Viewing Home Automation Systems as Multiple Agents Systems

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Abstract

In this paper we propose to use the formalism of Multiple Agent Systems (MAS) to the study of Home Automation Systems, which consist of a set of appliances and devices for house management, connected by a communication line. By adopting this point of view, it is possible to provide instrumental definitions and characterizations of basic properties that allow to investigate the structure of the system and to evaluate its performances in coherent conceptual framework.

Abstract

In questo lavoro si propone di applicare un formalismo basato su quello dei Sistemi a Multi-Agente (MAS) allo studio dei sistemi domotici di automazione domestica. L'adozione di tale formalismo garantisce la possibilità di definire e caratterizzare proprietà di base, che sono rilevanti per descrivere la struttura del sistema e per valutare le sue prestazioni.

1 Introduction

The paradigm of Multiple Agents System (MAS) is widely used in several areas of informatics, automation and robotics (see [8], [11] and the references therein). The aim of this preliminary, short paper is to investigate the possibility of using in a profitable way such paradigm in the analysis and study of home automation systems.

Home automation systems consist essentially of a number of appliances and devices for house management, which are connected by a communication line of some kind. Appliances and devices are endowed with individual control systems that, in a more or less sophisticated way, can govern their behaviour and exchange and process data and information. In addition, the system may include a central control unit, which, up to a certain degree, can coordinate the actions of the different elements. At the present stage of development, home automation systems are mainly conceived for regulating the concurrent use of limited resources, like electric energy or hot water, and for facilitating operation, monitoring and survey of groups of appliances. In any case, a home automation system can roughly be viewed, in a sense, as a partially distributed control systems, whose components are essentially autonomous, possess a certain degree of intelligence and share some common objectives.

Although this description fits well with the MAS paradigm, provided some basic features of the system are suitably specified, this latter does not seem to have been completely exploited in the study of home automation systems and related problems. In facts, except in some cases (see for instance [9] and related works), design and development of home automation systems have progressed mainly without the help of a unifying conceptual framework of some kind. The main disadvantage of this situation is that, in general, it results difficult to determine precisely the key features of a home automation system, as well as to define widely acceptable criteria for evaluating its performances and, what is perhaps more important, to develop a satisfactory, systematic design methodology. The use of a formalism derived from that of MAS can, in principle, respond to these needs, providing a suitable conceptual framework and appropriate methodological tools.

In order to show this, we, first, give a general description of the structure of a home automation system, referring, for sake of exemplification to the ARISTON-Digital structure described in [2], [4], [3]. Then, we propose a conceptual model for a system of that kind that is akin to the MAS formalism. Properties and features of such model are described and investigated in connection with typical problems arising in the area of home automation. Our aim, at this preliminary stage of study, is mainly that of establishing some key points in the analysis of the system's structure and behaviour, which are essential in evaluating its performances and, then, in improving them. Summarizing, these concern the possibility of executing given tasks, which involve one or more appliances and devices at a time, by respecting given constraints, generally about the load and/or energy consumption, and achieving a suitably defined degree of user's satisfaction. Although, for the moment, we can do little more than formalizing properties and problems, we believe that the suggested approach can provide useful answers to these latter in the next future.

2 Home Automation Systems

Home automation systems basically consist of a number of appliances, which can exchange information on a communication network of some kind. The system may include a central control unit and appliances may be endowed with individual control systems, so to enable the overall system to manage electric energy consumption or to perform specific tasks that require coordination and/or cooperation. Just to fix the ideas, we can make reference to the Ariston-Digital structure of a home automation system described in [2], [4], [3]. In the considered system, the appliances are connected to the power line through a special device called Wr@p Enabled Smart Adapter (WESA) (see [7] for a discussion of this device's functionalities), whose basic function is that of allowing communication using the power line as carrier and employing a suitable protocol. The WESA is capable to measure the electric load generated by the connected appliance and, provided it has additional information about the appliance's behaviour, it can monitor its functions and detect its status. Appliances endowed with a suitable interface can also be controlled by WESA. In this structure, the WESA nodes concentrate (part of) the intelligence of the overall system and they, together with a central control unit, if it is present, implement the software procedures which allow it to work as a (partially) distributed control system. The system or single parts of it may interact with human users through the interfaces of the appliances or through other specific interfaces. In addition, the system may be endowed with gateway(s), so to allow communication with remote locations. An important, further element of the system is represented by a power meter, which is able measure the electric load imposed at each time on the energy source and to inform the elements of the home automation system about the quantity of electric energy that is available (see [6]). In standard installations, the meter is coupled with a power limiter that, according to some specific procedure, may disconnect the energy source in case of excessive load. This action, which causes a black out in the house, must be avoided by a proper functioning of the home automation system (see [1], [5]).

More precisely, among the tasks of the home automation system, those of major concern at the present stage of development consist in

- regulating energy consumption, in the sense of avoiding peaks in the electric load that exceed either fixed or time depending thresholds and, possibly, of planning energy use according to tasks and to time varying cost;
- monitoring the behaviour of different appliances and, possibly, detecting and signalling malfunctions or failures;
- facilitating the interaction with human users by allowing remote control, planning and monitoring.

Concerning the first point, namely the regulation of energy consumption, in case of conflict between appliances the system has to assign priority and to distribute the available energy accordingly. The development of efficient policies for assigning priorities, which take into account the peculiarities of the tasks assigned to the single appliances and the preferences of the human user is probably the key area where the MAS formalism could result useful in analysing and, then, improving the system's performances. Similar remarks apply to the second point, for which, in addition, are of particular importance the kind and quantity of data the system is able to process and the way in which it can extract structured information from them. This is also relevant for the third point, which requires the development of simple system's architectures and easiness of communication between agents and human users.

3 A general MAS model for home automation systems

In order to consider a home automation system as a MAS, we propose, in the following, a series of points that have to be taken into account.

3.1 Agents in an home automation system

Natural agents in a home automation system are the appliances and the devices for house management that employ house resources like electric energy and hot water. Agent may be cognitive (at various degree), that is able to construct a model of the environment and endowed with situation awareness, or simply reactive. Up to some extent and in particular situations, it may be useful to consider human users also as agents of the system, although in general they should be considered as external agents. An agent of different kind that we assume is always present is the pair power-meter/power-limiter. In a sense, this allows us to consider the home automation system as constructed around the power-meter/power-limiter (PM/PL) agent.

3.2 Structure and configuration of the system

The PM/PL agent can detect the presence of other agents, when they are active, by observing the electric load, as this feature is intrinsic in its nature. In addition, it can communicate, according to specific modalities and protocols, this information together with others concerning energy availability or cost to other possible agents. It is not crucial, at this stage, to specify these aspects of communication, nor to discuss about communication channels. However, in order to have at least an elementary structure in the system, it is necessary to assume that there are agents which are able to receive (and possibly to employ in some way) this information. In the home automation system we described above, these are represented by the WESA nodes, which communicate via power line. The above considerations lead us to conclude that, in addition to the PM/PL agent, at least one cognitive agent, more precisely one agent which recognizes the information coming from the PM/PL agent, has to be present. In this way, we have an elementary structure in the considered home automation system and, once this is established, it derives that the basic activity concerning (auto)configuration of the system consists, for the general cognitive agent, in establishing a passive communication link with the PM/PL agent by receiving and recognizing the information it is dispatching. The cognitive agent can in turn communicate directly its presence, if it is able to do so, by sending appropriate messages, which will possibly be received by other agents. In any case, when it is active, the cognitive agent, as well as any other agent, signals indirectly its presence by imposing a load on the source of electric energy, which is detected by the PM/PL agent. It is advisable, in this situation, that the cognitive agents signals to the human user (possibly, if requested to do so) that it has established this passive communication with the PM/PL agent, so to inform him that the home automation system is configured and, at some level, that it is in function.

In accordance with the general MAS point of view, it is not assumed that among the agents that form the system there is one capable of controlling in a direct way, to some extent, the behaviour of the others. This, in facts, would be a scarcely realistic assumption, as, in general, appliances and devices of different brands may cohabit in the same house and may be added or removed freely by owners at any time, making practically impossible to design the system as a centralized control system.

3.3 System functioning

By a *(global) task* assigned to the system by the human user, we mean a set of individual tasks assigned simultaneously to a corresponding set of agents. To perform a given task will therefore imply that agents (generally more than one) will be asked to activate and will start to employ the common resources. Clearly, the concurrent use by several agents of electric energy may cause conflict due to limitation in the availability of such resource. Cognitive agents are made aware of this and may possess the ability to regulate their behaviour in order to limit energy consumption, while degrading their performances with respect to some *index of satisfaction* of the human user. A simple strategy for achieving this result could, for instance, be based on a first-arrived/first-served rule. When a task is assigned, the cognitive agent checks availability of electric energy on the basis of the information dispatched by the PM/PL agent and either it activates or it goes to a stand-by status, depending on the answer. Activation is delayed until availability increases because some other agent becomes inactive. The satisfaction indices related in some way to execution speed are, of course, sacrificed by this choice. It is reasonable to think that qualitatively better performances are obtained by integrating the above policy with the assignment of priorities, which can be communicated and recognized by cognitive agents. Priorities can either be fixed or dependent on task and/or agent's status and, according to the degree of intelligence of the agent(s), they can either be negotiable or not.

Similar considerations apply to the use of other resources, as for instance hot water, for which direct or, more likely, indirect measures of load or consumption can be made available. In general, in facts, the use of other resources than electricity is made possible by the action of devices that, in turn, employ electricity: for instance, the use of hot water may require electric pumps to circulate water or electric fans to assist combustion in gas boilers. Indirect information on the use and availability of such resources may therefore be acquired by the system, although this may require to endow it with specialized knowledge and intelligence, and dispatched to agents. In the structure of the home automation system we have briefly described in Session 1, this can for instance be done by instructing a WESA node to interpret the behaviour of a gas boiler that uses electricity for circulating water and regulating fluxes of combustion gases by monitoring the electric load it generates.

3.4 Agent and system classification

On the basis of the above remarks, we may classify agents at various levels, depending on their ability in handling information and in regulating their behaviour accordingly. Cognitive agents at the lowest level can only interpret the information about energy availability coming from the PM/PL agent and act consequently by activating or going to a stand-by status. Agents at the higher levels can, in addition, communicate their needs and priority in order to cause other agents to yield, can interpret requests and information about priority coming from other agents and can also negotiate between them. Roughly, we can think of three initial levels, characterized by increasing ability or *degree of intelligence*, described as follows:

- level 1: agent is able to receive and interpret the information dispatched by the PM/PL agent on energy availability and to control its behaviour accordingly;
- level 2: in addition to what is above, agent is able to communicate its needs, together with some indication of priority, so to cause other agents that recognize priority, if any, to yield, in case of insufficient resources;
- level 3: in addition to what is above, agent is able to receive and interpret messages from other agents about their needs and priority and to control its behaviour accordingly.

Further levels can be added in connection with further abilities and features and the resulting structure can be refined considering sublevels, in order to respond to different classification objectives. In turn, classification of agents may be used for developing a way to evaluate on a quantitative basis the *complexity* of the home automation system at issue.

3.5 Performance evaluation

After having chosen one or more satisfaction indices (for example, the execution time of tasks, or more complex ones), we can investigate the performances of the system with respect to those indices and to the requirement of keeping electric load below a given threshold at any time. To introduce some notations, let us denote by t a generic global task in a set of tasks T and by $E(t)$ the set of possible behaviours (viewed as collective behaviours of the single agents) of the home automation system that result in the execution of t. Then, for each $t\in T$ and $e\in E(t)$,denote by $I(t,e)\in R$ the value of a satisfaction index I associated to the execution e of task t and by $L(t,e)$ the maximum value of the electric load reached during execution. Now, we can formally state the following Definition.

<u>Definition 1</u> *A home automation system S is said (M,m)-performing with respect to a satisfaction index I, if, for given values M and m, for every task* $t\in T$ *there exists* $e\in E(t)$ *such that* $I(t,e) \geq M$ *and* $L(t,e) \leq m$.

The sense of the above Definition is clearly that a performing home automation system can execute every task in a sufficiently satisfactory way - defined by the choice of I and M - while respecting the constraint on the load - defined by the choice of m. Remark that the system itself has no global knowledge about $E(t)$ and therefore it cannot compute a priori $I(t,e)$ and $L(t,e)$, but, to some extent, this can be doneby the system designer. The property defined in Definition 1 can of course be weakened or made less crisp and more fuzzy, as it seems to be more appropriate for an artificial system that interacts strictly with human users, by limiting the requirement to a (fuzzy) subset of T or by introducing fuzzy satisfaction indices.

In addition, we can take into account disturbances of a certain kind acting on the system and robustness with respect to such disturbances. Practically, disregarding situations in which the malfunctioning of some agent prevents the system to execute a given task (since the control system of each agent is expected to take care of this), disturbances concern the information which is exchanged between agents and, more precisely, the load or, equivalently, the availability of electric energy. We can model such disturbances as errors in the measure of the load taken by the power meter component of the PM/PL agent and, in general, we can assume that such measurement error is limited in norm by αm, where $0 \leq \alpha \leq 1$ is known and m is the chosen constraint on the load. Then, we can state the following Definition.

<u>Definition 2</u> *Assume that, for given values M and m, the home automation system S is (M,m)-performing with respect to a satisfaction index I and assume that the measurement error of the PM/PL agent is limited in norm by* αm, *for a given* $0 \leq \alpha \leq 1$. *Then, the system S is said* α*-reliable if, for every task* $t\in T$ *there exists* $e\in E(t)$ *such that* $I(t,e) \geq (1-\alpha)M$ *and* $L(t,e) \leq (1-\alpha)m$, *i.e. it is* $((1-\alpha)M,(1-\alpha)m)$*-performing.*

3.6 Design and control problem

Remark that the above given Definitions describe properties which are independent from the actual behaviour of a home automation system S in relation to a given task. The fact of being *(M,m)*-performing, in facts, implies that the agents could chose individual behaviours that satisfy the user and that respect the constraint, but it does not guarantee that this will really happen. The design of a satisfactory home automation system S can therefore be split in two parts. The first one consists in making S *(M,m)*-performing and possibly α-reliable for assigned (intervals of) values of the parameters M, m and α. The second one consists in developing a control procedure that try to optimise the global behaviour, in the sense of maximising $I(t,e)$ over $E(t)$, while keeping $L(t,e)$ below the threshold. More or less the same remarks apply to the analysis of an existing system and, in both situations, the tools developed for designing and controlling or for analysing MAS's can be used (see, for an account of those, [8]).

4 Simulating domestic environment. An example

Simulation is a basic methodology for investigating features and behaviours of MAS's and it turns particularly useful in studying home automation systems, since experiments, even in an emulation environment, are costly and time consuming. Here, we briefly present and discuss the main lines of the development of a virtual environment that simulates a common domestic environment (see also [10]).

In designing this simulator, we guarantee the possibility of integrating into it, by means of suitable interfaces, objects of the real world, so to make virtual appliances and real ones to interact, if needed, for increasing realism and significance of simulations. This is facilitated by the choice of a software environment like NI LabView, which allows rapid prototyping and, by means of suitable hardware, easy interfacing between virtual environments and the real one. The domestic environment considered in the simulator is described by the scheme of Figure 1: its set of agents includes a dishwasher, a washing machine and a PM/PL device. In addition, there is a gas boiler that uses electricity for circulating water and regulating fluxes of combustion gases, so that the available resources for the first two agents are electricity and hot water. Two external agents, representing respectively a human user and the house heating circuit have access to the hot water resource and they compete with the dishwasher and the washing machine for its use, while dishwasher, washing machine and boiler compete for the use of electricity, whose availability is limited by the power limiter. No limitation on the gas used by the boiler is considered. It is assumed that the dishwasher and the washing machine find more economic to use the hot water produced by the boiler than to heat water by themselves and that the boiler can respond satisfactorily to the request of only one agent at a time. This configuration reproduces a standard home environment, as can be found in several Italian and European houses.

Each agent, except the human user, is described by means of a software program that reproduces its behaviour. In designing the virtual agents, structural information, identification procedures and European norms about operational modes of electrical and gas appliances have been taken into account. The hot water, electricity and information that are made available to agents are described by means of global external variables, which are shared by all (the programs that represent) the agents. The various programs that represent the agents can be executed by the same PC or by different ones, which may interact by the TCP/IP protocol or via shared memory. Modularity of the simulator permits to substitute any virtual agent by a real one by connecting it through opportune hardware and software interfaces.

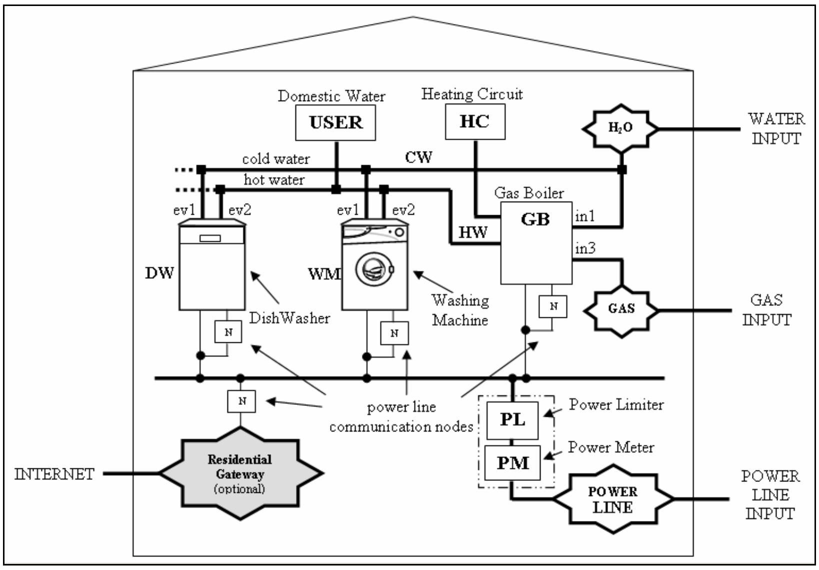

Figure 1

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The information exchanged between the agents concerns, potentially, availability of electricity; status of the gas boiler and, indirectly, availability of hot water; status of the dishwasher and of the washing machine, together with request and related priorities coming from them. Different modalities of communication between agents can be simulated, using global variables to describe the information that is exchanged. The program describing the behaviour of the various agents may be given access to all or part of the available information and, according to this as well as to their instructions and to the assigned task, they implement in a decentralized way the control policies that regulate the global system behaviour.

Figure 2 shows, by means of the time evolution of the global electric load, the result of a simulation concerning the execution of a given task in a situation of excessive load. In the first period [48, 828], the washing machine activates in response to a direct command and, as it requires hot water from the boiler, it causes also the latter to activate its internal electric pump and fan ([120, 310]). After the washing machine finishes its task, the dishwasher activates (at time t=873) in response to a direct command, causing again a similar reaction in the boiler. During the operation of the dishwasher, the washing machine activates again (at time t=1138) in response to a direct command and, since in this case no regulation strategy has been implemented, this causes the load to go over the threshold. As a result, the power limiter intervenes to cut off the power and, of course, the load goes to zero.

The simulator allows to experiment the result of various regulation strategies in the above situation, so to check the existence of an execution of the considered task that avoids the intervention of the power limiter and meets the user expectation.

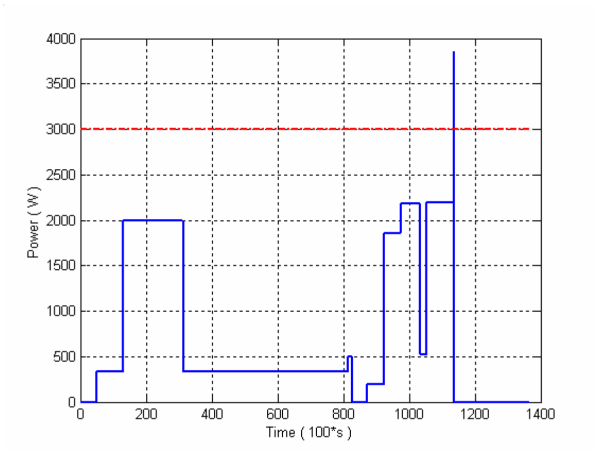

Figure 2

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