Environmental Modelling & Software 78 (2016) 1–15

Contents lists available at ScienceDirect

Environmental Modelling & Software

journal homepage: www.elsevier.com/locate/envsoft

Future Internet technologies for environmental applications

Carlos Granell [a,1], Denis Havlik [b,*], Sven Schade [c], Zoheir Sabeur [d], Conor Delaney [c], Jasmin Pielorz [b,2], Thomas Usländer [e], Paolo Mazzetti [f], Katharina Schleidt [g], Mike Kobernus [h], Fuada Havlik [b], Nils Rune Bodsberg [i,3], Arne Berre [j], Jose Lorenzo Mon [k]

[a] Universitat Jaume I of Castellón, Spain
[b] Austrian Institute of Technology (AIT), Austria
[c] European Commission, Joint Research Centre (JRC), Italy
[d] University of Southampton IT Innovation Centre, Electronics and Computer Science, Faculty of Physical Sciences and Engineering, United Kingdom
[e] Fraunhofer IOSB, Germany
[f] National Research Council of Italy, Institute of Atmospheric Pollution Research, Italy
[g] Umweltbundesamt GmbH, Austria
[h] Norsk Institutt for Luftforskning (NILU), Norway
[i] Norwegian Science and Technical University (NTNU), Norway
[j] SINTEF, Norway
[k] Atos Spain, Spain

A R T I C L E I N F O

Article history:
Received 26 November 2014
Received in revised form
15 December 2015
Accepted 16 December 2015
Available online xxx

Keywords:
Environmental informatics
Environmental observation web
Future internet
Cloud computing
Internet of things
Big data
Environmental specific enablers
Volunteered geographic information
Crowdtasking

A B S T R A C T

This paper investigates the usability of Future Internet technologies (aka "Generic Enablers of the Future Internet") in the context of environmental applications. The paper incorporates the best aspects of the state-of-the-art in environmental informatics with geospatial solutions and scalable processing capabilities of Internet-based tools. It specifically targets the promotion of the "Environmental Observation Web" as an observation-centric paradigm for building the next generation of environmental applications. In the Environmental Observation Web, the great majority of data are considered as observations. These can be generated from sensors (hardware), numerical simulations (models), as well as by humans (human sensors). Independently from the observation provenance and application scope, data can be represented and processed in a standardised way in order to understand environmental processes and their interdependencies. The development of cross-domain applications is then leveraged by technologies such as Cloud Computing, Internet of Things, Big Data Processing and Analytics. For example, "the cloud" can satisfy the peak-performance needs of applications which may occasionally use large amounts of processing power at a fraction of the price of a dedicated server farm. The paper also addresses the need for *Specific Enablers* that connect mainstream Future Internet capabilities with sensor and geospatial technologies. Main categories of such Specific Enablers are described with an overall architectural approach for developing environmental applications and exemplar use cases.

Software and/or data availability

Name of software Future Internet Generic Enablers (http://catalogue.fiware.org); Specific Enablers for Environment (http://catalogue.envirofi.eu)
Developers The FI-WARE and ENVIROFI Consortia.
Contact information Those interested should address individual project partners responsible of each specific enabler and/or application as indicated on the FI-WARE and ENVIROFI catalogue sites.
Hardware required Smartphone device for mobile applications; computer (farm) for the backend.
Software required Android or Internet browser for the GUI components; Linux or Windows OS (usually hosted on "the cloud") for backend.
Program language Multiple programming languages.

* Corresponding author.
E-mail address: denis.havlik@ait.ac.at (D. Havlik).
[1] Carlos Granell was affiliated with European Commission, Joint Research Centre during the project.
[2] Jasmin Pielorz was affiliated with Ubimet GmbH, Vienna during the project.
[3] Nils Rune Bodsberg was affiliated with SINTEF, Norway, during the project.

http://dx.doi.org/10.1016/j.envsoft.2015.12.015
1364-8152/

Availability and cost Users can access directly to the catalogue to download Generic and Specific Enablers, applications, technical documents and user manuals. Please note that not all enablers have the same status of implementation, maturity or user licensing.

1. Introduction

In the course of the past four decades, we have witnessed a continuous evolution of geospatial information technologies for the support of earth and environmental sciences (Budhathoki et al., 2008). Starting from enhanced Geospatial Information System (GIS) desktop solutions, via Spatial Data Infrastructures (SDIs) of varying maturity, we are moving towards innovative technologies to realise the next-generation Digital Earth vision (Goodchild et al., 2012). Now, the pervasive connectivity promised by the Cloud Computing paradigm, the Internet of Things (IoT) phenomenon, and Big Data innovations might lead to disruptive changes in the design and development of data-intensive applications (Douglas, 2001). In this article, we will refer to a set of related emerging technology and standards as the *Future Internet* (FI).

Environmental applications often process large collections of data sets. Earth Observation data, from sensors with ever-growing spatial, temporal and radiometric resolution, gets combined with complex environmental models and simulations at all scales. Until recently, such processing chains were unthinkable without domain-specific technology and tailored solutions to process and handle large data sets, and consequently of interest or affordable only for a small number of professionals and institutions. This situation may radically change in the not-so-distant future as Future Internet technologies excel at processing unformatted, scarcely populated, and uncertain data sets. Such data is rare in the orderly world of the “old” Environmental Informatics but omnipresent today due to the Internet, the improved connectivity of electronic devices, and the increasing role of citizen-generated data for many emerging environmental applications.

These ongoing trends trigger changes in the environmental sector. Research undertaken by the authors indicated that (especially governmental) environmental organisations are facing the following data stewardship challenges:

- How are we to address the increasing societal expectations and legal requirements for data gathering, processing and dissemination with limited budgets (in public sector) and resources?
- How can societal expectations for data quality be met while supporting an increasing number of citizen observatories (Volunteered Geographic Information) and citizen science initiatives without jeopardising existing business models and reputations?
- How can we harness data with varying degrees of quality from diverse sources including citizen observatories and public government sources without compromising the quality of our own results?

At the abstract level, the answer to these challenges is clear: (1) sensor data gathering, quality assurance, and dissemination has to be optimized; (2) the business models of all stakeholders must be adopted to a situation where data is abundant and cheap; and (3) model developers must learn how to deal with auxiliary observations of low -and even unknown-data quality. At the technological level, one part of the solution is provided by the Future Internet technology.

To make the best use of both, geospatial and Future Internet technologies, we have to investigate new directions for designing and developing environmental software applications. While Big Data challenges still have to be addressed within the environmental domain (Hampton et al., 2013; Chen and Zhang, 2014), we have to provide holistic, flexible and scalable solutions that apply to a wide audience and ultimately enable multi-disciplinary research that is requested by initiatives such as the Global System Science[4] and Future Earth.[5] It will be essential to cross the artificial boundaries between current sectors, interconnect already existing systems, and break technical as well as organisational barriers.

Anticipating these developments, Havlik et al. (2011) suggested a paradigm shift towards a data-centric Environmental Observation Web, where the output of processing and modelling services, as well as the data provided by humans and from hardware sensors are (almost) always modelled as observations. The Environmental Observation Web should account for semantically enriched content, modularized environmental simulations and content contributed by citizens. It shall enable the consumption, production and re-use of environmental observations in cross-domain applications. The design of a multi-style service-oriented-architecture was identified as a major challenge to facilitate existing generic Information and Communication Technology (ICT) solutions, enable robustness and scalability, and increase the interoperability between already existing systems (Usländer et al., 2010).

With this article, we present our experiences with the development of FI-enabled Environmental Observation Web specifications, services and applications. We summarise the technical challenges for the construction of an Environmental Observation Web, including the access to crowd-sourced environmental observations, handling of heterogeneous data sources, and data processing at varying aggregation levels. Furthermore, we outline our development methodology together with the resulting architecture and service specifications. This work provides a crucial step in combining generic Future Internet technologies with functionality that is specific to earth and environmental sciences.

The remainder of this article is organised as follows: Section 2 introduces the key elements of the Future Internet processing paradigm, from the Environmental Informatics perspective. Section 3 outlines key characteristics of an FI-enabled environmental architecture. Examples of environmental use cases and actual application prototypes illustrating the advantages of the proposed architecture are shown in Section 4. Finally, Section 5 presents the key outcomes of our work and identifies follow-up research activities.

2. Relevant technologies and standards of the Future Internet

In 2011, the European Commission (EC) initiated an ambitious 5-year “Future Internet — Public Private Partnership” (FI-PPP[6]) programme. The FI-PPP programme aims to deliver economic benefits from fast to ultra-fast Internet based interoperable applications (EC, 2011). The high-level objectives of the FI-PPP are: (1) to improve key Information and ICT infrastructures of Europe's economy and society; (2) to foster a European-scale Internet-enabled market and service economy; (3) to propel the creation and provision of FI-enabled services and applications over and across domain sectors, businesses and stakeholders; and (4) to integrate and harmonize the relevant policy, legal and regulatory frameworks.

4 http://global-systems-science.org.
5 http://www.icsu.org/future-earth.
6 http://www.fi-ppp.eu.