A MULTI-AGENT HOME AUTOMATION SYSTEM FOR POWER MANAGEMENT

Shadi ABRAS[§] Stéphane PLOIX[§§] Sylvie PESTY[§] Mireille JACOMINO[§§]

[§]*Laboratoire Leibniz-Institut IMAG*
CNRS, UMR5528, 46, Avenue Félix Viallet
38031 Grenoble, France.
Phone: 00 33 4 76 57 50 59, Fax: 00 33 4 76 57 46 02
Email: {Shadi.Abras, Sylvie.Pesty}@imag.fr

[§§]*Laboratoire d'Automatique de Grenoble*
CNRS, UMR5528, BP 46
38402 Saint Martin d'Hères, France.
Phone: 00 33 4 76 82 62 44, Fax: 00 33 4 76 82 63 88
Email: {Stephane.Ploix, Mireille.Jacomino}@inpg.fr

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Abstract: This paper presents the principles of a Home Automation system dedicated to power management that adapts power consumption to available power ressources according to user comfort and cost criteria. The system relies on a multi-agent paradigm. Each agent is embedded into a power resource or an equipment, which may be an environment (thermal-air, thermal-water, ventilation, luminous) or a service (washing, cooking), and cooperates and coordinates its action with others in order to find acceptable near-optimal solution. The control algorithm is decomposed into two complementary mechanisms: an emergency mechanism, which protects from constraint violations, and an anticipation mechanism, which computes the best future set-points according to predicted consumptions and productions and to user criteria. The paper details a negotiation protocol used by the both mechanisms and presents some preliminary simulation results.

1 INTRODUCTION

For the next decades, the two major problems concerning energy are the greenhouse effect and the depletion of petrol resources especially the energy provided by oil and gas. Therefore, by conscience or by necessity, the resort to renewable resources of energy such as wind or solar radiations, arrives in the buildings knowing that the building represents 47% of the energy consumption and it is responsible for 25% of the greenhouse effect (Fontaine, 2003). Moreover, undoubtedly, the user will be confronted to variable tariffs of energy according to hour and days and to energy producers. It is in this varied and dynamic context of production and consumption of energy that a building, equipped with a Home Automation system to control the energy, takes its importance. The role of a Home Automation system dedicated to power mangement is to adapt the power consumption to the available power resources in taking into account user comfort criteria: it permits to limit the use of supplementary resources requiring additional investment and to avoid the expensive need of storage. A Home Automation system has to reach a compromise between the priorities of the user in term of comfort and in term of cost while satifying technological constraints of equipments and user's comfort constraints.

This problem can be formulated as a scheduling problem. In (Ha et al., 2005), a solution based on a Resource Constrained Project Scheduling Problem (RCPSP), to improve the management of thermal-air equipments, is presented. Its aim is to satisfy resource constraints by coordinating the control of thermal-air equipments. Nevertheless, this approach requires precise predictive models and RCPSP techniques are hardly adaptable to the context of multi energy resources and multi equipments. In (Ha et al., 2006), an anticipation mechanism using Bellman-Ford's algorithm (Cherkassky et al., 1994) is presented for solving the problem of managing predicted events in Home Automation system. The principal advantage of Bellman-Ford's approach is that the optimal solution is guaranteed (if exist) but the major disadvantage is the high order of complexity.

An alternative approach is to use Multi-Agent techniques. Algorithms based on Multi-Agent Systems are nowdays used in several areas such as Computer science or Automatic Control. The first MAS approach for energy distribution have been presented in (Jennings, 1994) and (Hägg and Ygge, 1995). (Kok et al., 2005) presented a market-based control concept for the supply and demand matching (SDM) in electricity networks. Its aim is to propose a Multi-Agent system for electronic market. Its purpose is to control tasks in future electricity network which is expected to come along into a network of networks in which a vast number of system parts communicate and coordinate with each other.

The developments of solutions based on Multi-Agent Systems, well suited to solve spatially distributed and opened problems, permit to imagine an intelligent Multi-Agent Home Automation system. This paper presents a Multi-Agent Home Automation System (MAHAS). It focuses on the definition of a negotiation protocol between agents embedded into equipments as well as in energy resources. The paper is organized as follows: section 2 describes, in a general view point, the Multi-Agent Home Automation System. Section 3 presents the two main mechanisms of this system: *the emergency and anticipation mechanisms*. Section 4 presents, in detail, the principle of the negotiation protocol for emergency and anticipation mechanisms. Then, the paper presents some preliminary results and highlights the future work.

2 MULTI-AGENT HOME AUTOMATION SYSTEM

The three main features of the Multi-Agent Home Automation System (MAHAS) (Figure 1), which consists of agents embedded into energy resources and into the different equipments, are the following:

- Distributed: the energy resources and equipments are distributed spatially and their control systems are independent.
- Flexible: the energy resources are few but also some equipments can accumulate energy (thermal-air, thermal-water) or satisfy with delay to demands of services (washing service, cooking service).
- Opened: the number of connected resources and equipments may vary with time (equipments or resources can be connected or disconnected) without having to completely redefine the control mechanism.

In Multi-Agent Systems, the notion of control involves operations such as coordination and negotiation among agents, elimination of agents that are no longer present and adding new agents when needed.

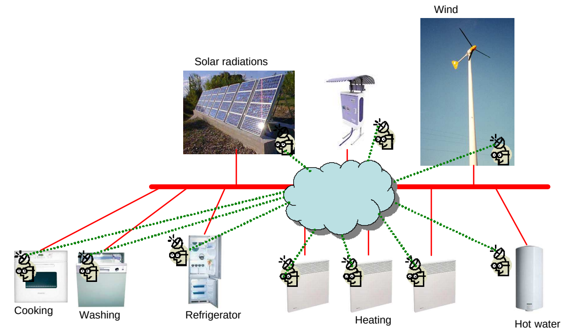

Figure 1: *Energy network and communication between embedded agents housing.*

2.1 Agent Architecture

The main functionalities of an agent in MAHAS are shown in figure 1.

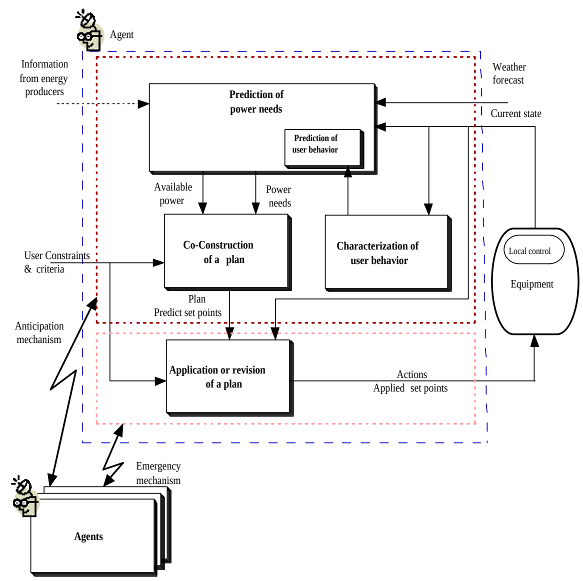

Figure 2: *Structure of an agent in MAHAS.*

Depending on weather forecast, energy resource information and user habits:

- Resource agent calculates the available power resources: to determine what is and what will be the available power. For the moment, the energy resources are represented by a virtual energy resource which manages operations between the different resources.
- Equipment agent calculates the prediction of power consumption: to determine what are the future power needs taking into account the usual behavior of users.

From these predictions and in taking into account the user constraints and criteria, a plan is jointly constructed by the different agents which negotiate their future power consumption (section 4). The construction of a plan by cooperating and negotiation between agents is called the anticipation mechanism (subsection 3.2). This plan includes predicted values of the variables that characterize the environments (for example: the room temperatures) or the end dates of services (an oven for instance). Then, this plan is applied but it can be modified in case of unforeseen perturbations (for example: consumption peak). If the perturbation is too important, the agents renegotiate in order to recalculate plans. The real time adjustment of a plan in order to match constraints is achieved by cooperation between agents: it is called the emergency mechanism (subsection 3.2).

A third mechanism may exist: the local control mechanism i.e. the controllers endowed into equipments by manufacturers. Its time response is very fast. This mechanism receives set points from the agents. Besides, some information on its current state (power needs) are sent back to the agents so that they can be taken into account in the future plans. This mechanism is not mentioned in this paper because other mechanisms are slower and local controls are assumed to be transparent.

One of the objectives of the MAHAS is to fulfil user comfort. A notion bound directly to the comfort is the satisfaction function (Simonin, 2001). Satisfaction functions have been defined for energy resources as well as for equipments. The equipment satisfaction function will be expressed by a function defined on the domain of the characteristic variable corresponding to the interval $[0, 100\%]$ where zero means ”inadmissible” and 100% ”perfect”. For example: thermal air envronment satisfaction function, which is defined on room temperature value corresponding to an interval selected by user, can be represented by figure 3. The resource satisfaction function is also ex-

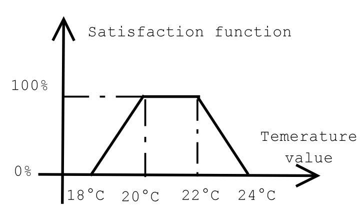

Figure 3: *Thermal air environment satisfaction function.*

pressed by a function where characteristic variable corresponds to producted power. When the producted power exceeds the resource capacity, the satisfaction function falls to 0%. The nominal power of the resources corresponds to 100%.

3 AGENT MECHANISMS

3.1 Emergency mechanism

The emergency mechanism is a real time adjustment mechanism which is triggered when the level of satisfaction of an agent falls below weak values (10% for example). This mechanism, which relies on the negotiation protocol (section 4), permits to react quickly to avoid violations of energy constraints and to guarantee a good level of user satisfaction. It is considered as transparent for anticipation mechanism because emergency adjustments have very small impact on the period considered by anticipation.

Therefore, the emergency mechanism adjusts, in real time, set points coming from the predict plan, equipment current state (equipment satisfaction value) and constraints and user criteria. The predict set points can be directly transmitted to the local control mechanism or modified in case of emergency.

When the emergency mechanism is triggered, each agent has multiple roles:

- It evaluates, at predefined intervals, its current satisfaction. Therefore, it uses an infinite internal loop. This interval of time is called checking period.
- It can request help from other agents, by sending messages, when its satisfaction falls below a level of emergency.
- It analyzes the other agent demand and makes some propositions.
- When it receives some answers to its demands, it chooses and accepts the interesting propositions (to have a maximum value of satisfaction).
- It can allow, according to received messages, to activate or inactivate its associated equipment.

If an equipment agent satisfaction decreases, it sends messages requesting *help* from resource agents to initiate a negotiation. Other agent answers are collected during a fixed delay and are sorted out according to their satisfaction values. Then a solution which maximizes the satisfactions of equipments and resources is chosen.

3.2 Anticipation mechanism

The emergency mechanism is sufficient to avoid constraint violations but a MAHAS can be improved in order to avoid emergency situations. This improvement is obtained thanks to the anticipation mechanism. The objective of this mechanism is to compute the predict set points depending on predictions of consumptions and on predictions of energy resources. The anticipation mechanism relies on the fact that there is on the one hand, some electric equipments which are capable of accumulating energy and on the other hand, some services that have a variable date as for their execution: some services can both be delayed or advanced. From these preliminary observations, it is possible to imagine that if the equipment consumption can be anticipated, there is a way to organize it better.

The anticipation mechanism relies on learning algorithms which are not explained in this paper. As for the emergency mechanism, the anticipation mechanism relies also on a negotiation protocol (section 4). It works on a time window (anticipation period) larger than checking period and works with average values of energy, because it is difficult to make precise predictions, in order to keep emergency mechanism transparent for it.

During anticipation mechanism, each agent has multiple roles:

- When requested, it predicts future needs or resources over a given number of anticipation period. This period is a multiple of the checking period.
- It analyzes the other agent demands and makes some propositions.
- When it receives some answers to its demands, it chooses and accepts the best propositions (to have a maximum value of satisfaction for all).
- It calculates, according to received messages, its predict set points.

The message exchanges between agents during emergency and anticipation negotiations are defined by a protocol which is presented in the next section.

4 NEGOTIATION PROTOCOL

The negotiation protocol has been defined on the basis of contract negotiation model (Mathieu and Verrons, 2004), CNP protocol ((Smith, 1980), (Yang et al., 1998)) and algorithms of distributed constraint satisfaction problems (Makoto and Hirayama, 2000). This protocol can be used for agent mechanisms according to checking period for emergency mechanism and anticipation period for anticipation mechanism.
The negotiation protocol is characterized by successive messages exchanged between resource and equipment agents. Agents exchange messages for two objectives:

- avoiding to overpass the maximum available energy.
- keeping the satisfactions over a certain value: acceptable characteristic variable for environments which accumulate energy and acceptable shifts for services.

The agreements issued from negotiations are based on satisfactions of equipments (representing user comfort criteria) and on satisfactions of resources (representing the ideal power production).

4.1 Phases of negotiation protocol

The negotiation protocol (Figure 4) may be decomposed into three phases:

- Energy demand phase: During this phase, the resource agents request equipment agents for propositions that lead to satisfactions greater or equal to a attempting satisfaction value and wait for equipment agent answers.
- Proposition phase: A conversation between resource agents and equipment agents takes place during which new propositions are exchanged. Then, resource agents analyse these propositions and can either accept them or request for equipment agents to send all the solutions for a new attempting satisfaction.
- Final decision phase: The resource agents take the decision, so equipment agent demands can either be accepted or refused.

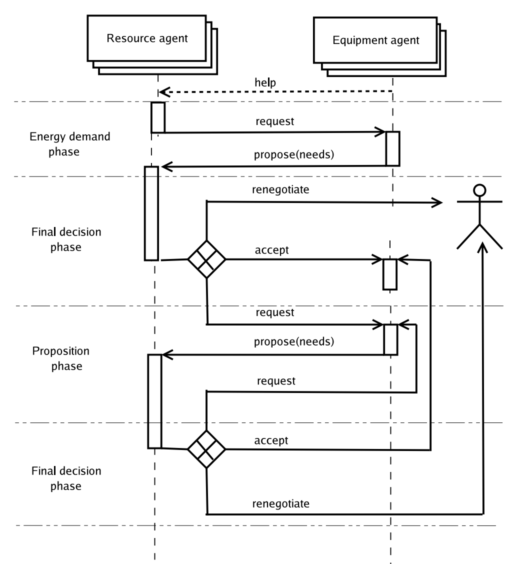

Figure 4: *Negotiation protocol.*

The global success of negotiation is reached when all equipments have reached quite similar satisfactions. When an event is under negotiation and that no solution is possible, a negotiation with user starts to modify user constraints.

4.2 Primitives of negotiation protocol

The primitives of negotiation protocol are decomposed into two groups.

Energy resource agent primitives:

- Request: The resource agents intiate a negotiation by asking equipment agents to send them their power needs in order to reach a satisfaction greater or equal than an attempting satisfaction provided by resource agent. It collects the answers, it verifies if there is a global solution. Next request indicates to the equipment agents that there is no solution for the attempting satisfaction because the energy asked by equipments overpasses the maximum available energy provided by resources, so resource agents request equipment agents to send them other propositions about their needs for a smaller attempting satisfaction. A request may be defined as:
  `request(mechanism-name, period, satisfaction)`
  where *mechanism-name* has two values "emergency" or "anticipation". *period* value may be equal to the checking period or to the anticipation period. *satisfaction* is the attempting satisfaction value provided by resource agent.
- Accept: This message indicates to equipment agents that one of the proposed solutions has been accepted by a resource agent. This message may be defined as:
  `accept(proposition)`
  where *proposition* is one of the solutions proposed by equipment agents.
- Renegotiate: This message indicates that there is no solution that satisfies the constraints defined by user. A negotiation with user starts. This message may be defined as:
  `renegotiate(constraints)`
  where *constraints* is the set on constraints that cannot be satisfied.

Equipment agent primitive:

- Help: This message initiates a negotiation. It is sent when an emergency situation is detected or foreseen for the next checking period. It may be defined as:
  `help()`.
- Propose: This message replies to a request from resource agents. It contains a set of propositions of possible sequence of energy consumption covering one period for emergency mechanism or several periods for anticipation mechanism. This list may be empty if there are not any possible propositions. This message may be defined as:
  `propose(set-of-powers, satisfactions)`
  where *set-of-powers* are the propositions of equipment agent during the checking or anticipation period. *satisfactions* are the predict satisfaction values corresponding to each proposition.

4.3 Preliminary results

In this subsection, an illustrative example is presented for Home Automation system which consists only of thermal air environments which are the largest part of consumption of electricity in buildings in winter. This system consists of three electrical heaters of $1kW$ each and a $2100W$ energy resource knowing that the initial temperatures in rooms are fixed to 18^oC and desired value of temperature is 20^oC (satisfaction function takes its values between 0% for 18^oC and 100% for 20^oC). The temperature

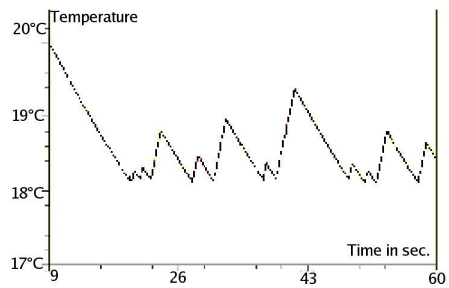

Figure 5: *Simulated temperature in room 1.*

values for other rooms are quite similar to room 1 (Figure 5). The control system, in this example, is capable of maintaining temperature values for each environment above 18^oC: because of the lack of power, the temperatures remain close to the minimum acceptable value. An example of exchanged messages between energy resource agent and equipment agents is presented below:

```
Heater2:  help(heater2)
Resource:  request
("emergency",15s,90%)
Heater2:  propose (900W,90%)
Heater1:  propose (900W,90%)
Heater3:  propose (900W,90%)
Resource:  request
("emergency",15s,80%)
Heater3:  propose (800W,80%)
```

```
Heater1:  propose (700W,70%)
Heater2:  propose (750W,75%)
Resource:  request
("emergency",15s,70%)
Heater1:  propose (650W,65%)
Heater3:  propose (700W,70%)
Heater2:  propose (600W,60%)
Resource:  accept(650W, 600W, 700W)
Heater1:  help(heater1)
Resource:  request
("emergency",15s,90%)
Heater2:  propose (900W,99%)
Heater1:  propose (900W,90%)
Resource:  accept(900W, 900W, 0W)
```

Heater2 agent has requested help from resource agent to start the negotiation. Then a conversation between agents takes place during which resource agent requests equipment agents to send their propositions for an attempting satisfaction value, and during which equipment agents send their propositions, which may be empty, to resource agent.
In the absence of MAHAS but with an unbalancing system, always the same heater is penalized when all heaters simultaneously consume energy according to user predefined priorities. Contrary to MAHAS, the maximum user satisfaction cannot be guaranteed.

5 CONCLUSION AND PERSPECTIVES

This paper has presented a Multi-Agent Home Automation system allowing the agents to cooperate and coordinate their actions in order to find accepted near-optimal solution for power management. Negotiation protocol has been detailed. The experimental results have showed the performance of the negotiation algorithm. This paper have provided evidence that cooperation and negotiation capabilities of Multi-Agent systems can be advantageously used in automatic control systems for spatially distributed and opened systems. The implementation of a simulator for the emergency and anticipation mechanisms is not finished yet. This simulator will be tested on a reduced-scale model of an apartment composed of two thermal environments ans several services (washing machine,. . .). Each environment contains a reduced-scale electric heater, a temperature sensor and a micro-controller card with an embedded Java Virtual Machine.

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