HYDRA: A Development Platform for Integrating Wireless Devices and Sensors into Ambient Intelligence Systems

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1 Developing Middleware to Enable Software Developers to Create Services for Embedded Systems

Embedded Systems are everywhere, built into healthcare devices, into building automation, heating systems and home appliances, into mobile phones and communication, into cars, roads, bridges, and tunnels, and even into our clothes. They are interconnected into networks of many devices and they form the building blocks of the future Internet of Things.

Embedded Systems technologies are deployed in all relevant market sectors and have a major impact on the way these sectors work and collaborate, how they will develop, and how successful their products will be on the world market.

Manufacturers are thus increasingly seeking to network their own products with other systems in order to provide higher value-added solutions for their customers – often a difficult, time-consuming, and costly development process, in particular for SMEs.

The HYDRA project aims to alleviate the problems facing European industries by researching and developing middleware for networked embedded systems that allows developers to develop cost-effective, high-performance AmI applications using heterogeneous physical devices.

Middleware is software that connects different components or applications to enable multiple processes running on one or more machines to interact across a network. The 52-month Hydra project is working on developing middleware that allows developers to create AmI applications, i.e., electronic environments that are sensitive and responsive to the presence of people. HYDRA will showcase its prototype for

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D. Giusto et al. (eds.), *The Internet of Things: 20th Tyrrhenian Workshop on Digital Communications*, DOI 10.1007/978-1-4419-1674-7_36,

secure home automation. This will demonstrate how future ambient environments can be designed, realized, and integrated. It will also allow users and developers to provide their input and feedback.

2 Hydra

The HYDRA project [1] develops middleware for networked embedded systems that allows developers to create AmI applications utilizing device and sensor networks.

Device and sensor networking research has seen increasing activity in the last years, with advances in sensor node and radio hardware [2,3]. This work has been instrumental in clarifying the trade-off between computation and communication and the need for in-network processing. Most of this work is based on topographically addressed sensor nodes; other researchers (Heidemann et al. [4]) have based their work on the use of attribute-based naming for structure and data diffusion. The use of attribute-based naming is an interesting concept that will be further investigated in HYDRA. Internet ad hoc routing (Broch et al. survey several protocols [4] such as DSR and AODV) can also be used in sensor networks. SPIN evaluates several variants of flooding for wireless sensor networks [5]. We instead use attributes to name data alone; globally unique identifiers are not used. Through its unique combination of Service-oriented Architecture (SoA) and Model-Driven Architecture, HYDRA will enable the development of generic services based on open standards. In particular, Hydra aims at creating middleware, which operates with limited resources in terms of, e.g., energy and memory. Taking advantage of the HYDRA-middleware interoperability of complex processes as well as heterogeneous infrastructures, services, and devices, Hydra addresses three application domains: home automation, healthcare, and agriculture.

The Hydra middleware as an intelligent software layer, is placed between the operating system and applications. The middleware contains a large number of software components – or managers – who handles the various tasks needed to support cost-effective development of intelligent applications for networked embedded systems. The middleware can be incorporated in both new and existing networks of distributed devices, which operate with limited resources in terms of computing power, energy, and memory usage.

The Hydra middleware allows developers to incorporate heterogeneous physical devices into their applications. It provides easy-to-use web service interfaces for controlling any type of physical device irrespective of its network interface technology. It is based on a semantic Model-Driven Architecture for easy programming and also incorporates means for device and service discovery, peer-to-peer communication and diagnostics. Hydra-enabled devices offer secure and trustworthy communication through distributed security and social trust components of the middleware (Fig. 1).

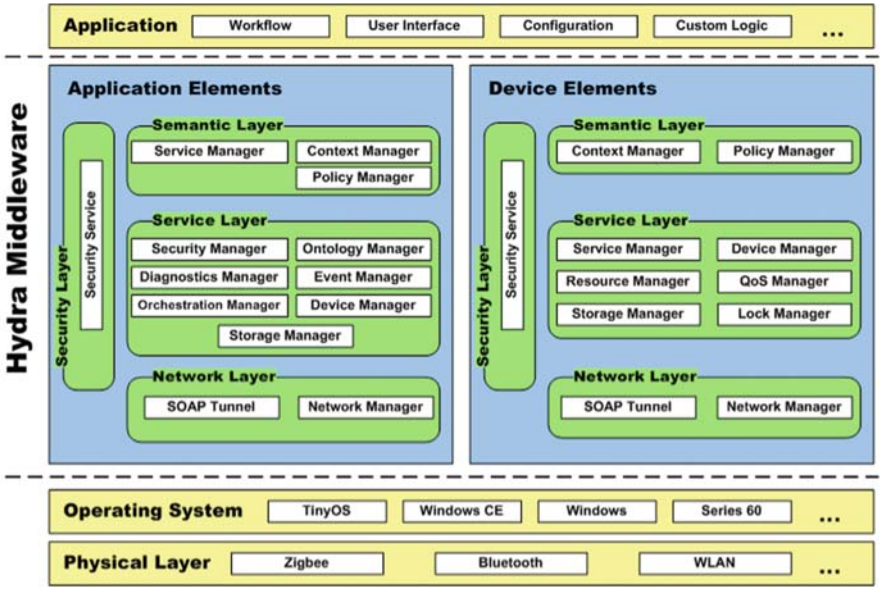

Fig. 1 Software architecture layers

The Hydra Software Development Kit (SDK), Device Development Kit (DDK), and Integrated Development Environment (IDE) will allow developers to create new networked embedded AmI applications and devices quickly and cost effectively. The main research fields in Hydra are briefly summarized below.

2.1 *Embedded Ambient Intelligence Architecture*

In Hydra AmI applications, any physical device, sensor, actuator, or subsystem can be considered as a unique web service. A major novelty in the Hydra approach is that the middleware provides support for using devices as services both by embedding services in devices and by proxy services for devices. Another novelty is that the middleware supports dynamic reconfiguration and self-configuration, which are indispensable properties in any AmI application [6, 7].

2.2 *Wireless Communication and Networks*

To assist application developers in addressing a wide variety of mobile and stationary devices and networks, the Hydra middleware hides device-dependent and network-dependent details and provides comprehensive open interfaces to the display, communication port, input facilities, and memory management of each class of device. The Hydra middleware can also manage communication in the Hydra network, route data, provide session management in the communication, and synchronize the different entities in the network.

A novel implementation in the Hydra middleware is the use of peer-to-peer (P2P) network technologies to identify and utilize the services available in the network, even if they are behind firewalls or NATs [8]. P2P pipes are used as an alternative to WS communication between Hydra-enabled devices.

2.3 Service-Oriented Architecture

The Hydra middleware has features that allow developers to create AmI services and systems through a Service-Oriented (SoA) and Model-Driven Architecture approach. The network part of the Hydra middleware can interconnect devices, people, terminals, buildings, etc. with the SoA providing interoperability at a syntactic level. However, the Hydra middleware also provides interoperability at a semantic level by extending semantic web services to the device level, thus opening up for semantic interoperability of AmI applications.

Hence, the Hydra middleware offers a real novel possibility to discover primitive resource constrained devices, dynamically embed them as Hydra enabled nodes in Ambient Intelligent device networks and provides interoperability between them. In order to achieve this extraordinary discovery capability, the capabilities of the devices must be semantically described in such a way that machine agents can understand and use it [9]. In the Hydra middleware, the semantic description of devices is based on ontologies using OWL, OWL-s and SAWSDL.

2.4 Trust, Privacy and Security

Security goals, such as confidentiality, authenticity, and nonrepudation, can be addressed by a particularly trustworthy design and implementation of wen-service-based mechanisms, enriched by ontologies. The concept behind Hydra security metamodel is semantic resolution of security focusing on moving security from identity-based into a semantic, credential-based framework [10].

2.5 Application Domains

Hydra addresses three application domains: home automation, healthcare, and agriculture.

2.5.1 Building Automation

The field of Intelligent Buildings, Intelligent Homes and Building Management Systems encompasses an enormous variety of technologies, across commercial, industrial, institutional, and domestic buildings, including energy management systems and building controls. The potential of the Hydra middleware in these markets is vast, and peoples' lives are heavily influenced by the effects of Intelligent Buildings technologies. Hydra allows for light-weighted and completely networked "smart homes", both internal and external, controllable, electronically secured, and equipped with different features based on self-learning software.

2.5.2 Healthcare

Hydra improves the productivity of healthcare provisioning.

eHealth services and the development of sophisticated personal wearable and portable medical devices will also allow patients and healthcare professionals to become more mobile and stay longer in the workforce. Hydra will improve the interoperability of intelligent devices and overcome the lack of interconnectivity and interoperability of the various proprietary components and subsystems.

2.5.3 Agriculture

The Hydra middleware will support time-planned data processing, intelligent decision support, and interconnectivity via heterogeneous networks. The Hydra middleware will enable devices and subsystems to communicate and allow developers to develop intelligent, secure applications where devices and subsystems cooperate to perform common tasks in Agriculture.

3 Prototype

Intelligent home automation shows how future ambient environments can be designed, realized, and integrated to provide energy efficiency solutions with a maintained or even increased level of comfort for users.

Taking advantage of the HYDRA-middleware interoperability of complex processes as well as heterogeneous infrastructures, services and devices in future ambient environments can be efficiently modelled and semantically secured; the prototype shows context-awareness and its security and privacy implications in a proof-of-concept implementation.

The HYDRA project has implemented several prototypes in three considered domains within the scope of the project: home automation, e-health, and agriculture. They all make use of the intelligent service layer provided by the middleware that allows every device, no matter the communication technology it uses (Bluetooth, ZigBee, X-10, etc.), to be presented to the application developer as an UPnP device (proxy) that offers both UPnP and WS services. Thus, the application developer does not need to deal with the particularities of the devices and can access its functionality in a systematic and standardized way.

The prototype we present here implements a set of energy efficiency context-aware ambient intelligent applications in the home automation domain. It is based on the sensors and actuators that are deployed in a living lab in Telefónica I + D premises in Valladolid (Spain), called "Casa Domótica" and where a complete house is available to test the HYDRA applications. A HYDRA middleware instance is deployed also in the house, controlling all the discovered sensors, actuators and devices. Another HYDRA middleware is deployed in a laptop, which may be connected to a different network and still being able to access the devices' services in "Casa Domótica". The context that is taken into account in the prototype is the location of the user (an avatar is used in the application to show the position of the user in the house) and the moment of the day in which the action takes place (whether there is daylight or not). The applications developed in the prototype are:

- *Give me light*: The system provides the user with the needed light regarding his context. For instance, if the user is in the living room and there is daylight, the system will pull up a blind. Otherwise, a lamp will be switched on.
- *Follow me light*: In connection with the "Give me light" application, this application follows the user in the house, switching on or off the lights in the house when the user enters or leaves a particular room respectively.
- *Goodbye, stand-by*: This application takes care of switching off all the lights in the house and of turning down all those devices that are in stand-by mode.
- *Energy-consumption information*: The user gets real-time information about the energy consumption at home as he interacts with the electric appliances. Moreover, each device includes an energy profile, which allows the user to check the consumption of a particular device within the house.

Acknowledgment This work was supported in part by the European Commission under the Integrated Project HYDRA contract FP6-IST-034891.

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