Toward Wise Cities: a knowledge-based approach for home and building resilience

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***Abstract*—The *Smart City* model implies usage and sharing of information to enhance home and building resilience, improve energy management and minimize environmental impact. Current solutions, however, poorly support fully dynamic scenarios and context-awareness. As a next step, we envision the *Wise City* paradigm, where the integration of knowledge representation features and reasoning techniques enables high-level services and further improves flexibility. It aims to enrich standard automation architectures by adapting technologies originally devised for the Semantic Web as well as advances in pervasive computing. Particularly a semantic-based approach to Building Automation and Control Systems (BACS) is proposed, able to interface autonomous devices (whose characteristics are expressed by means of annotated profiles) within a multi-agent service-oriented architecture, aiming to bridge the gap between raw data coming from on-the-field detection (sensors, devices, systems) and high-level knowledge.**

I. Introduction

The *Smart City* vision implies environments capable of being sensitive and responsive by recognizing user needs and self-adapting accordingly. Devices communicate and interact autonomously, without direct human intervention, also making decisions based on multiple factors, including user presence and preferences. They are coordinated by intelligent systems acting as supervisors, devoted to manage available resources in order to meet given requirements. Usage and sharing of information is a key factor for enhancing resilience, improving energy management and minimizing environmental impact. Pervasive computing research has allowed integrating innovative smart capabilities into *Building Automation and Control Systems (BACS)* to save energy and minimize waste and maintenance costs. Nevertheless, current systems are still configured according to a static set of operational scenarios defined during the system design and they are usually driven by explicit user interactions. Consequently, specification of user's needs and resource management both allow limited flexibility and context-awareness.

In this work we envision the *Wise City* paradigm as the next evolutionary step of Smart Cities. In Wise Cities, the integration of Knowledge Representation and Reasoning (KRR) features and technologies enables high-level services and improves versatility. Adaptation of technologies originally devised for the Semantic Web allows enriching standard building automation and grid architectures. As a proof of concept of the feasibility and effectiveness of this semantic-based approach, a framework for BACS scenarios was studied, where autonomous systems –whose characteristics are expressed by means of annotated profiles– interact within a multi-agent service-oriented architecture. The Wise City idea aims to bridge the gap between raw data coming from field devices and high-level knowledge useful for decision making. The proposal is based on a semantic enablement extension of of the *EIB/KNX* ISO/IEC 14543-3 standard protocol for building automation [1, ch.58].

The reference scenario is a knowledge-based enhancement to current energy grid infrastructures where advanced Energy Management Systems (EMSs) act at multiple levels. The primary goal is to create a unified network where autonomous distributed nodes cooperate to optimize energy consumption by efficiently managing and transferring electricity in the grid, according to actual service needs and context. To this aim, the devised multi-agent framework allows requests coming from users and/or devices being collected by one or more *mediators* which act as a broker between users and appliances. Each request is treated as a one-to-many negotiation among sender agent and various device agents. Such a complex process is divided in concurrent one-to-one negotiations between the coordinator and each node agents. Services/resources so selected are used to cover sender requirements to the best possible extent.

Section II describes the proposed approach and overall framework architecture, whereas conclusion and future work are presented in Section III.

II. Proposed approach

The proposed framework refers to the general and distributed Multi-Agent System (MAS) architecture outlined in [2], oriented toward an intelligent energy grid vision, aiming to control the demand of electricity and perform brokering activities on the market of energy services. As shown in Figure 1, a machine-to-machine negotiation process for energy management occurs at three stages: home, building and district. Each level is conceived as a MAS. The Home level reflects a single autonomous unit within a building, *e.g.*, a house, an apartment or a floor. The building level refers to structures containing multiple home units which share common facilities. Similarly, the district level refers to the coordination among buildings in a commercial or residential block/neighborhood

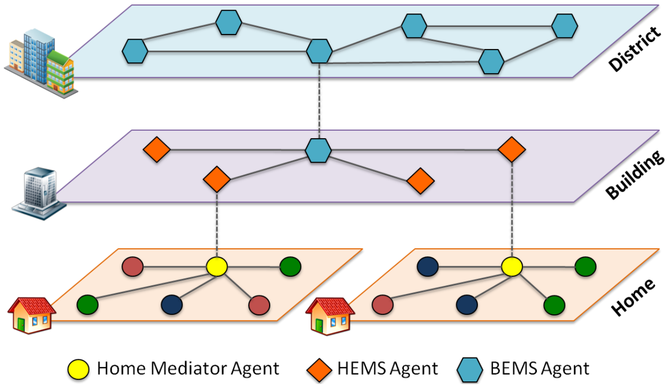

Fig. 1. Multi-layer Agent Architecture

and to the interface toward external energy providers, where each building is represented by an agent. Either mediator-based or fully peer-to-peer coordination schemes can be conceived at this layer.

The home-level MAS comprises a *mediator* agent and specialized agents representing users, smart meters and sensors, actuators, appliances and subsystems, including energy-providing systems, *e.g.*, photovoltaic collectors. The number of available resources and agents may vary dynamically and unpredictably without redefining the communication and negotiation framework. The MAS leverages a knowledge-oriented evolution of EIB/KNX standard [3], which implements a semantic micro-layer on the top of the protocol stack. Semantic-based enhancements allow to fully describe device features by means of annotations expressed in the logic-based *OWL 2*[1] Web Ontology Language. Within this MAS architecture, agents are able to: (i) retrieve *service* (*i.e.*, functional profile) descriptions of devices, expressed as OWL 2 annotations; (ii) perform matchmaking based on semantic relevance score to identify the best services for fulfilling a request of a user or of another device agent; (iii) explain the matchmaking outcome, showing possible issues and negotiation options to the user/agent; (iv) support users in selecting settings and SLAs (Service Level Agreements) ranked w.r.t. utility in order to optimize costs and efficiency. The goal is to minimize the consumption of external energy sources (electricity, gas) via cogeneration, micro-generation and net metering, *i.e.*, favoring the usage of energy produced by equipment installed in the building. This makes home units and buildings more resilient w.r.t. shifts in the energy market and environmental conditions influencing renewable sources.

A unique novelty introduced by the approach is the support for requests coming not only from user agents, but also from devices. In this way, home appliances can embed device agents, able to provide services and issue requests autonomously. This enables more dynamic environment adaptation w.r.t. current BACS standards through decentralized device cooperation, whereas the central control unit basically acts as a service broker. After an initialization step, when a request comes from a device the home mediator performs an orchestration of suitable services via a semantic-based process relying on the resolution of a slightly revised version of the *Concept Covering Problem (CCoP)* [4], a non-standard reasoning task. For all suitable services, a matchmaking process is performed to compare both functional and energy requirements with the available energy providers; a *penalty function* [5] is defined to enable a ranking based on user needs and energy requirements. Finally, the algorithm returns: the set of services to activate, along with the most suitable energy sources; the (possibly empty) set of services to be disabled; a description of the uncovered request part, if present.

III. Conclusion and Future Work

We presented the Wise City vision for the knowledge-based future of Smart Cities. Characteristics and benefits of the approach were discussed in a distributed multi-agent framework to support energy-management in BACS, based on the semantic enhancement of building automation standards exploiting KRR technologies.

In order to expand the framework to district and city levels, future work will pursuit the integration of pervasive computing technologies. They enable infrastructureless connection of tiny sensors and devices for capillary information gathering and management. Web of Things technologies fitting the proposed vision include semantic-based evolutions of the *Physical Web*[2] framework to connect information with objects and the *Linked Data Platform*[3] –particularly in its adaptation to CoAP (Constrained Application Protocol) [6]– to organize pervasive knowledge.

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