT will use SDN components to configure interconnection at network level and also will use ICN/CCN as support for interoperability and roaming of smart objects between different platforms of the same ecosystem while keeping secure connectivity and also guaranteed quality of service. Resource management and scalability so as reliability, trust, privacy and security will be non-functional requirements that will be addressed by the project to provide optimal interoperability at network layer [6, 30, 47].

4.4 Middleware Platform Interoperability

Middleware, widely used in conventional distributed systems, is a fundamental tool for the design and implementation of both IoT devices and IoT systems. They provide general and specific abstractions (e.g., object computation model, inter-object communication, sensory/actuation interfaces, discovery service, knowledge management), as well as development and deployment tools, through which IoT devices, IoT systems and their related applications can be easily built up. Indeed, middleware (i) enable connectivity for huge numbers of diverse components comprised at Device Layer, (ii) realize their seamless interoperability at Networking Layer, and (iii) ensure operational transparency at Application Service Layer. In such a way, heterogeneous, often complex and already existing IoT devices and IoT systems, belonging to different application domains and not originally designed to be con-