Inria International program
Associate Team final report

Middleware for Sensor as a Service (SeaS)

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Associate Team acronym:	SeaS
Period of activity:	2010–2013
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1 Team Members

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[a] PhD thesis defended in Lille as part of the associated team
[b] PhD thesis defended in Oslo as part of the associated team

2 Collaboration Objectives

Along the three years of activity, the SeaS collaboration targeted to incrementally achieve the following objectives:

TASK 1, addressed during the first year of the collaboration, refers to the capability of composing hybrid sensors within a homogeneous service-oriented architecture. This objective therefore requires the integration of standard service descriptions and communication protocols at the sensor level and the definition of standard data collection and processing services at the network level. These services should be packaged as software components that could be reused across a large set of sensors. Both of these levels involve models are be exploited by a modelling studio for describing and implementing a WSN application.

TASK 2, addressed during the second year of the collaboration, aims at introducing more flexibility in the SeaS platform by covering issues related to the support of dynamic adaptation of the sensor and network services over time and depending on the application requirements. This objectives therefore requires the definition of deployment and reconfiguration services at the sensor level, while the network level will have to be extended with further services dealing with the adaptation strategies to apply according to the evolutions observed in the physical and virtual environments.

TASK 3, addressed during the third year of the collaboration, focuses on the development of a scalable data dissemination infrastructure for novel WSN Internet-based applications. This objective should therefore build on the two former objectives to provide reusable services dedicated to the dissemination and processing of collected data. This includes the support for distributed data storage and query services. This objective also considers issues related to data security and privacy in order to ensure the applicability of cross-domain sharing of hybrid sensors. The sensor level should therefore integrate security and privacy services, while the network level should cover the robustness and dependability concerns of the data dissemination.

3 Scientific Achievements

In order to progress efficiently, the associated team has been structured into two task forces, whose results are reported below. Each task force obtained an excellent track of results by publishing joint papers and articles.

Reflecting Sensor as a Service: The Remora Component Model

This first task force, led by Amirhosein Taherkorki, focused on the design of a component model implementing for programming sensor nodes. Remora is a lightweight component model designed for *Wireless Sensor Networks* (WSNs), including other resource-constraint embedded systems. The strong abstraction promoted by this model allows a wide range of embedded systems to exploit it at different software levels from operating system to application [11, 13, 14, 15, 16].

Remora provides a very efficient mechanism for event management, as embedded applications are inherently event-driven. Remora components are described in XML as an extension of the *Service Component Architecture* (SCA) in order to make WSN applications compliant with the state-of-the-art componentization standards. Additionally, the C-like language for component implementation in Remora attracts both embedded system programmers and PC-based developers to programming for WSNs. Finally, Remora features a coherent mechanism for component instantiation and property-based component reconfiguration in order to facilitate lightweight event-based programming in WSNs.

The current version of Remora has been successfully deployed on the Contiki operating system. Principally, Remora can be used for application development on any WSN system software platform that is written in C language. To achieve that, the Remora runtime should be customized in such a way to efficiently use the features and services of the operating system. For example, the Remora runtime for Contiki is able to read the Contiki-generated events and translate them to corresponding application level events.

Packaging SeaS as reusable components: The DigiHome Service-Oriented Platform

The second task force, led by Daniel Romero, has been working on the definition of a software platform for demonstrating the integration of hybrid sensors. DigiHome exploits the SCA extensibility to incorporate the REST (*REpresentational State Transfer*) architectural style, and in this way leverages on the integration of multi-scale systems-of-systems (from WSN to the Internet) [6, 7, 8, 9, 16]. In particular, DigiHome detects adaptation situations by integrating context information using an SCA-based architecture. This architecture promotes the modularization of concerns and fosters the application of the REST principles by exploiting the SCA extensibility. The simplicity and data orientation of REST, combined with the SCA independence of implementation technologies, make DigiHome an attractive solution to deal with heterogeneity in terms of interactions.

The definition and application of ubiquitous bindings in the platform enable spontaneous communication by means of standard protocols (*e.g.*, UPnP and SLP), and furnish context provider selection (based on QoC attributes). On the other hand, the modularized architecture of DigiHome allows the definition of variants for the platform, called DigiHome objects, that can be deployed on resource-constrained devices. The functionality of these objects is exposed as services, accessible via several protocols, which can be accessed by clients that do not have to be part of the platform. Furthermore, the clear separation of concerns in the DigiHome architecture encourages the exploitation of WSNs for simple processing and local decision making. The suitability of our platform for context integration was evaluated with different discovery and context representations. Additionally, the platform applies CEP (*Complex Event Processing*) technology that detects application-specific situations.

We claim that the modularization of concerns fostered by DigiHome and materialized in a service-oriented architecture, makes it easier to incorporate new services and devices in smart home environments. The benefits of the DigiHome platform are demonstrated on smart home scenarios covering home automation, emergency detection, and energy saving situations.

4 Overview of the Activities

Meetings & Visits

In order to efficiently work together, we decided to organize regular meetings by Skype for each task force. In addition to these meetings, several physical visits have also been organized in order to discuss scientific and technological issues related to the objective of the collaboration, but also to investigate the submission of joint project proposals to the IST FP7 program. The objective of these submissions was to sustain the collaboration and to provide substantial resources to further develop our scientific contributions. In particular, during the period of activity, we submitted a STREP proposal, named OCTOPUSES, to the Call 5 and an IP proposal, named HARMONY, to the Call 7. Both of the proposal got a very good review score, but unfortunately they did not get funded by the European commission.

In addition to these visits, we also exploited the opportunity of meeting during conferences of the domain (*e.g.*, DAIS or Middleware) to spend some additional days on working on the objectives of the associated team. Finally, we also contributed to the organization of several workshops [1] and conferences [3, 4] in order to increase the visibility of the associate team and open our collaboration to external researchers.

5 Production

Publications

The following table summarizes the publications achieved by the members of the associated team. The detailed publications are listed in the end of this report.

Year	Workshop	Conference	Book Chapter	Journal	Editor	Talk	PhD thesis	Total
2010	2	2			1	1		6
2011	2		1	2	2		2	9
2012				2				2
Total	4	2	1	4	3	1	2	17

More specifically, the major publications of the associated team are the following articles:

1. A. Taherkordi, F. Loiret, R. Rouvoy, and F. Eliassen. *A Generic Component-based Approach for Programming, Composing and Tuning Sensor Software.* **Oxford – The Computer Journal, 54(2)**. 2011 [14]

2. D. Romero, G. Hermosillo, A. Taherkordi, R. Nzekwa, R. Rouvoy, and F. Eliassen. *The DigiHome Service-Oriented Platform.* **Wiley – Software: Practice and Experience (early view)**. 2012 [9]

3. A. Taherkordi, F. Loiret, R. Rouvoy, and F. Eliassen. *Optimizing Sensor Network Reprogramming via In-situ Reconfigurable Components.* **ACM – Transaction On Sensor Networks (TOSN)**, 9(2). 2013 [15]

Software

Two software platforms have been developed the task forces during the period of activity:

- The reference implementation of the REMORA component model is currently maintained and distributed by Amirhosein Taherkordi at the following URL: `http://folk.uio.no/amirhost/remora`;

- The DIGHOME platform is currently integrated in the ADAPT ADT project, which aims at building a demonstrator of the ADAM software technologies in the application domain of smart digital homes.

Problems

The associate team had to adapt to the occurence of several critical events along the period of activity. First of all, Amirhosein Taherkordi and Daniel Romero did successfully defended their PhD thesis in 2011. Given their role as task force leader, the dynamics of the collaboration temporarly suffered from this situation to recover from their leave. Secondly, Frank Eliassen—the Norwegian coordinator of the associate team—had a serious bike accident in September 2010. This accident kept him away from office during several months and he is only partially back on work for a few months. Finally, we failed to recruit a postdoc on the topic covered by the associated team. The orginality of this associate team is to combine software engineering, distributed systems and embedded systems. Althougth we selected a couple of qualified applicants, they prefered to withdraw their application and accept another offer. Under these specific conditions, the associate team managed to collaborate and obtain very good results, even if one could have expected a longer list of publications in 2012.

Opportunities

The third task is still under investigation as part of the associate team. More specifically, two PhD students are working on extensions of the results we achieved. These PhD students are co-supervised by Frank Eliassen, Roman Vitenberg, and Romain Rouvoy. In particular, Kashif Dar is currently working on an extension of the DigiHome platform to support the orchestrations of healthcare sensors and actuators according to prescriptions made by medical experts [2]. Navneet Pandey is currently working on the definition of a self-adaptive dissemination middleware that can adjust the throughput of data according to subcriptions made by consumers, while taking into account privacy concerns. A specific case study is currently under investigation with the University of Toronto (Canada) and relates to the challenge of energy performance monitoring in large-scale environments.

Beyond these topics, the associated team also initiated a new domain of research, known as *crowdsensing*, which consists in dynamically programming remote sensors to adapt their behavior to address mission-specific objectives. A PhD student in the ADAM research group is now working specifically on this topic.

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