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Decentralized and Embedded Management for Smart Buildings

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Abstract. Future buildings will be smart to support personalized people comfort and building energy efficiency as well as safety, emergency, and context-aware information exchange scenarios. In this work we propose a decentralized and embedded architecture based on agents and wireless sensor and actuator networks for enabling efficient and effective management of buildings. The main purpose of the agent-based architecture, which is currently implemented in MAPS, is to efficiently support distributed and coordinated sensing and actuation operations. The high modularity of the proposed architecture allows for easy adaptation of higher-level application-specific agents that can therefore exploit the architecture to implement intelligent building management policies.

Keywords: Multi-agent systems**,** Building Management Systems, Wireless Sensor and Actuator Networks, MAPS.

1 Motivations and Related Work

Nowadays, due to advances in communication and computing technologies, the need to have high comfort levels together with an optimization of the energy consumption is becoming important for inhabitants of buildings. Moreover, buildings should also support their inhabitants with automatic emergency and safety procedures as well as context aware information services. To meet all these requirements, future buildings have to incorporate diversified forms of intelligence [1].

We believe that agent-based computing [2] can be exploited to implement the concept of intelligent buildings due to the agent features of autonomy, proactiveness, reactiveness, learnability, mobility and social ability. Specifically agents can continuously monitor building indoors and their living inhabitants to gather useful data from people and environment and can cooperatively achieve even conflicting specific goals such as personalized people comfort and building energy efficiency.

A few research efforts based on agents have been to date proposed to design and implement intelligent building systems. In [3] the authors present the MASBO (Multi-Agent System for Building cOntrol) architecture that aims to provide a set of software agents to support both on-line and off-line applications for intelligent work environments. MASBO is used to develop a multi-agent system (MAS) able to tradeoff energy saving and inhabitants' preferences where preferences can be learnt and predicted through an unsupervised online real-time learning algorithm (analyzing inhabitants' behavior). MASBO agents reside on a server and constantly monitor data from sensors and eventually actuate some commands. MASBO works as an enhancement to an existing building automation system by adding learning, reasoning and autonomous capabilities. The responsibility of controlling sensors and actuators, and keeping a requested environmental value constant is not addressed by MASBO.

In [4] the authors propose a working solution to the problem of thermal resource distribution in a building using a market-based MAS. Computational agents representing individual temperature controllers bid to buy or sell cool or warm air. The agents, running in a monolithic process on a workstation, are able to distribute the thermal resources so that all the building offices have an equitable temperature distribution. Temperature sensors and air flow actuators are all accessible directly through distributed hardware modules via a network connection.

In [5] the authors describe a MAS that monitors and controls an office building in order to provide added values like energy saving together with the delivery of energy. The developed system is distributed in the sense that some agents are located on PDAs and others run on the Bluetooth access points (workstations) that communicate with the PDAs. The system makes use of the existing power lines for communication between the agents and the sensing and actuation system controlling lights, heating, ventilation, etc.

However, all the aforementioned contributions do not provide agents embedded in the sensor and actuator devices that would introduce intelligence decentralization and improve system efficiency. This is due to the exploitation of conventional sensing and actuation systems that do not offer distributed computing devices for sensing and actuation. To overcome this limitation, wireless sensor and actuator networks (WSAN) [6] can be adopted. WSANs represent a viable and more flexible solution to traditional building monitoring and actuating systems (BMAS), which require retrofitting the whole building and therefore are difficult to implement in existing structures. In contrast, WSAN-based solutions for monitoring buildings and controlling equipment, such as electrical devices, heating, ventilation and cooling (HVAC), can be installed in existing structures with minimal effort. This should enable monitoring of structure conditions, and space and energy (electricity, gas, water) usage while facilitating the design of techniques for intelligent device actuation.

In this paper we propose a decentralized and embedded management architecture for intelligent buildings that is based on WSANs and overcomes the limitations of the aforementioned solutions [3][4][5]. In particular, the aim of our architecture is to optimize and fully decentralize the sensing and actuation operations through distributed cooperative agents both embedded in sensor/actuator devices and running on more capable coordinators (PC, plug computers, PDA/smartphones). The proposed architecture can be easily programmed to support a wide range of building management applications integrating comfort, energy efficiency, emergency, safety, and context-aware information exchange aspects.

2 Agent-Based Architecture

The agent-based architecture (see Fig. 1) for decentralized and embedded building management is composed of coordinator agents (CAs), which run in the basestations, and sensor agents (SAs), which are executed in the sensor/actuator nodes. Specifically, the architecture relies on a multi-basestation approach to allow for large buildings composed of multiple floors and diversified environments. Thus, the architecture is purposely hybrid: hierarchical and peer-to-peer. Interaction between CAs is peer-to-peer whereas interaction between coordinator agents and their related SAs (or SA cluster) is usually master/slave. Moreover, SAs of the same cluster coordinate to dynamically form up a multi-hop ad-hoc network rooted at the master CA.

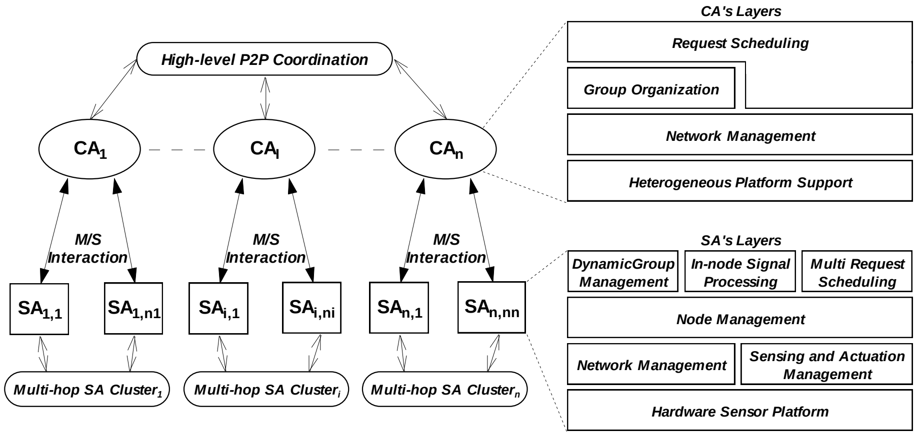

Fig. 1. Agent-based architecture for decentralized and embedded management of buildings based on wireless sensor and actuator networks.

On the right side of Fig. 1 the main functionalities of CA and SA are shown according to a layered organization that is partially derived from the Building Management Framework (BMF) [7].

CA includes the following layers:

- *Heterogeneous Platform Support* incorporates a set of adapters that allow interfacing the system with different type of sensor/actuator platforms. An adapter is linked to a specific hardware device able to communicate with a specific sensor platform in the network.
- *Network Management* allows to fully manage a WSAN cluster. This layer supports packet coding/decoding according to the BMF application-level protocol and packet transmission/reception to/from the WSAN cluster. Moreover, this layer supports device discovery within the cluster.
- *Group Organization* provides group-based programming of sensors and actuators, tracking of nodes and groups in the system, and management of node configurations and group compositions. Node organization in groups is specifically defined to capture the morphology of buildings. Nodes belong to

groups depending on their physical (location) or logical (operation type) characteristics.

- *Request Scheduling* allows the support for higher-level application-specific requests. Through this layer, a CA can ask for the execution of specific tasks to single or multiple SAs or groups of SAs. Moreover, this layer keeps track of the requests submitted to the system, waits for data from the nodes and passes them to the requesting applications. A request is formalized through the following tuple: $R = <Obj, Act, R, LT>$, where *Obj* is a specific sensor or actuator belonging to a node, *Act* is the action to be executed on *Obj*, *R* is the frequency of each executed *Act*, *LT* is the length of time over which these actions are to be reiterated. Moreover, a request can target a single node or a group of nodes having *Obj*.
- *Inter-CA Coordination* offers efficient mechanisms for coordination between CAs. Specifically, CAs cooperate for submitting queries and retrieving data spanning multiple SA clusters.

SA is designed around the following layers:

- *Hardware Sensor Platform* allows to access the hardware sensor/actuator platform. In particular, the layer facilitates the configuration of the platform specific drivers and the use of the radio.
- *Network Management* manages the node communication with the reference CA and among the cluster nodes according to the BMF application protocol.
- *Sensing and Actuation Management* allows to acquire data from sensors and execute actions on actuators. In particular, this layer allows to address different types of sensors/actuators in a platform independent way.
- *Node Management* is the core of the SA and allows to coordinate all the layers for task execution. In particular, it handles events from the lower layers every time that a network packet arrives or data from sensor/actuator are available, and from the upper layers every time that data are processed or a stored request has to be executed.
- *Dynamic Group Management* provides group management functionalities to the SA. A node can belong to several groups at the same time and its membership can be dynamically updated on the basis of requests from CAs.
- *In-node Signal Processing* allows the SA to execute signal processing functions on data acquired from sensors [8]. It can compute simple aggregation functions (e.g. mean, min, max, variance, R.M.S.) and more complex user-defined functions on buffers of acquired data.
- *Multi Request Scheduling* allows the scheduling of sensing and actuation requests. In particular, it stores the requests from CAs and schedules them according to their execution rate.

Currently the agent-based architecture is implemented in JADE [9] at basestation side and MAPS [10] at sensor side.

3 Conclusions and Future Work

In this paper we have proposed an agent-based architecture for flexible, efficient and embedded sensing and actuation in buildings. Specifically, the distributed software architecture is embedded into both WSANs and more capable computing devices (e.g. PCs, smartphones, plug computers). The proposed architecture can be seen as basic middleware for developing intelligent building management systems to achieve the Smart Building concept. Currently the proposed architecture is exploited to monitor the space occupation and energy expenditure in computer laboratories for students to analyze energy consumption patterns with respect to users' behavior so as to semi-automatically implement behavior policies. On-going work is devoted to the design of a higher-level agent-based architecture for Smart Buildings atop the proposed architecture to trade off inhabitants' personal comfort and building energy expenditure.

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