Auto-adapting homes to context: a semantic-based evolution of KNX standard protocol

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***Abstract*—Home and building automation aims at improving features and capabilities of household systems and appliances. Nevertheless, current solutions lack in context-awareness. The integration of knowledge representation features and reasoning techniques (originally devised for the Semantic Web) into standard home automation protocols can offer high-level services to users. A semantic-based approach is proposed, able to interface users and devices (whose characteristics are expressed by means of annotated profiles) within an advanced home infrastructure.**

I. Introduction

In latest years, the design of smart Home and Building Automation (HBA) environments is attracting efforts from several disciplines, including mobile and pervasive computing, wireless sensor networks, artificial intelligence and agent-based software, coalescing into a research area known as *Ambient Intelligence* (AmI) [1]. AmI refers to a vision where people are surrounded by intelligent and intuitive interfaces, toward all kinds of objects in a given environment, able to organize and adapt themselves to user profiles in a seamless and unobtrusive way. Current HBA systems and standard technologies are still based on explicit user commands over static sets of operational scenarios, established during system design and installation. Consequently, they allow a low degree of autonomicity and flexibility. This work aims to propose a framework for pervasive knowledge-based HBA systems which is grounded on the *Semantic Web of Things (SWoT)* [2]. The SWoT is an emerging vision in Information and Communication Technology, integrating the *Internet of Things* [3] and *Semantic Web* [4] paradigms. It exploits semantic annotations coming from a large numbers of heterogeneous micro-devices, each conveying a small amount of useful data, on the whole providing intelligence and expressiveness to devices and environments.

II. State of the Art

Currently, most widespread technological standards for HBA –including KNX (www.knx.org), ZigBee (www.zigbee.org) and LonWorks (developed by Echelon Corporation, www.echelon.com)– only offer static automation capabilities, consisting of pre-designed application scenarios. They do not allow autonomicity in environmental adaptation and dynamic context-awareness. Unfortunately, current solutions either require direct user intervention or only support basic interaction between devices, lacking advanced resource discovery and composition capabilities. An early approach towards AmI was proposed in [5]. Intelligent agents were used to automate a service composition task, providing transparency from the user's standpoint. Nevertheless, such an approach was based on service discovery protocols such as UPnP and Bluetooth SDP, presenting a too elementary discovery and supporting only exact match of code-based service attributes. The use of knowledge representation can allow to overcome such limits. Knowledge Bases (KBs) will be exploited to enable a user-device interaction and to interconnect household appliances, using different protocols, in order to share resources. In [6] a more advanced domotic framework incorporating a rule-based reasoning module was introduced to manage and coordinate heterogeneous devices endowed with semantic descriptions. The main weakness of the above work is in the presence of static rule sets and centralized KBs. A really flexible solution requires a different approach, able to deal with the intrinsically dynamic, decentralized and unpredictable nature of the context-aware computing.

III. Proposed approach

A general-purpose framework for HBA has been proposed, supporting semantic-enhanced characterization of both user requirements and services/resources provided by devices. Following pervasive computing spirit, during ordinary activities the user should be able to simultaneously exploit information and functionalities provided by multiple objects deployed in her surroundings. Each device should autonomously expose its services and should also be able to discover functionalities and request services from other devices. Technologies and ideas are borrowed from the Semantic Web initiative and adapted to HBA scenarios. Semantic Web languages, such as OWL[1], provide the basic terminological infrastructure. The full exploitation of semantics in user and device description has several benefits which include: (i) machine-understandability (interoperability); (ii) possibility to automatically infer novel knowledge starting from user and environmental conditions (context).

The proposed framework was based on a fully backward-compatible extension of ISO/IEC 14543-3 EIB/KNX protocol [7]. KNX was selected as reference HBA standard due to its support for multiple communication media, availability of development tools and wide industry acceptance. At protocol level, main contribution includes the definition of new data structures and application-layer services conforming KNX 2.0 specification to store and exchange semantic metadata. Due to the reduced availability of both device storage and protocol bandwidth in current domotic infrastructures, the proposed

[1]OWL 2 Web Ontology Language Document Overview (Second Edition), W3C Recommendation 11 December 2012, http://www.w3.org/TR/owl2-overview/

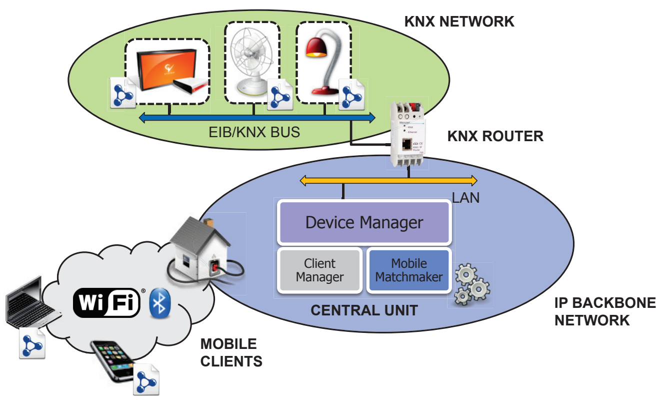

Fig. 1. Framework Architecture

(a) Testbed (b) Device Panel

Fig. 2. Developed Testbed

enhancements envisage the use of a compression algorithm specifically targeted to XML-based ontological languages [8]. The framework has been defined in detail in [9], including: (a) a terminology (ontology) for the HBA application domain; (b) an embedded matchmaking engine [10], providing standard and non-standard inferences to support deductions and inferences over circulating meta-information.

The reference framework architecture, shown in Figure 1, integrates both semantic-enabled and legacy home devices in a domotic network with an IP backbone: an agent-based approach is followed. Coordination among user agents and domotic agents (representing devices, rooms and areas) is facilitated by a home unit. Communication between client agents and the home system may occur through either IEEE 802.11 or Bluetooth wireless standards. The optimized inference services [11], [12] feature a Decision Support System (DSS) hosted by the coordination unit. Service/resource discovery and orchestration is not limited to identity matches (infrequent in real situations), but it supports a logic-based ranking of approximated matches allowing to choose services/resources best satisfying a request, also taking ancillary numerical data into account. Such an approach allows the user to require complex services instead of simplistic single device features.

Based on the theoretical framework, a prototypical testbed (shown in Figure III) has been developed to evaluate the effectiveness of the approach and to experiment about performance –considering several case studies, varying in consistency and complexity. It represents a small set of home environments equipped with different KNX-compliant off-the-shelf devices.

The integration of the proposed system in a more complex agent framework devoted to energy management is a further step toward a Smart Grid vision. In [13], main characteristics of a Building Energy Management System (BEMS) framework are highlighted and early performance evaluation is presented. There a semantic-based negotiation protocol is adopted to maximize energy efficiency in buildings. The agents are able to: (i) negotiate on available home and energy resources through a user-transparent and device-driven interaction; (ii) reveal conflicting information on energy constraints; (iii) support non-expert users in selecting home configurations.

IV. Conclusion

A semantic-based evolution of KNX-based homes has been proposed to overcome existing limits of HBA solutions. The integration of knowledge representation and reasoning technologies with current standards and systems allows to improve the degree of autonomicity and flexibility enhancing the context awareness of building appliances. As ongoing research the proposed framework has been integrated in a more articulated BEMS for an intelligent energy provisioning and in sight of a Smart Grid vision.

Further information about the proposed research can be found on the project Home Page[2].

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