Towards a User-centric and Auto-adaptative Building Operating Systems using Intelligent Agents for Energy Optimization

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Abstract

Currently, there is a trend globally to use artificial intelligence in various sectors, such as industry, healthcare, and security, to solve problems and improve efficiency. The goal is to create smart systems. This trend can also be seen in building management, where the use of Multi-Agent Systems through building operation systems and the Internet of Things can improve user well-being by ensuring energy efficiency, access control, building maintenance management, and other services in real time. The purpose of this article is to propose a new agent-based approach for designing and implementing a distributed building energy management system and distributed building operation system to improve energy efficiency and sustainability in smart buildings. In addition, this article proposes to use the ASPECS agent-oriented methodology and its implementation and execution environment, named SARL/Janus.

Keywords: *Multi-Agent System, Building Operation Systems, Internet of things, Building Energy Management Systems*

I. Introduction

Nowadays, digitalization for the management and maintenance of buildings has become the target of many research works, this is due to the support that it provides for controlling access, air conditioning, and low energy consumption and thus the reduction of the bill to be paid, as well as the optimization of internal processes inherent to the management of a building. According to [1], smart building is a modern building that allows residents to have sustainable comfort with high efficiency of electricity usage.

Buildings are important contributors to energy consumption accounting for around one-third of energy consumed in cities, where large public buildings are the dominant energy consumers [2] and energy consumption might be significantly decreased through building energy management systems. [3]

In the building environment, *Building Energy Management Systems* (BEMS) offer promising flexibility for *Demand-side Management and Demand Responses* (DSM & DR), while interacting with the smart grid. BEMS is a smart grid part that controls, monitors, and optimizes energy for the building and plays a critical part in achieving overall energy efficiency while reducing carbon footprints as it is a key requirement for designing modern buildings and industries [4], [5].

BEMS is usually based on the *Building Operating System* (BOS). BOS provides all the hardware and software components that are needed to support the features of the building, including BEMS.

According to [6], decentralized or semi-centralized decision-making procedures are more desired in electrical distribution systems, because of computing resource limitation in large-scale centralized electrical distribution systems mainly because of peak demand hour, which happens for only a period of time in any given year. This point of view highlights the need for distributed BOS (DBOS) and consequently distributed BEMS (DBEMS) that enable to support of the features of the building using a fully distributed design approach.

To solve this issue, Multi–Agent System (MAS) [7] is considered as one of the modeling, implementation, and deployment paradigms that is natively supporting distributed complex systems [8]. MAS focuses on intelligent agent behaviors and interactions to solve problems and provide an improvement on technologies [5]. It is based on an agent-based model (ABM), which is a class of computational models for executing or simulating the actions and interactions of autonomous agents with a view to assessing their effects on the systems as a whole as described in [9], [10], [11]. Many research areas, such as transportation behavior modeling [12] and smart grids [2], need to analyze and understand the complex phenomenon of interactions between different entities. Internet of Things (IoT) objects is a typical example of a technology in a smart building in which the devices could be considered as agents that are communicating in real time.

In this paper, the proposed ABM follows the latest advancements in the fields of agent-oriented software engineering. Therefore, a novel agent-based approach towards the design and implementation of a DBEMS and DBOS is proposed. It is the first step in the context of two projects that share common software and artificial intelligence scientific questions and supported by French Ambassy in Angola and Zayed University. There projects aim to propose the models and execution infrastructure for BOS in touristic and economic environments, as a progress beyond the state-of-the-art.

The paper is structured as follow. Section II presents the short state-of-the-art. In Section III, Agent-Oriented Methodology for DBEMS (Distributed Building Energy Management System) is briefly described. Finally, conclusions are provided, and perspectives are summarized in Section IV.

II. Short State-of-the-Art

In the building environment, BEMS offer promising flexibility for Demand-side Management and Demand Responses, while interacting with the smart grid. BEMS is a smart grid part that controls, monitors, and optimizes energy for buildings, and plays a critical part in achieving overall energy efficiency while reducing carbon footprints, as it is a key requirement for designing modern buildings and industries [4], [5].

Supply Side Management (SSM) is defined as an electricity optimizer of various power sources. Intelligent energy distribution management is one of the key paradigms for future energy distribution systems, smart buildings, and smart devices. The solution to the problem must start at the supply sources, deciding how the electricity should be distributed, in a way that it would improve the electrical efficiency, by developing algorithms for the system [13].

On the other hand, Demand Side Management (DSM) is defined as an optimizing demand-side energy consumption, allowing to achieve better efficiency and operation in the electrical system. DSM usually involves demand response and peak load scheduling, as electricity consumption is cheaper overnight, due to the wholesale electricity market [14].

According to [1] and [15], to deal with this, decentralized control has been highlighted as a suitable way to control and monitor energy systems, while improving reliability, flexibility, and system efficiency.

To design and implement a multi-agent system for BEMS or BOS, many open-source agent platforms are available in the literature, that helps developers to build complex agent systems. The platforms open source includes : JADE [15], Voyager [16], Zeus [17], Tracy [18], Springs [19], Aglets [20], and SARL/Janus [21].
The comparison of agent platforms will not be discussed in this article, as the performance of these agent development toolkits has been studied in several previous articles [22] [23] [24] [25].

From [22] [23] [24] [25], that are dedicated to the modeling of BEMS, it is possible to build Table 1:

Table 1: BEMS agent types

Architecture	Agent Type	Role
Centralized	Cognitive Reactive	High-level decisions, communication Quick response
Distributed	Local	Local information discovery, communications
Two-level hierarchical	High-Level	Infrastructure management, inter-microgrid communication, low-level agent scheduling
	Low-Level	Accept schedules, asset management
Three-level hierarchical	High-Level	Critical decisions, data, and policy management
	Mid-Level	Fault location, grid-connected/islanded mode switching
	High-Level	Sensor management, hardware I/O

Decision-making procedures, decentralized or semi-centralized, are most preferred in electricity distribution systems. this preference is due to the limitations of centralized computing resources in large-scale power distribution systems. MAS is a promising communication system for solving multiple objectives in the optimal period for distribution systems. MAS focuses on the interaction of artificial intelligence agents to solve issues and improve technology [26].

From different scientific articles, such as: [5],[3], [13] and [27], it is understandable that to choose the MAS architecture for a building scenario, it is necessary to classify well the building sources of energy (Supply Side Management**)** and the building energy consumer device (Demand Side Management).

As summarized in Table 2, the state-of-the-art report, which aims to present the modeling platforms used by the articles to build the Building Energy Management Systems (BEMS).

Table 2: Platforms Comparison.

Language	**Platform**	**Modeling Approach**
JAVA	JADE	Decision Making
JAVA	ZEUS	statistical analyses
PYTHON	VOLTRON	Report generation,
	Voyager (Commercial)	NE
	Aglets	NE
	Spring	Decision Making

According to [6], in summary, JADE is best suited for advanced developers building stable and scalable, MAS control for microgrids. ZEUS could be best employed by new developers for rapid prototyping and testing of, MAS concepts for microgrid control. VOLTRON is best employed by facilities and building managers for managing sensors and instrumentation data.

The following section describes the methodology that is used in this research work and makes it possible to design the DBEMS.

III. Agent-Oriented Methodology for DBEMS

According to [9] , MAS may consist of large numbers of agents operating in rapidly evolving dynamic environments. Since data and environment are decentralized, the roles and responsibilities of intelligent agents need to be clearly defined to resolve potential conflicts, that may arise through agent interactions. Multi-agent system is a complex software, for which appropriate engineering methods are required to build it correctly.

Several agent-oriented methodologies with a clear organizational vision have been created in recent years to support modeling complex systems. The methodologies identified in the literature are Agent, Group, and Role (AGR) [27], Agent-Oriented Software Process for Complex Engineering Systems (ASPECS) [28], Extended Gaia [7], Engineering for Software Agents (INGENIAS) [29], Model of Multi-Agent Systems Organization (Moise+) [30] and OperA [31]. Based on [32], ASPECS is an appropriate methodology for considering both the MAS and the organizational consideration of the system. Using ASPECS, the building system is modeled as a set of organizations with different levels of abstraction, in which each organization represents a subsystem, with a collection of roles played by agents that interact while executing their role plans. Roles operate through their capacities. ASPECS is a methodology associated to an implementation and deployment framework: SARL/Janus [21]. However, because of the DBEMS and DBOS context, the selection of the implementation framework is still considered as an open issue. Indeed, such systems have specific properties such as the amount of computing power that may make SARL or Janus unable to be used without adaptation.

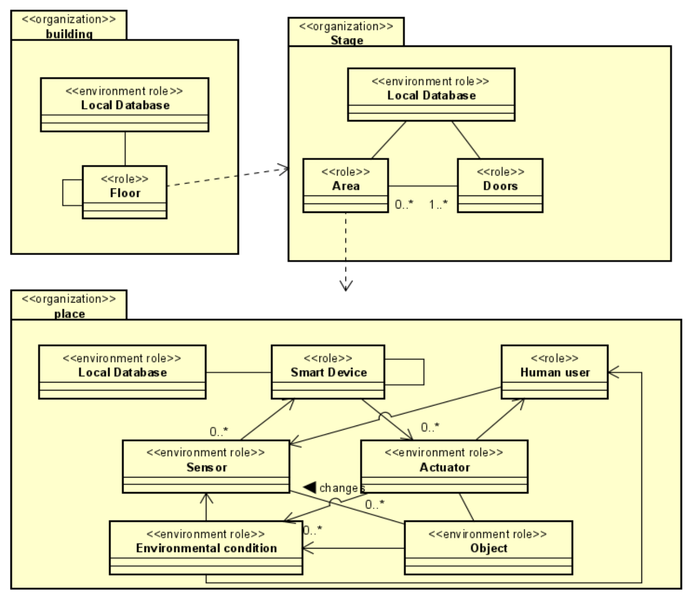

Figure 1: Schematic diagram for DBEMS (ASPECS Organization Diagram)

IV. Agent-Model for DBEMS

From organization theory and systemic point of view, the smart building could be considered as composed of sub-systems that are each described with an organizational point of view in turn. Consequently, the agent model that is proposed for DBEMS is structured in three main levels (illustrated in Figure 1 with the ASPECS agent-oriented modeling methodology):

- **Building** – The whole system that is representing the smart building is represented by the "building" organization. Each organization represents a part of a system in which entities (autonomous or not) are interacting by playing several roles for solving a common problem in the context of the organization. Consequently, the building system is decomposed into floors. Each floor is represented by a specific role that allows to describe the interaction of a single floor with the other entities in the building, and to semi-formally describes the expected behavior of a floor. . This behavior is based on the optimization of the energy consumption for the given floor (and its sub-systems) and to interact with the other floors (with are supposed to be autonomous entities) to reach a common agreement for optimizing the global energy consumption at the building level. It is worth to say that the floor entities are also considered other criteria than the energy consumption in their decision process, e.g., realization of tasks, increasing of the building user comfort, etc. Since the behavior of a floor corresponds to those of a complex system, it is necessary to define more in detail the floor. This sub-system is described in the second level of organization below. To save any data at the building level, the floor entity is linked to an entity that is managing a local database. The structure of the database depends on the detailed behavior of the floor that will be defined in further works.

- **Stage** – Organization stage represents a floor of in a building. From a structural point of view, a stage is decomposed in areas that may represent rooms, corridors, and halls, for examples. A specific role is defined for representing the areas and the associated and expected behavior for them. In a similar approach as in the more abstract level, this expected behavior is related to the optimization of the energy consumption of the areas (and its components) regarding the tasks and goals that must be fulfilled by the area itself. The area's behavior is influenced by the neighbor areas through a connector entity, named door. Door is considered as a role since it may exhibit an autonomous behavior, such as an automatic door. As in the higher abstraction level, an entity managing the local data is introduced to allow the area and door entities to store data. Since the area behavior is too complex to be designed, the organization "place" is introduced for supporting its specification.
- **Place** – Each area in the smart building is modeled with the organization "place". The entities in a place are the followings:
    - **Environmental condition:** represents the set of environmental variables that must be supported and computed for a place. Examples of environmental conditions are the temperature, the humidity level, or the natural lightning for examples. These environment conditions are influences by the other entities in the place and described below.
    - **Object:** represents the entities that are physical objects in the place. The definition of these objects in the model allows to specify how they are influencing the environmental conditions, but they are not exhibiting an autonomous behavior.
    - **Sensor:** represents the devices that read variables (temperature, humidity, presence, etc.) in the environment in which they are inserted in. The type of the sensors will be refined in further works and will depends on a specific application use case.
    - **Actuator:** represents the devices that can act in the environment, such as switching on or off an equipment, opening a door, etc.
    - **Smart device:** represents the dynamic behavior of the entity that is composed by sensors, actuators, and embedded decision-making software. In other words, a smart device is an agent that is interconnected with sensors and actuators, in the sense that they can perceive and react to changes in the environment in which they are inserted in, depending on the behavior assigned to them. The behavior of each smart device contributes to the global behavior of a place that is supposed to optimize the energy consumption according to the constraints and tasks that must be individually realized by the smart sensor. As an autonomous entity, the smart sensor is also able to interact with the other smart devices to exchange data, or to negotiate action plans.
    - **Local database:** each smart device can save or read data from a local database that is shared among all the smart devices.
    - **Human user:** the human users in the system are included and may interact directly with the actuators. This interaction will indirectly influence the behavior of the smart device. In a similar approach, sensors can extract data related to human users, such as their position or their presence. Finally, if the smart building is executed in the context of a simulation, it is necessary to model the behaviors of the human users and how they are influenced by the environmental conditions. The organizational approach allows to specify the human user's behavior as a specific role.

V. Conclusion and Perspectives

Currently, there is a trend globally to use artificial intelligence in various sectors, such as industry, healthcare, and security, to solve problems and improve efficiency. The goal is to create smart systems. This trend can also be seen in building management, where the use of MAS through BOS and IoT can improve user well-being by ensuring energy efficiency, access control, building maintenance management, and other services in real time.

In this paper, a new agent-based approach is proposed for designing and implementing a DBEMS and its associated DBOS to improve energy efficiency and sustainability in smart buildings. This approach is based on the ASPECS methodology that allows to specify and design complex MAS and implement them using the SARL agent-oriented programming language and its associated execution environment Janus. An organizational model is proposed based on the definition of three major organizations (building, stage, place) and their respective roles and behaviors.

The detailed behaviors of the different roles, as well as the formal definition of the interactions, will be defined in further works. This definition will be applied in a mockup of a smart building that will be built for giving a proof of concept. Then, the model will be applied to the smart buildings of the different use cases of the associated projects (virtual buildings in Zayed University, academic buildings of Belfort-Montbéliard University of Technology, public buildings in the Badevel village France, touristic buildings in Angola).

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