Semantic middleware in Applications of the Internet of Things

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Abstract. Internet of Things (IoT) is an innovative trend in ICT where things of everyday use are wirelessly connected and controlled in innovative ways. The main aim is to increase quality of human life. IoT can communicate not only with things but also with web services and human beings. In that case we are talking about Internet of People, Things and Services (IoPTS). Semantic middleware LinkSmart is a software solution product for communication of entities in IoPTS. This solution was developed within the European research project called HYDRA and is further developed in subsequent EU R&D projects in which authors participate (Elliot, ebbits, Adapt4EE, INERTIA). An important part of the LinkSmart middleware is a semantic module enabling reusable description of particular entities of IoPTS. This module enables easy connection of new entities to a dynamic IoPTS environment and it also simplifies development of applications based on the LinkSmart middleware. This article describes irrelevant RD projects and author's contribution to them.

Introduction

Internet of Things (IoT) is an innovative trend where things of everyday use are wirelessly connected and controlled in an innovative ways. The overall aim is to make quality of human life better. IoT can communicate not only with things but also with web services and humans. In that case we are talking about Internet of People, Things, and Services (IoPTS). Semantic middleware LinkSmart is a software solution product for communication of entities in IoPTS. This solution was developed within the European research FP6 project HYDRA and is further developed in other FP7 projects where authors of this paper participate (ebbits, Adapt4EE, INERTIA). Important part of the LinkSmart middleware is a semantic module enabling reusable description of particular entities of IoPTS. This module enables easy connection of new entities in a dynamic IoPTS environment and it also simplifies development of applications based on the LinkSmart middleware. This article describes involved projects and authors contribution to them. Firstly we will introduce projects HYDRA, ebbits and Adapt4EE, later we introduce some of models developed by us and used within these projects.

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Projects overview

The FP6 Hydra project (http://www.hydramiddleware.eu) was a 4-year Integrated Project that developed middleware for Networked Embedded Systems. The Hydra middleware (currently named LinkSmart) allows developers to incorporate heterogeneous physical devices into their applications by offering easy-to-use web service interfaces for controlling any type of physical device irrespective of its network technology such as Bluetooth, RF, ZigBee, RFID, WiFi, etc. Hydra incorporates means for Device and Service Discovery, Semantic Model Driven Architecture, P2P communication, and Diagnostics. Hydra enabled devices and services can be secure and trustworthy through distributed security and social trust components of the middleware.

The FP7 integrated project ebbits (www.ebbits.eu) builds on results of the HYDRA project. The ebbits project does research in architecture, technologies and processes, which allow businesses to semantically integrate the Internet of Things into mainstream enterprise systems and support interoperable end-to-end business applications. It will provide semantic resolution to the Internet of Things and hence present a new bridge between backend enterprise applications, people, services and the physical world.

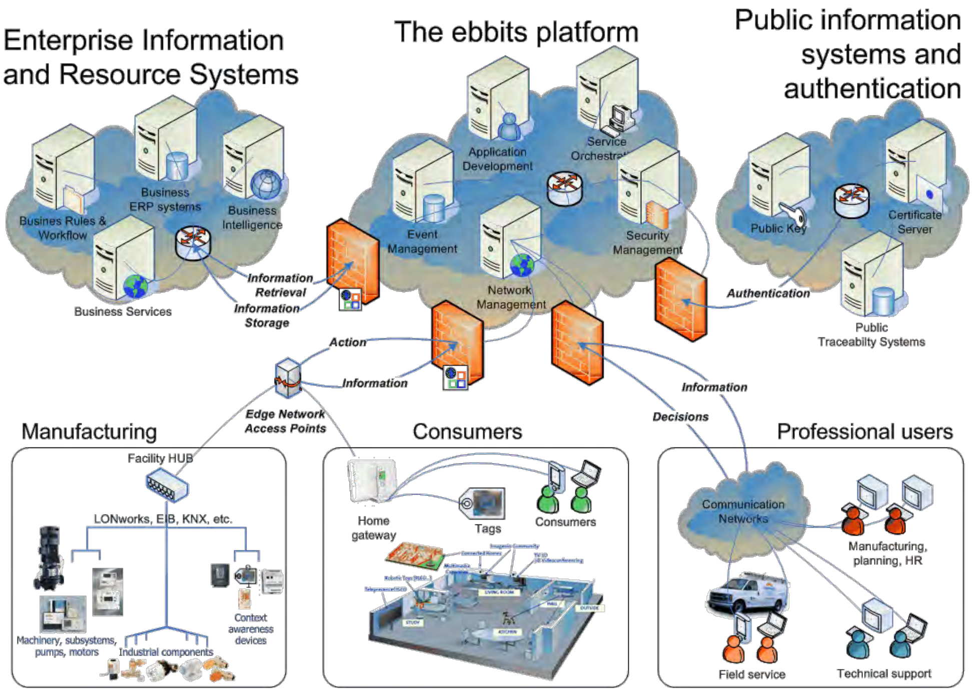

Figure 1 Ebbits architecture

The ebbits platform features a Service oriented Architecture (SoA) based on open protocols and the LinkSmart middleware, effectively transforming every subsystem or device into a web service with semantic resolution. Position of the ebbits platform within the ebbits architecture is depicted in **Figure 1**. The ebbits platform enables the convergence of the Internet of People (IoP), the Internet of Things (IoT) and the Internet of Services (IoS) into the “Internet of People, Things and Services (IoPTS)” for business purposes. We are currently developing a semantic infrastructure to support service discovery within the ebbits platform.

Another project employing results of the HYDRA project is FP7 Adapt4EE project. The LinkSmart middleware is used here to connect sensors in real buildings to gain information about occupancy behavior within these buildings. The behavior of occupants is then simulated in newly proposed buildings of the same domain to predict Key Performance Indicators of such a building. The performance indicators are combined from energy efficiency, human comfort and business performance values. Architecture of the Adapt4EE system for the measurement phase (where most of semantic technologies within the project are used) is depicted in the scheme in Figure 2.

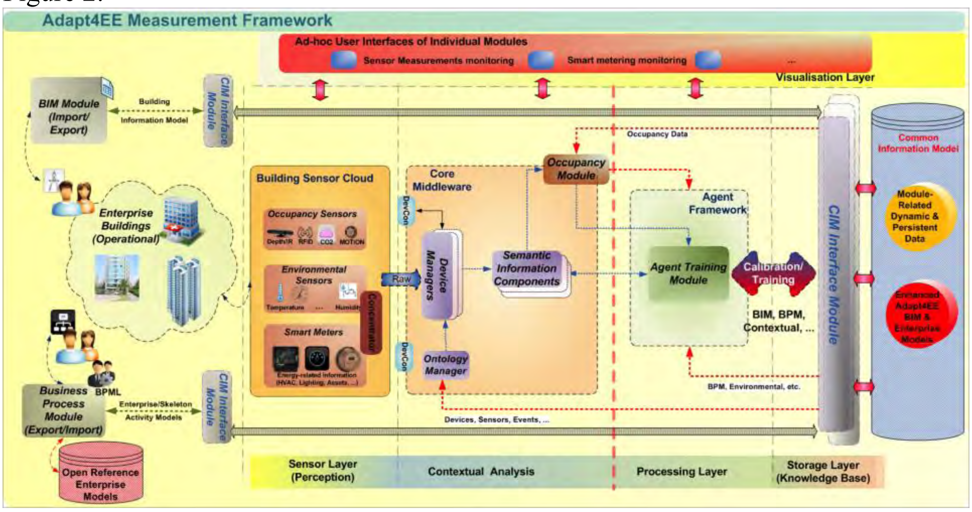

Figure 2 Adapt4EE Measurement Framework

LinkSmart ontologies

The semantic Model Driven Architecture (MDA) of the LinkSmart middleware includes a set of models (ontologies in this case) used at the design as well as run-time. The semantics of the system can be looked at from the two perspectives:

Design-time: during the design (development) phase, semantic descriptions act as a labour-saving element for a developer working on an application using the LinkSmart enabled devices. The semantic descriptions can be used to generate a code to call a service, to query a device that implements the service, and to work with data the service operates upon. The semantic description and appropriate stubs determine compilation target, or code skeletons are created for a web service that will run on the target device. A support code for reporting on the device status, which serves as a support of self-* properties of the device, can be also generated.

Run-time: during the runtime the semantic models are mostly used for discovery purposes. Application should work only with types of devices and services that the developer selected and will work with a more abstract description of the devices. Within the device discovery process, the discovery information is resolved using the device description. The system will identify the most suitable template for the device and will create a new, unique run-time instance representing a specific physical device. Additional semantic information from the device/service description can be used in the application to resolve various security requirements or to select specific services according to the quality of service (QoS) measures.

Structure of LinkSmart ontologies is depicted in Figure 3. The LinkSmart Device Ontology represents concepts describing the device related information. The basic ontology is composed of several partial models representing specific device information. The ontology structure was designed with the aim to support maintainability and future extensions of the used concepts. Ontologies have been developed using the OWL language. Several parts of the model are stored in separate ontology files. References between more general and specific ontologies are implemented using the OWL import mechanism. The initial device ontology structure was based on the FIPA device ontology specification (FIPA). The initial device taxonomy was an extended version of the AMIGO project vocabularies for device descriptions (Amigo D3.2, 2006). The basic ontology is composed of several partial models representing specific device information.

The device ontology represents basic, high-level concepts describing the device related information, which will be used both in the development and run-time processes. Each instance of this ontology represents a specific device model and serves as a template for run-time instances of real devices connected to the LinkSmart middleware.

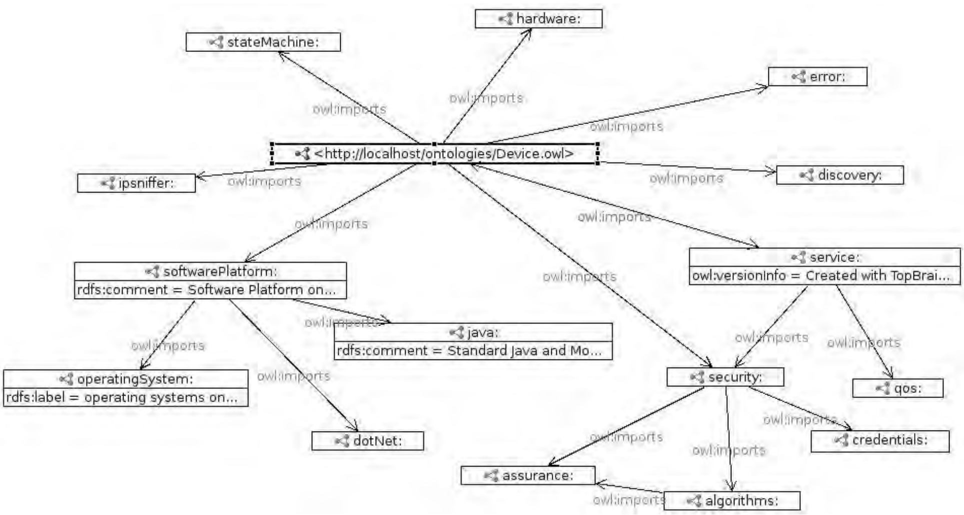

Figure 3 The Device Ontology components

The purpose of the LinkSmart Application Ontology Manager (**Figure 4**) is to provide a unified interface for using the Device Ontology and all related models within the LinkSmart middleware. The Manager also maintains run-time instances of the LinkSmart devices. The Ontology Manager was developed and implemented in Java, using the OSGi framework as a service platform, later refactored to be an independent web service based module (as LinkSamrt moved from the OSGi framework to more flexible P2P technologies)

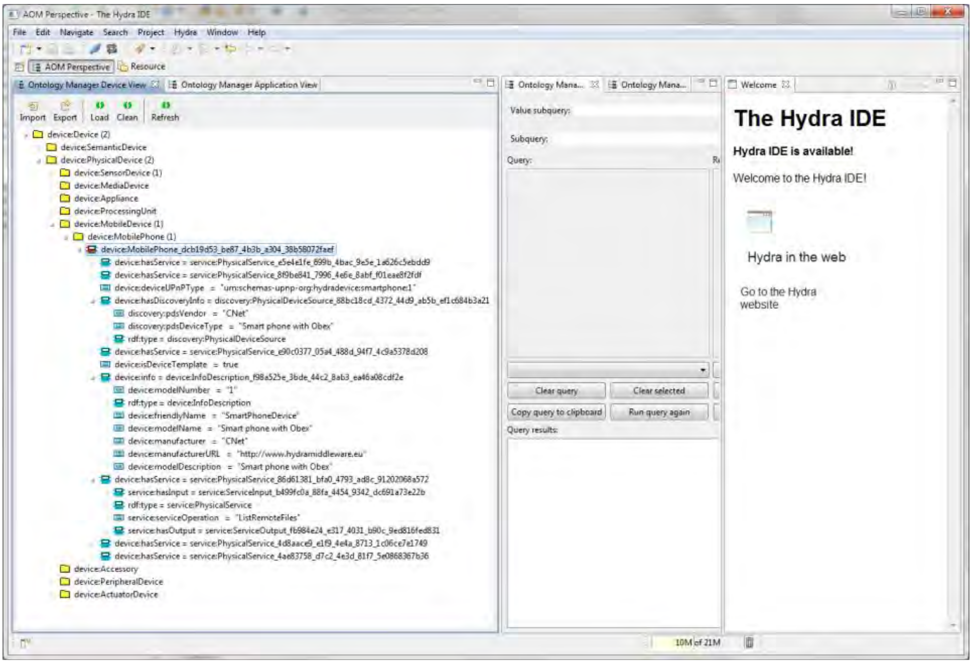

Figure 4 LinkSmart Ontology Manager

ebbits ontologies

Within the ebbits project, ontologies were further updated and the Ontology Manager component was modified. The current model is used in two novel pilot applications - food traceability and industry energy efficiency.

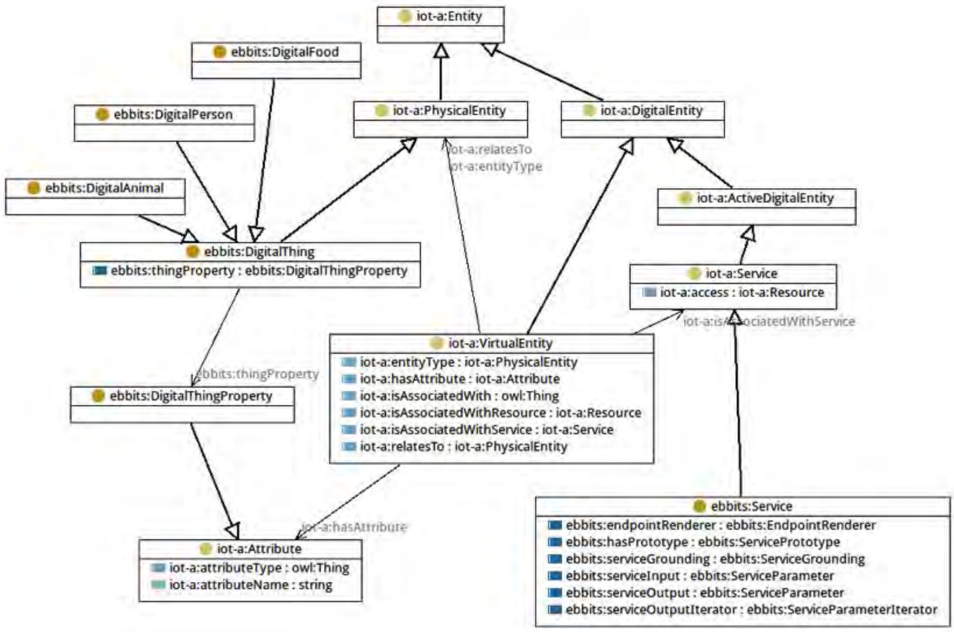

Figure 5: Mapping of ebbits Domain Ontology to IoT-A Domain Model

Using the IoT-A upper ontology it is possible to extend the ebbits specific ontologies with interpretation compatible with IoT-A architecture. In ebbits applications, there is no direct need to use this mapping, but this extension enables to translate ebbits specific semantic models to the language of IoT-A. This translation enables to transfer the part of semantic models to other IoT platforms implementing proposed reference architecture. But, the main disadvantage here is, that each implementation of IoT-A paradigm is in some way different, as it is created to fulfill specific requirements. This assumption leads to the facts, that each IoT-A implementation will need to use the specific semantic models. And this assumption leads to the fact, that implementing IoT-A reference models will ensure only the transport of limited information, as implementation specific models are not standardized.

The service ontology of ebbits (Figure 6) contains all the necessary information to support the service orchestration. The service ontology is handled by the Ontology Manager, which provides the service matching functionalities. The service ontology combines the domain models and service models.

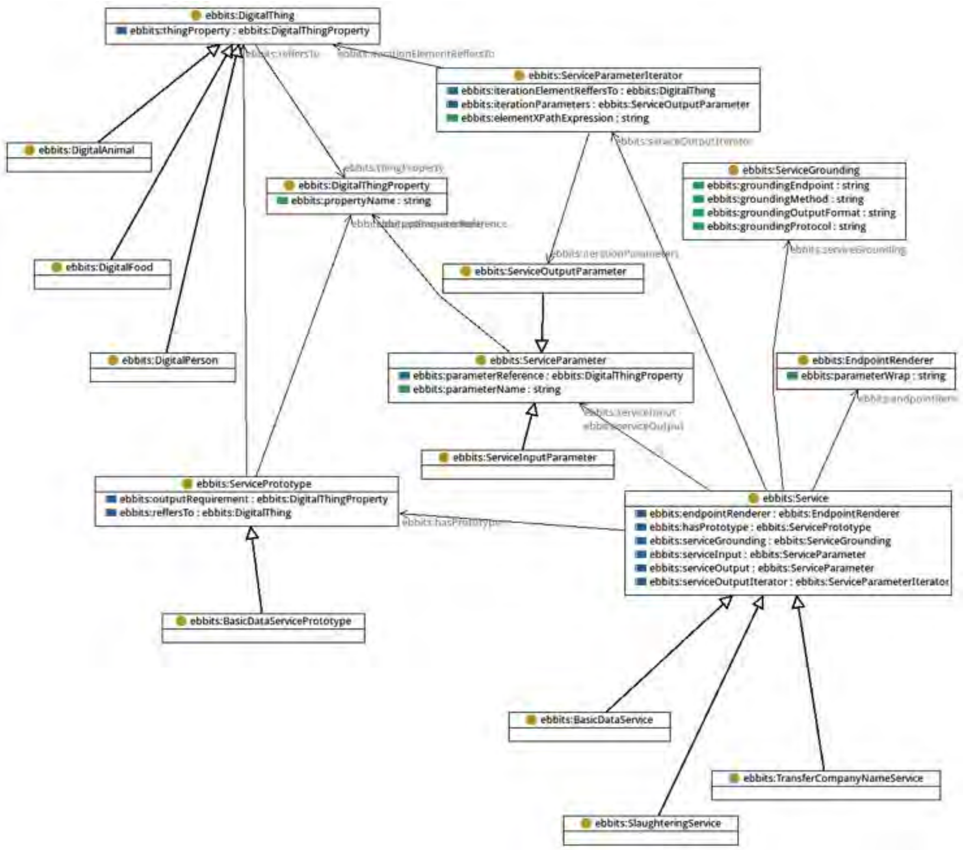

Figure 6 ebbits service and domain ontologies

The mapping to the domain models enables to extend the events metadata by information useful for the application logic. The extension model is illustrated in the **Figure 7**. The illustrated RDFS schema contains only the extensions of the basic event ontology.

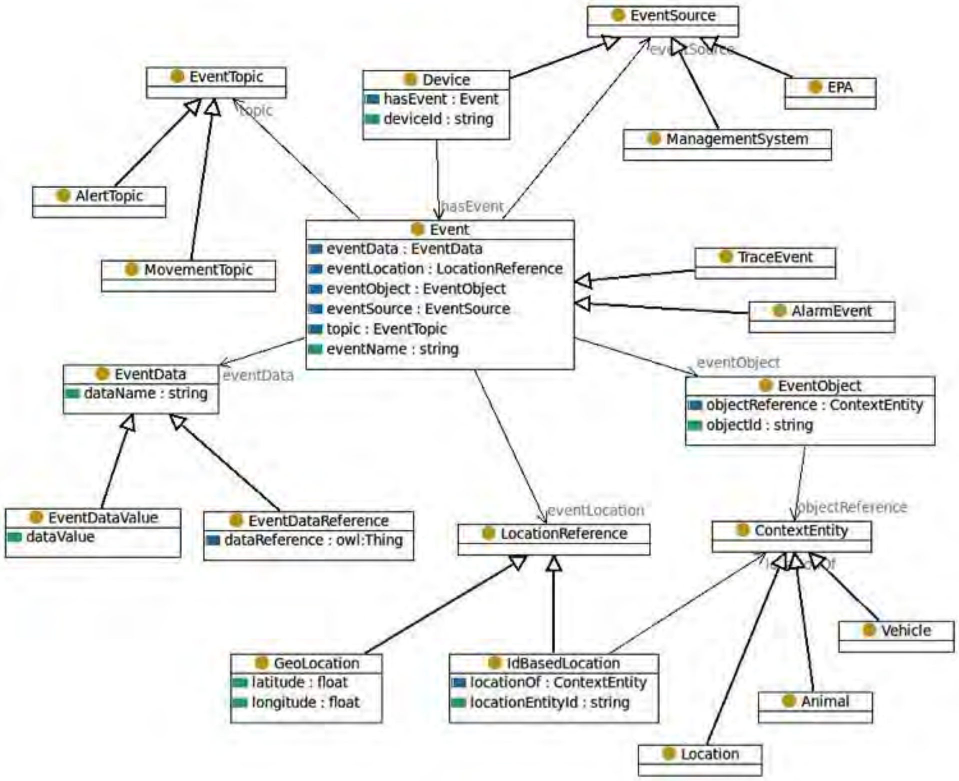

Figure 7: The ebbits extended event model.

Adapt4EE ontologies

The aim of the Adapt4EE project is to deliver a SW system, which can calculate an energy, business, and comfort performance of a building based on a simulation refined by values achieved in advance by real measurements in another buildings. The Common Information Model (CIM) of the Adapt4EE system describes the information sources that are used by modules of both measurement and simulation frameworks of Adapt4EE system. The design of the CIM for the Adapt4EE project is mainly determined by the information required by the Adapt4EE modules that can be generated only as a combination (and/or modification) of particular information models (BIM, BPM, Context Control Model, Ontology Model, General Surrounding Environment Model). The CIM is defined as a set of XML schemas defining inputs and outputs of the Adapt4EE SW modules and is supported by an owl ontology model generated from the schemas. These schemas are used to generate particular parts of the model in ontologies to enable semantic quarrying of these. Example of the fragment of ontology used for querying about events related to spaces within the building is depicted in **Figure 8**.

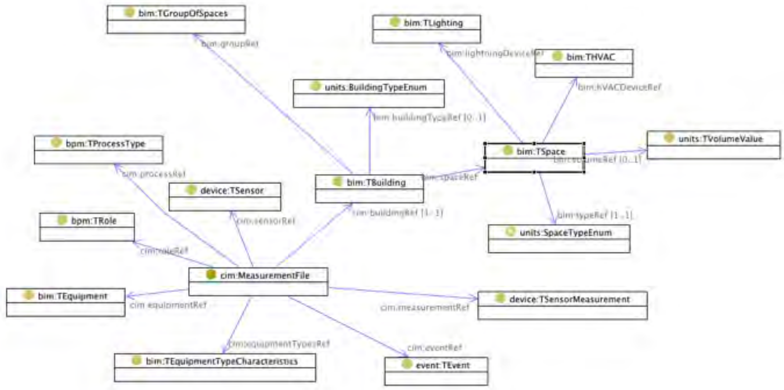

Figure 8 Adapt4EE Measurement file ontology

Conclusions

The paper provides a brief overview of research done in EU R&D projects HYDRA, ebbits, Adapt4EEE with focus on Semantic Technologies in Internet Of Things. We have focused on practical usability of semantic models in our research, thus we have prepared models using the bottom up approach where we create small ontology models based on project user scenarios. In our work we also reuse existing ontologies (mainly the t-box part of them) if possible. Semantic technologies proven to be a difficult topic for experts other than these from the semantic web community. That is why we try to hide a complexity of ontology behind easy to use well-defined web services of the Ontology Manager. By populating our ontologies with instances we will try to propose changes in these existing ontologies and standards in near future if possible.

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