Preface

The present book includes a set of selected papers from the third "International Conference on Informatics in Control Automation and Robotics" (ICINCO 2006), held in Setúbal, Portugal, from 1 to 5 August 2006, sponsored by the Institute for Systems and Technologies of Information, Control and Communication (INSTICC).

The conference was organized in three simultaneous tracks: "Intelligent Control Systems and Optimization", "Robotics and Automation" and "Systems Modeling, Signal Processing and Control".

The book is based on the same structure.

Although ICINCO 2006 received 309 paper submissions, from more than 50 different countries in all continents, only 31 where accepted as full papers. From those, only 23 were selected for inclusion in this book, based on the classifications provided by the Program Committee. The selected papers also reflect the interdisciplinary nature of the conference. The diversity of topics is an important feature of this conference, enabling an overall perception of several important scientific and technological trends. These high quality standards will be maintained and reinforced at ICINCO 2007, to be held in Angers, France, and in future editions of this conference.

Furthermore, ICINCO 2006 included 7 plenary keynote lectures and 1 tutorial, given by internationally recognized researchers. Their presentations represented an important contribution to increasing the overall quality of the conference, and are partially included in the first section of the book. We would like to express our appreciation to all the invited keynote speakers who took the time to contribute with a paper to this book, namely, in alphabetical order: Oleg Gusikhin (Ford Research & Adv. Engineering), Norihiro Hagita (ATR Intelligent Robotics and Communication Labs), Gerard T. McKee (University of Reading) and William J. O'Connor, University College Dublin.

On behalf of the conference organizing committee, we would like to thank all participants. First of all to the authors, whose quality work is the essence of the conference and to the members of the program committee, who helped us with their expertise and time.

As we all know, producing a conference requires the effort of many individuals. We wish to thank all the people from INSTICC, whose work and commitment were invaluable.

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A Multi-agent Home Automation System for Power Management

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Abstract. This chapter presents the principles of a Home Automation system dedicated to power management that adapts power consumption to available power resources 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 chapter details a negotiation protocol used by the both mechanisms and presents some preliminary simulation results.

Keywords. Home automation system, multi-agent systems, automatic control, negotiation and cooperation, power management.

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 [1]. Moreover, undoubtedly, the user will be confronted by variable tariffs of energy according to the hour and the days and to the 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 management is to adapt the power consumption to the available power resources taking into account user comfort criteria: it permits to limit the use of supplementary resources which require 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 satisfying technological constraints of equipment and user's comfort constraints.

This problem can be formulated as a scheduling problem. In [2], 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 equipment. Nevertheless, this approach requires precise predictive models and RCPSP techniques are hardly adaptable to the context of multi energy resources and multi equipments. In [3], an anticipation mechanism using Bellman-Ford's algorithm [4] is presented for solving the problem of managing predicted events in a 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 nowadays used in several areas such as Computer science or Automatic Control. The first MAS approach for energy distribution have been presented in [5] and [6]. Kok et al. [7] put forward a market-based control concept for the supply and demand matching (SDM) in electricity networks. It aims to propose a Multi-Agent system for the electronic market. Its purpose is to control tasks in future electricity network which is expected to develop 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 chapter 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 chapter 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 chapter presents some preliminary results and highlights the future work which will be done.

2 Multi-Agent Home Automation System

The three main features of the Multi-Agent Home Automation System (MAHAS) (Fig. 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.

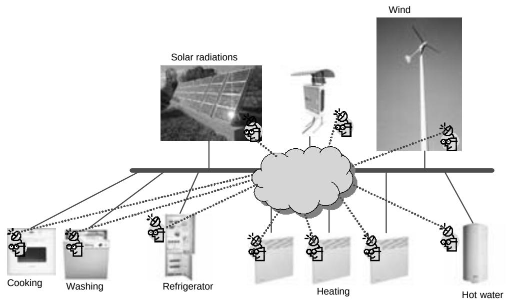

Fig. 1 Energy network and communication between embedded agents housing.

2.1 Agent Architecture

The main functionalities of an agent in MAHAS are shown in Fig. 2.

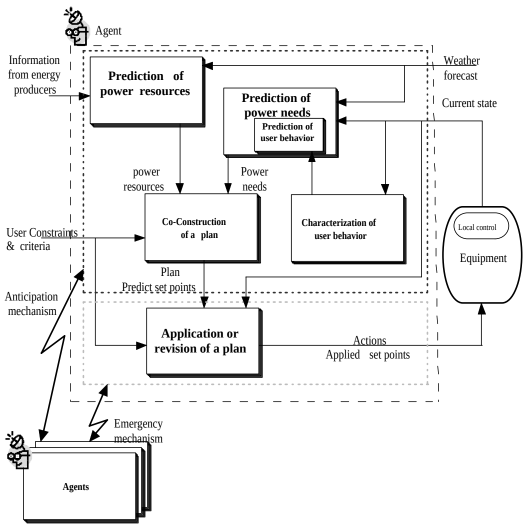

Fig. 2 Structure of an agent in MAHAS.

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 behaviour of users.

From these predictions and taking into account the user constraints and criteria, a plan is jointly constructed by the different agents which negotiate their future power consumption (Sect. 4). The construction of a plan by cooperating and negotiation between agents is called the anticipation mechanism (Sect. 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 so 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 (Sect. 3.2).

A third mechanism may exist: the local control mechanism i.e. the controllers endowed into equipments by the manufacturers. It's 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 chapter 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 [8]. 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% is "perfect". For example: thermal air environment satisfaction function, which is defined on room temperature values corresponding to an interval selected by user, can be represented by Fig. 3.

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

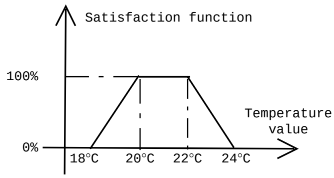

Fig. 3 Thermal air environment satisfaction function.

3 Agent Mechanisms

3.1 Emergency Mechanism

The emergency mechanism is a real time adjustment mechanism which is triggered out when the level of satisfaction of an agent falls below the weak values (10% for example). This mechanism, which relies on the negotiation protocol (Sect. 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 predicted plan, equipment's current state (equipment satisfaction value) and constraints and user criteria. The predicted 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 predicted 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 chapter. As for the emergency mechanism, the anticipation mechanism relies also on a negotiation protocol (Sect. 4). It works on a time window (anticipation period) larger than the 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 predicted 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 the contract negotiation model [9], CNP protocol [10] [11] and algorithms of distributed constraint satisfaction problems [12]. This protocol can be used for agent mechanisms according to the 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:

– To avoid to overpass the maximum available energy.
– To keep 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 (Fig. 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 an 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.

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

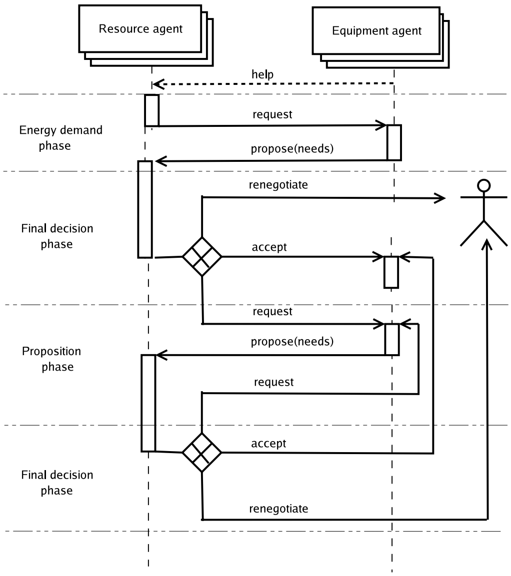

Fig. 4 Negotiation protocol.

4.2 Primitives of Negotiation Protocol

The primitives of negotiation protocol are decomposed into two groups.

Energy Resource Agent Primitives:

– Request: The resource agents initiate 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 exceeds 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 the equipment agents.
– Renegotiate: This message indicates that there is no solution that satisfies the constraints defined by the user. A negotiation with the user starts. This message may be defined as:

```
renegotiate(constraints)
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where *constraints* is the set of constraints that cannot be satisfied.

Equipment Agent Primitives:

– 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 sequences of energy consumption covering one period for an emergency mechanism or several periods for an 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 predicted 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 1 kW each and a 2100 W energy resource knowing that the initial temperatures in rooms are fixed to 18°C and the desired value of temperature is 20°C (satisfaction function takes its values between 0% for 18°C and 100% for 20°C). The temperature values

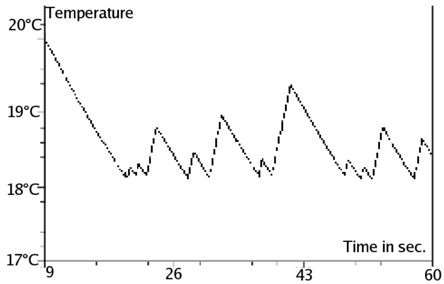

Fig. 5 Simulated temperature in room 1.

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

```
Heater2: help(heater2)
Resource: request ("emergency",15s,90%)
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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 the resource agent to start the negotiation. Then a conversation between the agents takes place during which the resource agent requests the equipment agents to send their propositions for an attempting satisfaction value, and during which the equipment agents send their propositions, which may be empty, to the 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 the user's predefined priorities. Contrary to MAHAS, the maximum user satisfaction cannot be guaranteed.

5 Conclusions and Perspectives

This chapter has presented a Multi-Agent Home Automation system allowing the agents to cooperate and coordinate their actions in order to find the accepted near-optimal solution for power management. Negotiation protocol has been detailed. The experimental results have showed the performance of the negotiation algorithm. This chapter 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 and 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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