INTER-Health: An Interoperable IoT Solution for Active and Assisted Living Healthcare Services


Abstract—The paper presents the first results of the ongoing INTER-Health pilot coming out from the application of the strategy proposed and developed within the framework of the INTER-IoT (Horizon 2020) European project. The novel IoT-based healthcare platform, supporting decentralized and mobile monitoring of assisted living in highly heterogeneous contexts, has been obtained by integrating other existing heterogeneous, non-interoperable IoT platforms following the INTER-IoT approach to provide value added mobile healthcare services (respect to the standard “manual” monitoring performed by conventional healthcare centers) in terms of faster detection and correction of wrong lifestyles or high risk critical situations. All the interoperability aspects and technological choices have been presented to discuss the ease of such integration process, also making easier and faster the interaction between doctor and patient drastically reducing the dropout rate of people leaving the pilot.

I. INTRODUCTION

One of the most attractive application environment in the IoT arena is healthcare [1]. IoT technologies have the potential to boost up many medical applications, such as remote and mobile health monitoring, human activity recognition, reduction of hospitalizations of chronic patients and elderly care at home. The development of new applications and services can help to decrease healthcare costs, improve the quality of life and enhance the patients’ experience; however, specific healthcare requirements were often faced developing particular and custom systems (i.e. proprietary, closed) that were not interoperable and/or reusable in different, though similar, contexts.

Today there is a plethora of IoT systems that are not enough scalable neither sustainable because they are not able to interoperate and whose integration process is almost expensive as the creation of a new solution from scratch. As an example, the work in [2], presented an IoT solution, developed from scratch, for monitoring groups of sedentary people by collecting users’ physiological data through wearable devices and sending such data to a computational cloud to be processed, stored and presented to the healthcare professional. This example is a typical custom solution that did not have any benefit from already existing systems and experiences.

Looking at the consumer electronic context, the major manufacturers (e.g. Samsung, Polar, FitBit, Garmin) offer a huge set of devices and applications for human activity recognition paving the way for the emergence of many new service platform (e.g. Runtastic, Strava, Google Fit). However, all these worlds are closed; they do not communicate with each other and create a barrier to the development of new services and platforms.

This trend has limited the development of many other IoT-based healthcare solutions that may constitute a higher added-value if we were able to create new services by combining existing ones, benefiting from the interoperability that can become the driving force behind a new development impulse in highly heterogeneous contexts. In fact, many different IoT platforms already exist [3],[4] providing specific solutions for different application scenarios such as healthcare, logistics, home automation, etc... however, the quick integration and interoperability of those heterogeneous IoT platforms, allowing heterogeneous elements to cooperate seamlessly to share data, infrastructures and services as in a homogeneous scenario, is still a challenging issue[5].

It is worth noting that, when we consider any IoT platform, the complexity of the technologies used to build up the platform further arises as each defined layer (device, networking, middleware, application service, data and semantics) exploits specific heterogeneous IoT technological solutions that need to be holistically adapted to form the final platform without providing any (or even limited) interoperability. 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.

Thanks to a novel interoperable approach, proposed and developed within the INTER-IoT [6] H2020 European framework, new cross-platform services can be implemented; hence, to demonstrate the main benefit of the proposed model of integration and interoperability, we created INTER-Health [7], a more powerful IoT healthcare platform for lifestyle monitoring of patients at risk of obesity.

This new platform has not been developed from scratch; on the contrary it come out through the interoperability of
The proposed INTER-Health platform aims to develop an integrated IoT system for monitoring humans' lifestyle in a decentralized mobile way to prevent health issues resulting from food and physical activity disorders. This 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.

In particular, the use of the INTER-Health platform, applied to a specific real use case, will take into account a set of health indicators: i) Body mass index (BMI); ii) waist circumference; iii) physical activity (i.e. the amount and the type of physical activity) and iv) eating habits (i.e. quality and quantity of food consumed daily and weekly).

The defined use case would be fully deployable atop the integration of two specific IoT platforms (UniversAAL [8] and BodyCloud [9]). Specifically, the automated monitoring at the healthcare center would be supported by UniversAAL, while the physical activity monitoring in mobility would be enabled by the BodyCloud mobile services. Finally, a specific software application, consisting of a professional web tool (PWT), is also integrated within the communication architecture in order to provide all the health services in a user friendly way to the doctors as shown in Fig. 1 where the fully interoperability among the different IoT platforms and components is implemented using the outcomes of the INTER-IoT project [6] as detailed in section III.

The main functionalities of the integrated and interoperable IoT platform are the followings:

A. Professional Web Tool (PWT)

Traditionally, patients went to the hospital for consultation for being interviewed by health professionals. The aim was to know about patient’s lifestyle in terms of nutritional and physical activity behaviour. It was complemented by measuring biometric data such as height, weight, blood pressure or waist circumference. Health professionals annotated this data by hand and later on, they had to introduce manually the answers into a spreadsheet to analyze them.

The advantage of using the professional web tool (PWT) resides in the fact that is able to integrate patient’s data flow coming from Internet of Things environment. The aim of the tool is to facilitate the work of the health professionals by providing understandability objective and subjective data coming from both BodyCloud and universAAL platforms. Moreover, thanks to INTER-IoT these platforms could be substituted easily by others that provide same services and in any case, the PWT will be able to show relevant aggregated data in a single dashboard to health professionals. Fig. 2 makes very clear the importance of using a PWT within the INTER-IoT framework.

B. universAAL

The universAAL IoT Platform provides an open source semantic framework that allows applications and sensors to communicate and interoperate with one another, based on an ontological description of their data models. The platform...
BEFORE

AFTER

Handmade questionnaires

Fig. 2. Before and after the use of the INTER-Health integrated platform.

is the outcome of the universAAL project [8], which was focused on the provision of IoT Ambient-Assisted Living services. However, the platform is suitable for generic IoT domains, and is currently maintained by the universAAL IoT Coalition [11]. During ReAAL project [12], universAAL was tested under real-life conditions with more than 5000 users across Europe. The platform architecture permits universAAL-enabled applications and hardware drivers to communicate with each other independently from which node they reside in. This happens automatically within the same network. For nodes in different networks, it is possible to establish bridged or multi-tenant connections [13], with direct gateways or RESTful APIs. This flexibility allows deploying universAAL-based solutions in multiple configurations.

Communication between applications and sensors happens through three different buses: An event-based bus for sharing contextual information, a request-based bus for on-demand execution and information retrieval, and a broker-managed bus that allows to define abstract user interfaces for different modalities. The messages and members of the buses are described semantically using the domain ontologies at hand. This way, applications and sensors only need to describe what they provide and what they require from others, instead of making them explicit. There is no need to specify recipients, connections nor addresses explicitly. The platform also includes a collection of so-called Managers. These dedicated applications provide advanced features such as semantic data storage or specific sensor drivers, among many others. Some of these managers are used in the INTER-Health pilot, such as drivers for the sensors or the REST endpoint.

C. Bodycloud

BodyCloud is a software as a service (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 [9]. Fig. 4 shows a high-level BodyCloud architecture 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 also delivering Cloud services via sensor-rich mobile devices.

Bodycloud has been used to support research prototypes in diversified application domains including physical rehabilitation [14], activity monitoring of healthy subjects [15] and community-scale cardiac monitoring.

The BodyCloud approach is based on the following four main decentralized components (or sides): Body, Cloud, Viewer, Analyst:

- The Body-side is the component, currently based on SPINE Android [16] to monitor an assisted living through wearable sensors also collecting data in the Cloud by means of a mobile device.
- The Cloud-side is the component, currently implemented atop Google App Engine, that provides fully support for specific applications through data collection, processing, analysis and visualization.
- The Viewer-side is the Web browser-enabled component able to visualize the output of data analysis through advanced graphical reporting.
- The Analyst-side is the component that supports the development of BodyCloud applications.

The core of the BodyCloud architecture is the Cloud-side that offers high-level Web-based programming abstractions for the rapid prototyping of Cloud-assisted BSN applications: group, modality, workflow, and view. A group formalizes a specific application which manipulates a specific BSN data source. A modality formalizes a specific interaction between the BodyCloud and Viewer-sides within a group. It specifies the input data, the actions to be performed on the input data, and the output data. A workflow formalizes an analysis process, producing output data from input data.

III. INTER-IoT INTEGRATION APPROACH

A possible solution to face the interoperability issues among different IoT platforms has been developed within the INTER-IoT project [6] whose main ambition is the design of a framework for interoperability, interconnection and integration between two or more heterogeneous IoT platforms. The project is part of the IoT European Platforms Initiative aiming at the definition of a common and homogeneous IoT environment at European level.

A. Layer-oriented approach

INTER-IoT provides the first full-fledged methodological and technological suite to completely address the fundamen-
The suite is composed of three main building blocks as shown in Fig. 5: (i) Layer-oriented infrastructures (INTER-LAYER) to adapt heterogeneous peer layers (device-to-device, networking-to-networking, middleware-to-middleware, application services-to-application services, data and semantics-to-data and semantics); (ii) Interoperable open framework (INTER-FW) to program and manage integrated IoT platforms; (iii) engineering methodology and tools (INTER-METH) to drive the integration process of heterogeneous IoT platforms.

In particular, the use of the INTER-LAYER allows the integration of heterogeneous IoT platforms throughout a suitable layered approach:

- at the device level (D2D), it allows a fast growth of smart objects ecosystems, seamless inclusion of novel IoT devices and their interoperation with already existing, even heterogeneous ones;
- at the networking level (N2N), it allows the design and implementation of fully connected ecosystems, seamless support for smart objects mobility and information routing, considering Network Function Virtualization (NFV);
- at the middleware level (MW2MW), it allows a global exploitation of smart objects in large (even extreme) scale (multi-platform) IoT systems, seamless service discovery and management system for smart objects and their basic services;
- at the application service level (AS2AS), it allows the reuse and exchange (import/export) of heterogeneous services between different IoT platforms, even the definition of new INTER-IoT services;
- at the data and semantics level (DS2DS), it allows a common interpretation of data and information based on global shared ontology in order to achieve semantic interoperability between heterogeneous data sources.

B. MW2MW interoperability

To face the interoperability issue of the INTER-Health, we decided to implement the platforms integration at middleware layer using an Inter-Middleware approach and the MW2MW component developed within the INTER-IoT project. This choice has been mainly motivated by the following considerations:

- scalability of the solution - every platform can be integrated without any fundamental modification of the specific software components;
- ease of implementation - the integrator needs to know only few simple “recommendations” to self-develop few software middleware components and small changes to its own platform.

C. INTER-HEALTH integration architecture

The developed software architecture support the INTER-Health integration is shown in Fig. 6 and it is composed of the followings main blocks:

1) PWT integration and components: The Professional Web Tool is a software system based on a Software as a Service (SaaS) model. The Front End and RESTful part of the system have been developed using Microsoft .Net Core 2.0 and the Daemon using .Net 4.7 Framework. The software is structured by using a Model View Controller (MVC) architectural pattern and the Data Access Layer (DAL) uses a Code First approach. The whole system is deployed in a Windows Server 2018 using Internet Information Server as a web server and Microsoft SQL Server 2016 as a relational database engine to store the data of the patients. When a doctor creates a new patient on the PWT it is stored locally and a set of requests to the REST
API of INTER-LAYER are performed. One request to create the mobile device associated with the patient and another request to define the PWT as a client for the information that this new device will produce. The Daemon associated is executed periodically (with a configurable time) and his goal is to call INTER-LAYER for download new available information if any. To do that, the daemon executes a request to the PWT RESTful API that knows how to communicate with INTER-LAYER using his RESTful API. It downloads, parses and stores the data in the local database. The first time the system is executed after a deployment, the PWT does some requests to the INTER-LAYER to be sure that the devices of UniversAAL used by the doctors are well registered and that the PWT is in the list of clients interested in that information. That information is also synchronized with the requests made from the Daemon.

2) UniversAAL integration and components: The existing infrastructure of universAAL that needs to be integrated consists on a set of universAAL-enabled software. A pair of smartphones run a tailor made application to pair to and receive data from weight scales and blood pressure sensors through Bluetooth. This application embeds the Android version of the universAAL core middleware [8]. This middleware instance connects to a server-based universAAL instance through its REST API. This universAAL server instance runs in a Karaf OSGi environment inside the same server machine as the rest of the solution. Because the server and the pre-assigned smartphones are located in the same premises and connect to the same private network, security is strengthened by these limitations. The integration through INTER-IoT is achieved thanks to a software component called “Bridge” at the MW2MW layer. This universAAL bridge takes care of translating the communication between the universAAL platform and the INTER-MW interfaces. At a user-facing level, the smartphone application allows the doctors using it to select their identifier when performing a measurement with any of the connected devices.

3) Bodycloud integration and components: To make the integration of Bodycloud we developed another “Bridge” to receive/forward messages from/to integrated platforms also carrying out preliminary operations, such as the syntactic messages translation. The Bodycloud side, also communicates through several devices (i.e., Blood Pressure, Weight Scale, Bracelet) equipped with Bluetooth Low Energy wireless interfaces through an Android based smartphone application named BodycloudApp. In this way, data measured from the devices can be acquired from the Bodycloud platform and forwarded to the INTER-IoT MW2MW layer whose components are depicted in Fig. 6.

IV. RESULTS

A. Pilot deployment

The INTER-Health pilot allows the conduction of an experimental nutritional consulting to reduce health risk factors, at the basis of major chronic diseases, such as incorrect lifestyles which are typically characterized by both high-caloric diet and the lack of an adequate physical activity. In such a way, the pilot involves a group of about 200 patients who want a medical support to improve their lifestyle.

Patients can be constantly monitored through a set of wireless wearable devices such as bangles, pedometers and heart rate monitors communicating through standard communication technologies (i.e., Bluetooth for medical devices and wearable sensor nodes); moreover, they have been equipped with smartphones, acting as interoperable gateways [17], toward a cloud repository to be accessed by experts in the specific field, such as doctors, nutritionists and personal trainers, in order to constantly monitor and change the user behaviours. The following objective and subjective measures have been detected through the use of such specific devices:

- weight with weekly frequency;
- blood pressure, only for those patients that, at the first nutritional counseling, had normal-high pressure values [systolic pressure $\geq 130$ and / or diastolic pressure $\geq 85$] with daily frequency, morning and evening;
- physical activity (number of steps and duration of physical activity practice) with daily frequency;
- eating habits and the practice of physical activity twice a week (by online questionnaire).

The study, non-invasive and without risk to health has been conducted by the Nutritional Unit (NU) of the Department of Prevention of the Complex Structure of Food, Hygiene and Nutrition of the fifth Local Health Unit of the Italian department of Turin (ASL TO5).

During the experimentation, the effectiveness, in terms of lifestyle improvement indexes, of the novel system has been evaluated with respect to the current “manual” monitoring performed by conventional healthcare centers.

The presented observational study involved subjects divided into two groups: a group called the Control Group (CG), represented by the patients involved only in the traditional nutritional consulting, and an Experimental Group (EG), represented by the patients that will be involved in the experimental nutritional counseling. In particular, the CG consists of 100 patients (80 females and 20 males) presenting an average age of 47 years while the EG consists of the same number of patients with a similar sex distribution (67 females and 33 males) and average age (46 years).

During nutritional counseling, the NU collected and monitored a set of patients data: anthropometric (i.e. weight, height, body mass index, blood pressure, waist circumference), clinical and dietary history (i.e. eating habits and physical activity) for both control and experimental groups. All the collected data have been stored in the electronic health records (EHRs) of the patients and after the first clinical visit, the health status has been constantly monitored through the INTER-Health technological platform. In particular, the nutritional counseling has been performed every three months for the CG and every six months for the EG.

B. Key Performance Indicators: description and measurement

In this section, the key performance indicators (KPIs), specifically designed to assess the success of the pilot deployment, are described to show in which way the efficiency
and productivity of the overall system is going to be improved through the use of the INTER-IoT components.

In particular, we focused our analysis on the following main indicators:

- Average BMI improvement
- Average waist circumference improvement
- Chronic diseases risk reduction
- Physical activity (minutes of activity) improvement
- Average eating habit improvement
- Dropout rate (patients who leave the experimentation)

Fig. 7 shows the obtained results after the first six months of experimentation testing the integrated platforms on the EG and making the comparison with the CG without any INTER-Health support. In particular, it is possible to observe that the apparent increase in the percentage of overweight patients is due to the notable decrease of obese patients which losing weight become overweight. Although both CG and EG experienced a comparable decrease in weight and high risk chronic diseases, the dropout rate is drastically decreased from the 45% of the CG to only 5% in EG testifying the interest of the patients in being constantly monitored through the new technological integrated platform that also assists them and motivates them in the periodic completion of the nutritional and habits questionnaires.

All subjects started to practice a correct physical activity because they have been constantly motivated through daily advises suggested by the software application installed on their mobile smartphones.

Regarding the eating habit improvement, we verified through the filled electronic questionnaires that all subjects consume 3 main meals a day and 85% of subjects consume 5 portions of fruit and vegetables.

Other interesting KPIs have been designed to measure the time spent by the users in using the developed software tools; in particular we verified that the average daily usage of the BodyCloud mobile application is around 10 minutes and the average time in using the PWT application from the doctors is about 2 hours a day.

V. CONCLUSIONS

This work presented the first results of the novel INTER-Health use case through which it is possible to provide, with reduced effort, new assisted living healthcare services thanks to the interoperability between different and already developed IoT-based healthcare platforms. The IoT platforms integration has been implemented and tested by following the INTER-IoT approach and all the new components have been described to highlight the ease of the integration process.

The obtained results on real group of patients confirmed how the INTER-Health framework overcomes the traditional methods in the relationship between doctor and patient making easier the interaction, increasing the number of patients that can be assisted and drastically reducing the dropout rate of patients leaving the pilot. Finally, it provides more responsive and effective nutritional advice services extending preventive action, in real time, to a larger population.

ACKNOWLEDGMENTS

This work has been carried out under the framework of INTER-IoT, Research and Innovation action - Horizon 2020 European Project, Grant Agreement #687283, financed by the European Union.

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