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A Web platform for interconnecting body sensors and improving health care

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Abstract

The Internet of Things (IoT) is a paradigm in which smart objects actively collaborate among them and with other physical and virtual objects available in the Web in order to perform high-level tasks for the benefit of end-users. In the e-health scenario, these communicating smart objects can be body sensors that enable a continuous real-time monitoring of vital signs of patients. Data produced by such sensors can be used for several purposes and by different actors, such as doctors, patients, relatives, and health care centers, in order to provide remote assistance to users. However, major challenges arise mainly in terms of the interoperability among several heterogeneous devices from a variety of manufacturers. In this context, we introduce EcoHealth (*Ecosystem of Health Care Devices*), a Web middleware platform for connecting doctors and patients using attached body sensors, thus aiming to provide improved health monitoring and diagnosis for patients. This platform is able to integrate information obtained from heterogeneous sensors in order to provide mechanisms to monitor, process, visualize, store, and send notifications regarding patients' conditions and vital signs at real-time by using Internet standards. In this paper, we present blueprints of our proposal to EcoHealth and its logical architecture and implementation, as well as an e-health motivational scenario where such a platform would be useful.

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Keywords: Internet of Things; IoT; Health care; e-health; IoT middleware; EcoHealth

1. Introduction

Recent technological improvements in wireless communications, low power processors, and electronic devices are making the *Internet of Things* (IoT)[1] a reality. In the IoT vision, every single object on Earth can be identified, addressable, controlled, and monitored via Internet. These smart objects would be able to communicate with each other

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and with other physical and virtual resources available in the Web, thus providing information about the environment where they are deployed and value-added functionalities for end-users. The wide dissemination of IoT has shown its potential to produce a considerable impact in the daily lives of human beings. This paradigm has been increasingly employed in applications from several real-world domains, such as domotics, ambient assisted living (AAL), energy, transportation, and environmental and urban monitoring. Several everyday objects are being "computerized" and equipped with network interfaces, e.g., washing machines, TVs, lamps, exercise bikes, heating/cooling devices, etc.

One of the application domains that can benefit from IoT solutions is *e-health*, which can be defined as the health care practice supported by electronic devices and information and communications technologies and that can include electronic medical records, electronic prescriptions, remote monitoring, and health knowledge management[2]. In the e-health context, wireless *body sensors* are small biomedical devices that are placed on the human body or are hidden under clothing[3]. These devices have wireless capabilities in order to allow increasing patient comfort and mobility, thus not impairing his/her normal activities while monitoring his/her health status regardless his/her location. In this perspective, such devices they can improve the quality while reducing costs of medical services by paving the way for the development of advanced, innovative health care monitoring applications[4]. Some noteworthy examples include remote monitoring of patients with chronic diseases and in AAL[5], as well as patient-centric prevention and treatment.

As smart objects, wireless body sensors can be accessed, controlled, and monitored via Internet. This feature opens up the possibility of providing an inexpensive and continuous real-time monitoring of vital signs measurements provided by body sensors attached to patients. Therefore, it is possible to achieve faster detection of emergency situations (and hence a faster medical care) and to improve medical diagnosis elaborated by doctors. Furthermore, with capabilities of smart objects, body sensors can easily communicate with each other, so that a given body sensor can use information provided by another one, thus increasing quality of the provided information and decision-making accuracy. On the other hand, considering body sensors as smart objects introduces some challenges. The major one is regarding interoperability among such smart objects, as it is necessary to seamlessly deal with a myriad of heterogeneous devices from several manufacturers, each one providing a different interface to communicate with the devices, thus creating operational barriers to use them in a holistic way[6]. Moreover, it is necessary to handle a large amount of sensible data continuously transmitted through the network, thus arising security and privacy issues.

In order to take advantage of the benefits brought by the IoT paradigm in the e-health scenario while addressing the aforementioned challenges, we introduce EcoHealth (*Ecosystem of Health Care Devices*), a Web middleware platform for connecting doctors and patients using attached body sensors. This platform is able to integrate information obtained from heterogeneous sensors in order to provide mechanisms to monitor, process, visualize, store, and send notifications regarding patients' conditions and vital signs at real-time by using Internet standards. EcoHealth is aligned with the *Web of Things* (WoT) paradigm[7], which envisions using existing Web technologies and protocols to enable the inclusion of physical devices in the digital world, so that their data and services can be (re)used in different applications as any Web resource[8], thus being an enabler technology for effectively realizing the IoT vision[9]. By being aligned with WoT, EcoHealth design and implementation are based on REST (*REpresentational State Transfer*)[10] principles and rely on current Web standards and protocols. In this paper, we give an overview about how middleware platforms can be an enabler technology for the e-health scenario and present blueprints of our proposal to EcoHealth.

The remainder of this paper is organized as follows. Section 2 presents an e-health scenario with some challenges that motivate the use of IoT middleware platforms. Section 3 introduces EcoHealth and describes its logical architecture and some implementation details. Section 4 presents an application scenario where EcoHealth could be used. Section 5 briefly discusses related work. Finally, Section 6 contains final remarks and directions to future works.

2. Background

2.1. A motivational e-health scenario

Nowadays, many e-health technologies are available in industry. Some of them have been simplified and embodied in daily life to assist exercise routines for athletes or to monitor health conditions of people that need continuous assistance, as the elderly and impaired people, for example. Body sensors or sensor units integrated to watches, in conjunction with mobile applications and other personal devices, allow real-time data monitoring to improve medical care of patients. Information provided by these devices can be related to measures of heartbeats per minute, temperature of parts of the human body, blood pressure, and other vital signs. The heartbeat rate is an essential vital sign, used to identify several health problems that may affect a patient. If the heartbeat rate is either too high or too low during a significant period of time or it changes abruptly, the patient might be in an emergency situation and proper medical care might be necessary. The heart can also be monitored by using an electrocardiogram (ECG) sensor capable of measuring the variation of electrical potentials generated by heart's activity. Similarly, the patient's blood pressure is also an important vital signal that can be continuously monitored. A low enough blood pressure may cause faints, whereas high blood pressure can cause headaches, dizziness, chest pains and other symptoms. Therefore, all of this information aligned with the patient's medical profile (e.g., if (s)he is smoker and/or obese, his/her diseases and/or allergies, previous medical events/diagnosis, etc.) can be very valuable in the hands of a doctor, so that medical assistance can be notified to help the patient at any sight of emergency. The body temperature is also an important measurement that can provide valuable information for doctors. A high temperature normally indicates that the patient is ill and needs medical care. In addition, patients galvanic skin response (sweating) can also be monitored in order to identify stressful situations, anxiety or even dehydration. Furthermore, the patient position (standing/sitting, supine, prone, left, and right) measured by an accelerometer is an important information to be monitored, mainly for elders. For instance, a rapid change from standing to the prone position coupled with low heartbeat rate may indicate that the patient has fainted. Another possible situation that may arise is a very steep variation of acceleration of patients body. If the patient was in a car, for instance, (s)he may have been involved in a car accident.

All of the previously mentioned body signs can be continuously measured so that this information can be used to provide urgent medical assistance to patients, especially those that belong to risk groups and need constant attention. The information obtained from each body sign can also be combined to describe more complex situations that need proper attention and recorded as historical, aggregated data about the patient. Moreover, doctors can make use of all this data in order to improve their diagnosis and provide better care for the patients.

In this scenario, the existence of several types of body sensors developed by different manufacturers is noteworthy. Therefore, a software platform would be suitable for integrating this myriad of heterogeneous devices in order to make the large amount of data collected by them available at the Internet. With the use of such a platform, the provided high-level interfaces allow accessing the heterogeneous body sensors in a transparent way, thus hiding their specificities from end-users (e.g., doctors) and/or medical applications that make use of them. Furthermore, the dynamic discovery and integration of new devices into the environment and the proper management of their state and location is an important requirement to be tackled. These requirements can be properly addressed by making use of an IoT *middleware platform*, as discussed in Section 2.2.

2.2. *IoT middleware platforms*

IoT environments are typically characterized by a high degree of hardware and software heterogeneity, encompassing several devices with different capabilities/functionalities and running different network protocols. In order to enable the creation of value-added IoT applications by combining resources available at the Internet, it is necessary to provide high-level models able to offer abstractions over physical devices and services, as well as several levels of transparency and interoperability. Furthermore, it is necessary to develop a more standardized and scalable approach to integrate smart objects in the Web. Such an integration pervades multiple levels. In a lower level, it is necessary to seamlessly integrate a myriad of heterogeneous physical devices with each other. At an intermediate level, data provided by the devices need to be easily made available at the Internet, thus providing value-added services on the top of the sensing functionalities. Finally, at a higher level, a standardized programming model can provide the ultimate integration in terms of transparently assembling and transforming information from sensing devices without requiring any specific knowledge regarding the specificities of these physical devices and the networking environment [8].

In this perspective, *middleware platforms* have arisen as a promising solution for providing interoperability capabilities and managing the increasingly variety of IoT devices associated with the applications and end-users that use data provided by them [11,12]. An IoT middleware is a software platform between applications and the underlying (communication, processing, and sensing) infrastructure that offers standardized means to access data and services provided by the smart objects through a high-level interface [12]. Such a platform also promotes the reuse of generic services that can be composed in order to facilitate the development of value-added applications and to alleviate developers from the burden of dealing with specificities of physical devices and the networking environment. Finally, IoT middleware platforms must support runtime adaptation under dynamic conditions of the environment where applications make use of the deployed heterogeneous devices.

The main requirements and functional elements of a middleware platform in an IoT environment encompass:

(i) a scalable *interoperability support* for the myriad of heterogeneous devices to enable smart objects (things) to communicate with users, Internet services, and among each other;
(ii) efficient *device discovery and management* mechanisms, which allow dynamically integrating new devices into the IoT environment, as well as to manage state and location of these devices;
(iii) *context-awareness* capabilities for managing and processing context data;
(iv) an efficient *dynamicity support*, as IoT environments are inherently dynamic and applications might be reconfigured at runtime according to changes in such environments;
(v) the *management of large amounts* of data collected from the smart objects and that must be made available for applications and/or end-users;
(vi) issues related to *security and privacy* in terms of confidentiality, authenticity, and integrity, which are important concerns mainly in critical applications, and;
(vii) the provision of a *high-level interface* for accessing the heterogeneous objects in a transparent way, thus hiding the specificities of the integrated devices from applications and/or end-users.

The development of middleware platforms for IoT is a recent research field to which academy and industry have drawn attention. Literature reports some initiatives [13,14,15] for conceiving and implementing IoT middleware platforms to address challenges such as the seamless integration of a broad range of heterogeneous devices and the provision of high-level mechanisms for enabling developers to build IoT applications by using data provided by these devices. However, in general these proposals have not still achieved a mature development state. They reveal gaps that require additional research efforts, such as: (i) the construction of robust, fault-tolerant infrastructures that are able to manage and process data gathered from several integrated smart objects; (ii) the management of uncertainties and conflict resolution; (iii) an adequate support for adapting applications under dynamic environmental conditions, and; (iv) the minimization of the overhead of security functions into the middleware platforms themselves.

3. EcoHealth: Ecosystem of Health Care Devices

In this section, we describe the logical architecture and implementation of EcoHealth, our Web middleware platform for integrating devices for e-health.

3.1. Architecture

In order to achieve its goals, EcoHealth is organized in several loosely coupled modules (middleware services) that compose its logical architecture, as illustrated in Fig. 1.

The *Devices Connection Module* aims to integrate physical devices (body sensors) to the platform. Device manufacturers develop *customized drivers* for each specific type of device platform according to the EcoHealth API. These drivers play an important role in terms of integrating devices from different providers since the heterogeneity of such devices is abstracted away from users and applications. In EcoHealth, there are two types of drivers, namely *active* and *passive* drivers. *Active drivers* obtain data from devices by continuously polling them (i.e., by making periodical data requests), even when the value of the information provided remains the same. In turn, *passive drivers* wait for notifications from the device's API triggered whenever there are changes in the data values. EcoHealth drivers are built upon REST principles [10] and they rely on current Web standards and protocols, such as HTTP and URIs, thus complying with the WoT paradigm. In WoT, the HTTP protocol is not only used as a communication protocol to carry data formatted, but it is also used as the standard mechanism to support all interactions with smart objects, which are viewed as Web resources. Therefore, the main operations defined in HTTP (i.e., the GET, POST, PUT, and DELETE verbs) provide a well-defined interface to expose the functionality of objects on the Web and the use of the HTTP protocol eliminates compatibility issues between different manufacturers, proprietary protocols, and data formats. After obtaining data (called *feeds* in the IoT scenario) from the integrated devices, the drivers structure them by using

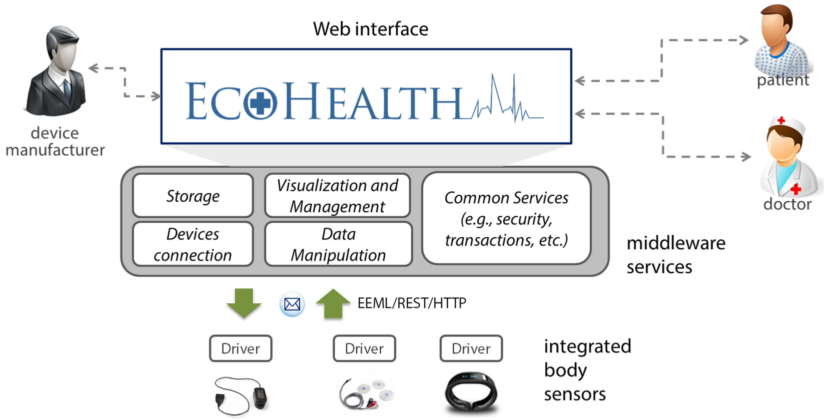

Fig. 1. EcoHealth architecture.

the Extended Environments Markup Language (EEML)[16], an XML-based language for describing data obtained from devices in a specific context (in this case, human body vital signs). Finally, such structured data are sent to EcoHealth via HTTP PUT requests in order to be registered at the platform by the *Data Manipulation Module*.

The *Visualization and Management Module* provides a Web interface for enabling users (doctors, patients, and system administrators) to manage all information about patients, body sensors attached to them, medical records, notifications, etc. By using such an interface, doctors can visualize current patients' information collected by body sensors, as well as historical information stored at the platform. Moreover, doctors can create *triggers*, which are event-based notification mechanisms that will inform them about critical conditions on the measured vital signs (*feeds*). For instance, consider a feed associated with the blood pressure of a given patient. In this case, a doctor can create a trigger to notify him/her whenever the measured blood pressure is above 160/100 mmHg.

The *Storage Module* encompasses a relational database and a file system for storing all data used in EcoHealth, such as medical records, historical data from body sensors, notifications, patient-related information, and information about emergency services. It is noteworthy that this module can use a Cloud Computing infrastructure to store relational data and files, thus providing quality attributes such as reliability, availability, and scalability to the platform.

The *Common Services Module* consists of infrastructure services provided by the platform, such as security (in terms of user authenticity, confidentiality, and integrity), notifications, etc. Considering the critical nature of data stored in EcoHealth, security is a very important concern. Therefore, the platform's authorization scheme will ensure that only the assigned doctor can access a patient's record and the data provided by his/her body sensors. It is also quite important to encrypt data transmitted by sensors via Internet in order to ensure their confidentiality and integrity.

Given the features of its modules, EcoHealth envisions three profiles of potential stakeholders, namely: (i) *device manufacturers*, which develop device drivers compliant with the EcoHealth API; (ii) *doctors*, which continuously monitor vital signs of patients via EcoHealth and use information available at the platform to improve diagnosis and response in emergencies, and; (iii) *patients*, which provide information to the platform via attached body sensors.

3.2. Implementation

Fig. 2 illustrates the main technologies used for implementing the modules that compose the logical architecture of EcoHealth. The platform is implemented in the Java programming language and it is deployed on a JBoss application server, which allows an easy management of distributed components and large data streams, as typically observed in IoT environments. Users can access the main functionalities offered by EcoHealth via the Web interface provided by the *Management and Visualization Module*, which is implemented with the JavaServer Faces (JSF) technology.

Once the connection between EcoHealth and the integrated devices is enabled by the respective drivers (through the *Devices Connection Module*), such drivers send data obtained from the devices to the platform through HTTP PUT requests, thus providing a RESTful interface for clients (either human or applications). In order to support such a RESTful approach in EcoHealth, we have adopted the RESTEasy implementation for the REST architectural style and the Java API for RESTful Web services (JAX-RS). As we have mentioned in Section 3.1, data (feeds) produced by

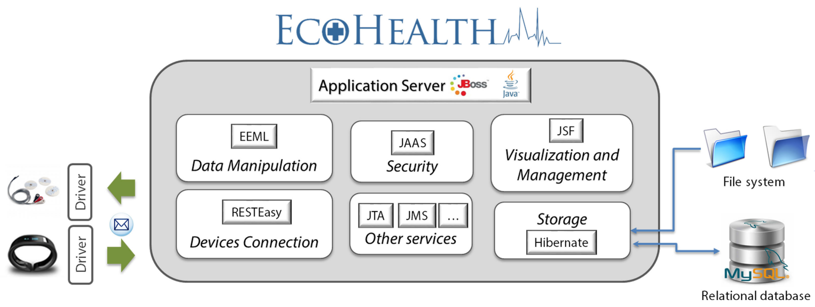

Fig. 2. Technologies used for implementing the EcoHealth modules.

devices are structured by using the EEML protocol and are handled by the *Data Manipulation Module* to be effectively registered in a MySQL relational database by using the Java Persistence API (JPA) specifications implemented in the Hibernate framework. Finally, the *Security Module* allows controlling user authenticity, confidentiality, and integrity by using the Java Authentication and Authorization Service (JAAS) specifications implemented in the JBoss server.

4. Application: Monitoring heartbeat rate and blood pressure

With the current habits of part of the population and the consequent increasing on the risk of cardiovascular diseases, heartbeat rate and blood pressure have been important vital signs used to identify a variety of health problems that may affect a patient. ECG sensors for measuring heartbeats have been one of the most commonly used medical tests in modern medicine due to its utility in the diagnosis of several cardiac pathologies. On the other hand, monitoring the blood pressure is important especially for hypertensive people, as high blood pressure can lead to serious problems, such as heart attack. Therefore, a continuous monitoring of such variables is quite important as a heart problem might not always show up on the ECG and high blood pressure usually does not have any symptoms. Moreover, such a monitoring can enable prevention procedures by improving medical diagnosis, bring proactive responses to possible emergency conditions, and even help to reduce the number of deaths due to cardiovascular diseases.

In this scenario, EcoHealth can be used to integrate cardiovascular-targeted devices and to monitor variables at runtime, as well as to trigger alert messages in case of abnormal conditions. We have chosen to monitor heartbeats and blood pressure of an individual, each measure registered at EcoHealth as feeds. In order to collect these measures, we have used an ECG sensor with electrodes fixed on the patient's chest and a blood pressure oscillometric sensor. These sensors were connected with the Arduino Uno open platform[17] coupled with a Cooking Hacks e-Health Sensor shield[18], which enables the integration of a variety of biometric sensors. In addition, we have developed an active driver developed to Arduino Uno that collects data measured by the sensors and sends them to EcoHealth.

EcoHealth can process data obtained from the sensors and present them in an efficient, useful way to doctors. Therefore, historical data regarding the measured heartbeat rate and blood pressure are displayed as a chart highlighting changes along the day and drawing attention to important occurrences, as illustrated in the screenshot from the EcoHealth Web interface shown in Fig. 3. Finally, triggers associated to these feeds can be created in order to send alert messages to doctors when the measured heartbeats are greater than 160 BPM (beats per minute) and/or the measured blood pressure is greater than 160/100 mmHg, thus indicating possible critical conditions for the patient.

5. Related work

Recent work in the literature has discussed the potential of IoT for improving health care applications, as well as the challenges and research opportunities in this scenario[2,4,6]. As we have mentioned, e-health scenarios are typically characterized by a high heterogeneity in terms of the devices to be integrated, so that IoT middleware platforms would be the promising solution for paving the way for interoperability among such devices and applications[19]. In this section, we briefly present some existing middleware platforms for IoT-based e-health as alternatives to our platform.

Sebestyen et al.[4] introduces CardioNet, a Web platform dedicated to the treatment of patients with cardiovascular diseases by using a Cooking Hacks e-Health Sensor shield in conjunction with the Arduino Uno platform (similarly

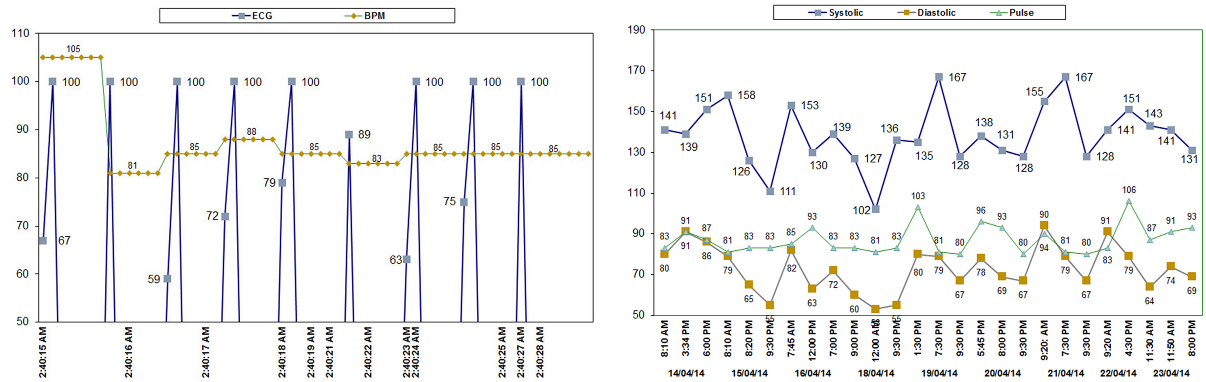

Fig. 3. Charts from EcoHealth Web interface showing the measured heartbeat rates (left) and blood pressure (right).

to the scenario presented in Section 4) to measure parameters such as ECG, blood pressure, temperature, oxygen level, and heartbeat rate. Besides the remote monitoring of patients, the CardioNet Web portal also supports online consultations and administration of hospital activity.

VIRTUS [19] is a middleware platform developed by using the Java programming language and structured upon the OSGi dynamic component model for ensuring portability, modularity, and dynamic composition of modules and heterogeneous biomedical sensors, as well as it uses the XMPP instant messaging protocol in order to provide fast, scalable communication. Data collected by sensors are received by the patient's smartphone that structures them in the XML format and sends them to VIRTUS by using the XMPP protocol. While providing feedback to the patient in his/her smartphone, VIRTUS allows processing such received data to present them more accurately, e.g., by providing daily reports with all information useful for doctor evaluation and diagnosis.

μWoTOP (*micro Web of Things Open Platform*) [20] is a middleware architecture that facilitates the integration of heterogeneous sensors. The key elements of μWoTOP are: (i) a heterogeneous set of wireless biometric sensors (e.g., heart monitors, accelerometers, body thermometers, etc.), which are integrated to the platform via adapters, similarly to drivers in EcoHealth; (ii) gateways, which are responsible for collecting data from the integrated sensors and transmitting urgent notifications to the interested stakeholders in case of critical events, and; (iii) consumer software applications. Furthermore, μWoTOP complies with the WoT paradigm by relying on current Web technologies (e.g., HTTP, URIs) and the REST architectural style, and it provides a development environment for easily reusing and sharing resources available at the platform. Therefore, consumer applications can make use of sensor data via RESTful interfaces as sensors are modeled as information resources by following the REST principles.

The abovementioned proposals have several common purposes with EcoHealth mainly regarding the goal of seamlessly integrating heterogeneous body sensors and the provision of value-added information from these sensors to doctors and/or medical applications. Furthermore, it is possible to observe some sort of trend to use of cloud infrastructures, which can ensure properties such as scalability, availability, performance, and on-demand resource usage. Finally, the WoTOP platform is the one that share more ideas with EcoHealth as both platforms rely on well-established Web standards and provide a RESTful API that enables applications to easily make use of available sensor data.

6. Final remarks

This paper has introduced EcoHealth, a Web-based IoT middleware platform that supports the connection of patients, heterogeneous body sensors, and doctors. EcoHealth aims to improve health monitoring and better diagnosis for the patients with real-time data control, visualization, processing, and storage functionalities. The EcoHealth design is based on several well established Web technologies in order to standardize and simplify the development of applications in the IoT context, thus minimizing compatibility and interoperability issues between manufacturers, proprietary protocols, and data formats. We have also presented blueprints of our proposal to EcoHealth and its logical architecture and implementation, as well as an e-health scenario where such a platform would be useful.

EcoHealth is an ongoing project and its implementation is still under work. After finishing the implementation of a prototype of the platform, we will further validate it with real-world case studies, as well as quantitative and qualitative evaluations. Moreover, we intend to provide support for the development of different applications on the top of EcoHealth in order to enable them to use information available at the platform. Such applications can be developed as Web mashups[21], a technology that has been advocated as suitable to the IoT paradigm and that consists of ad-hoc applications created from the composition of different types of information provided by several sources.

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