Multidimensional Adaptiveness in Multi-Agent Systems

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***Abstract*—The work presented in this paper is focused on the design and the implementation of an adaptive framework for ambient assisted living applications. The challenge is to design an approach to deal with a dynamic environment in order to provide an adequate service to an elderly or a sick person at home. It is necessary to take into account constraints such as, the degree of urgency of the service and the degree of intrusion of the system. The evolution of the degree of intrusion based on the degree of urgency and the availability of the different communication devices that constitute the ambient environment are particularly targeted. Through an adaptive approach based on coalitions of agents, our multi-agents system ensures answers to various and/or unforeseen situations. Our coalitions protocol formation has been implemented in a real scenario. A more sophisticated version of our system has been designed allowing an intelligent and a declarative method for modeling the coalitions formation process. Indeed, the system includes a rule-based system so that the reasoning implementing the coalitions formation process can be tuned in a declarative way. This new version of our system is characterized by a multi-dimensional adaptiveness because four levels of adaptiveness are observed. The computational dimension is observed during the coalition formation process. The functional and methodological dimension concerns the service modeling. The ethical level deals with the intrusion level of the system. At last, the control level allows the behaviors triggering and criteria management. *Application objective:* A mobile robot interacts and cooperates with a set of communicating objects in order to provide a set of services and teleservices to an elderly or a sick person at home. *Research objective:* Providing a multi-a gent system that could be used for evaluating the relevance of the rules that are used during the coalitions formation process. *Results:* The proposed solutions have been implemented on a real system and evaluated in real situations. Several protocols for coalitions formation are being compared.**

***Keywords*—Adaptive control, adaptiveness, rule-based system, multi-agent system, ambient assistance.**

I. Introduction

ADAPTIVITY is widely studied as a capability that makes a system able to exhibit a cooperative and intelligent behavior. Moreover, software increasingly has to deal with ubiquity, so that it can apply a certain degree of intelligence. Ambient assistive robotics can be defined as an extension of ambient intelligence which integrates a robot and its embedded sensors. The interaction among the components in such systems is fundamental. In a previous [1] work, we presented Coalaa (Coalitions for ambient assistance), which concerns the design and the implementation of an ambient assistive living framework that takes advantage of an ambient environment: a robot cooperating with a network of communicating objects present in the person's home. The aim was to provide a service to an elderly or a sick person. A multi-agent system (MAS) reifies the sensors and the mobile and autonomous robot, allowing the cooperation among the agents by means of adaptation features. The agents form coalitions by adapting the cardinality of the coalitions according to the availability of data sensors so that the whole system can answer to a user request (obtain a particular effect). In the present work, adaptiveness of Coalaa has been improved by integrating a rule-based system able to determine, in a dynamic way, a priority for the criteria to consider during the coalition formation process. On the other hand, new experimental results show the validity of the approach implemented in Coalaa. Multiple dimensions of the adaptiveness have been identified allowing Coalaa being extendable with a meta model of the adaptiveness.

The next section details the context application and describes a particular usage scenario. Section III includes a brief overview of existing ambient assistive living systems and argues for a new one based on adaptive coalition-based MAS. The designed system Coalaa is described in details in Section IV. The Section V describes the rule-based module and the adaptation behaviors of the agents. Evaluations and analysis of Coalaa in the context of robotic localization are presented in Section VI. Finally, Section VII draws some conclusions and introduce future works.

II. The problem description

Ambient Assisted Living (AAL) constitutes a fundamental research domain. It refers to intelligent systems of assistance for a better, healthier and safer life in the preferred living environment and covers concepts, products and services that interlink and improve new technologies and the social environment, with a focus on older people. A panorama of European projects can be found in [2]. Our specific context is to assist a person in loss of autonomy at home. It concerns either the elderly or people with specific disabilities. Maintaining such people at home is not only beneficial to their psychological conditions, but helps reduce the costs of hospitalizations. House is equipped with a network of communicating objects (CO) such as sensors or actuators for home automation. A complete telecare application for remote monitoring of patients at home, including a wireless monitoring portable device held by the patient, is added for detecting alarming situations. A mobile robot with embedded CO is also present in the house. The context application is essential in this work. So, a usage scenario is described in details so as to illustrate the different application challenges and the scientific issues addressed in this paper, which is implementing multidimensional adaptiveness.

A. A scenario description

The scenario consists of a variety of situations where an alarm has occurred. The scenario and robot configuration have been determined in cooperation with the remote monitoring center SAMU-92, which is attached to Public Paris Hospital [3]. An alarm can be triggered by a device worn by the person or the sensor network of the ambient environment. Thanks to its capability to move, the robot helps to confirm and evaluate the severity of the alarm by cooperating with the CO. The robot begins by searching the person and then provides an audiovisual contact with a distant caregiver. That way, the distant caregiver is able to remove the doubt of a false alarm, to make clear the diagnosis and to choose the best answer to the alarming situation. It is important to note that the embedded device monitors the physiological parameters and the activity of the person. The originality of the proposed approach is that the robot tries to take advantage of ubiquity. The autonomy of the robot is obtained by a close interaction between the robot and the ambient environment (AE). So, the services the robot can bring to the user are directly related to the effectiveness of the robot mobility in the environment. Even if the AE is installed in a static way for a period of time, the robot takes advantage of ubiquity and it does not perceive always the same data according to the degree of intrusion that is allowed. For example, off camera inhibits the robot to use images. So, the robot has to adapt its perception in order to locate itself and try to help the person. Indeed, before providing a service to the person, the robot has to locate itself by interacting with the AE. In such scenarios, an ethical dimension, named level intrusion of the system, has been introduced to preserve the privacy of the person. The level of intrusion of the system is defined according to the degree of freedom of the CO regarding to the actions. For instance: maximal distance allowed between the robot and the person, activating a camera, switching on a light and so on. The level of intrusion of the system is supposed to be minimal except in a case of emergency.

B. Robot localization task

Using a robotic assistant for the task rather than a simple set of fix cameras in all rooms is an advantage in two cases: i) the assistance is only needed for a limited period such as convalescence period or ii) the residence has many rooms, e.g., nursing homes. Moreover, the general quality of video and audio sensors increases. The goal of the robot is reaching the person and setting up an audiovisual communication with the distant surveillance center.

Figure 1 shows a robot in the person's home; the patient has fallen. To move towards her/him and to guide its camera to the remote caregiver, the robot has to be located first. A visual contact will help the remote caregiver to perform a correct diagnosis of the situation.

If the robot is located at P1 position, then its mobile camera can identify the visual marker Y. With further information from a fixed camera environment, the robot manages to locate itself by a mean of an adequate localization algorithm. The direction taken by its mobile camera that detected a visual marker also allows the robot to know its orientation relative to a fixed reference in the environment. This information can also be inferred from previous values using odometry on the one hand and its linear and angular speeds on the other hand. It is thus easy and straightforward to identify and understand that the more information you have the better the accuracy of the location of the robot is. If the robot is in P2 position, it has no marker on its visual field and has no element enabling it to locate itself. It then uses two different strategies to find a visual marker. Either its moves randomly or turns its pan-tilt camera. In two cases, it is necessary that the intrusion level of the system permits it. It can also query the detectors of presence to learn about the place in which it has been seen lately. In the case of several conflicting reports, it will be decided according to the data freshness criteria, or according to the consistency with the data criteria already available thanks to the sensors of the robot. This simple scenario shows that robot localization is a complex task and there is no evidence for an approach that could be able to choose the relevant interactions between the robot and the AE. The difficulty lies in choosing the most relevant criterion to be considered first: is it the closest CO, the most accurate and or the least intrusive? The problem analysis suggests that depending on the context, the criterion to consider is different. As the context itself is dynamic and difficult to predict, a centralized algorithmic solution is to be excluded. What is required is an approach that can adapt the selection and the use of criteria based on the context and the choice of a level of intrusion aligned with the level of urgency.

III. State of the art

Adaptive systems [4] are known to meet the requirements of the addressed scenario in our work. More precisely, adaptation features are inherent to MAS. So, the designed and implemented approach exploits the MAS adaptiveness [5] potential to design a distributed system to deal, in a dynamic way, with scenarios such as the one described above. The adaptiveness is also needed to deal with dynamic addition and suppression of sensors. Furthermore, MAS are relevant to our applications domain because they allow easy deployment in new and temporary environments. While the purpose of the paper is not to describe the localization algorithm but a selection mechanism of the agents participating to this task, it is not necessary to explain the robot localization. Before addressing a state of the art in the MAS domain, a brief overview of existing ambient assistive living approaches is given.

A. Ambient assistive living existing approaches

In the context of ambient intelligence, the communicating objects of the AE play a "facilitator" role in helping the

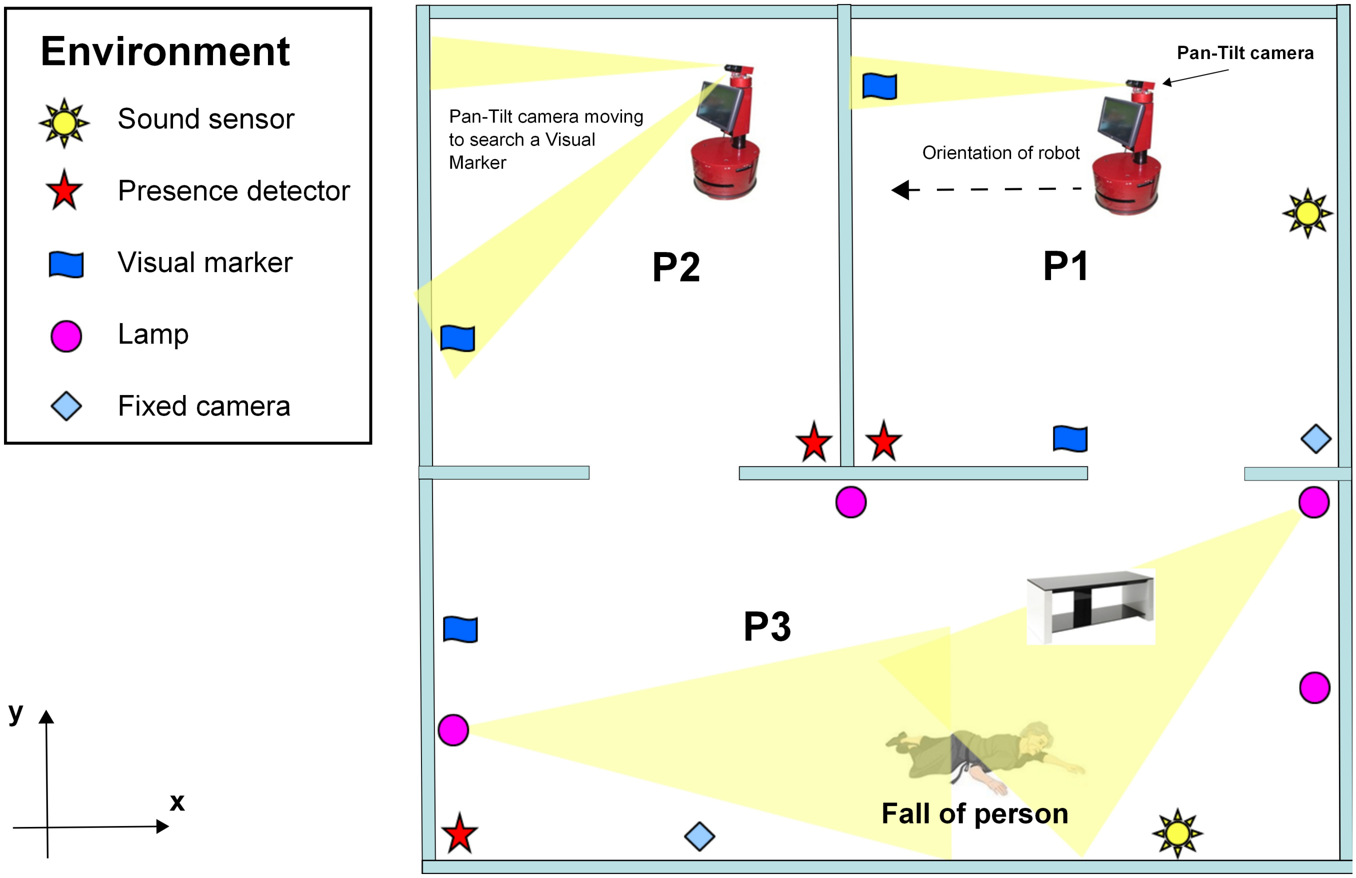

Fig. 1. A person falls scenario

robot in the Ambient assistive living. Conversely, sensors and robots can be seen as communicating objects which are used by services to the person in loss of autonomy. Several projects have been interested in combining home automation, pervasive sensors and robotics, for the safety of the patient at home. The IDorm project [6] is designed to assess an ambient environment composed of three categories of communicating objects: static objects associated with the building, a robot and mobile devices. IDorm architecture consists of a MAS that manages the operations of all the environment sensors and the robot. The sensors are controlled by an agent and the robot by another one. The sensor agent receives the different measures from sensors and controls actuators which are linked to sensors like a pan-tilt camera. The robot agent acts as a data server and coordinates exchanges of information between the user and the robot. It controls the navigation of the robot by combining different functions such as the obstacle avoidance or the search for targets. The CARE ([4]) project is a Research and Development activity running under the Ambient Assisted Living Joint Program, which is co-funded by several European countries. Its main objective is fall detection and person monitoring at home by Smart camera. As part of this project, algorithms essentially based on a biologically-inspired neuromorphic vision sensor for fall detection have been developed. The system aims to define a level of reliable supervision by avoiding as much as possible interactions with the person in her/his own home. ProAssist4Life ([5]) is a German project of situation of helplessness detection System for elderly. This project consists in developing an unobtrusive system that provides permanent companionship to elderly people living in single households or in retirement facilities. Multisensory nodes mounted on the ceiling of a room register an individual's movements. One multisensory node contains six motion sensors, one brightness sensor, and one oxygen sensor. According to data provided by various physiological sensors, the system is based on a predictive approach based on finite state automata modeling the previous activities of the patient. Another project developed at the University of Camerino is named ACTIVAge [7]. In order to keep people at home also, this project aims to provide services and teleservices based on the context. The system consists of an adaptive planning solver based on webservices orchestration and choreography with decision making algorithms. A knowledge base is used to model persistent data of the ambient environment. In each of these projects, the authors seek to design a system to avoid interfering with the patient at home. Ethical dimension is still much debated in the field of ambient assisted living, this constraint is managed by the projects mentioned above by discrete sensor systems. Although the last described project pretends dealing with adaptiveness, this concept remains a major challenge in ambient assistive applications. The work presented in this paper is focused on implementing adaptiveness while designing several application aspects. The evolution of the inconvenience (intrusion level of the system) based on the degree of urgency and the availability of different communication devices that constitute the environment are particularly targeted. The coalition-based MAS presented in this paper reflects this constraint. The purpose of the paper is to describe a selection mechanism of the agents participating to the localization task, so localization algorithm is not presented in details.

B. *Coalition-based protocols*

Multi-agent systems involve agents interacting, with each other on one side and with their environment on the other side. The agents work to achieve individual and/or group goals. The achievement of group goals requires that agents work together within teams. As it is argued in [8], there exist several ways for the modeling the team behaviour. The principle of coalitions aims at temporarily putting together several agents for reaching a common goal. Several works have illustrated the relevance of coalition-based approaches for adaptiveness [9], [10], [11], [12]. The methods are various: either incremental or random or centralized. But, all of them proceed in two stages: (1) the formation of agent coalitions according to their ability to be involved in achieving a goal and (2) the negotiation stage between the coalitions in order to choose the one that provides the closest solution to the goal. The interests of the coalition-based formation protocols are the flexibility with which coalitions are formed and straightforwardness of the coalition formation process itself. The coalitions can get rid of dynamically reorganize with local and simple rules defined in the agents.

IV. Coalitions for Ambient Assisted living applications

Coalaa (Coalitions for Ambient Assisted living applications) is a MAS [13], [14], [15] based on coalitions formation protocol.

The particularity of our system reside in the fact that each agent encapsulates one CO. The CO include not only those which are installed in the home nor the ones which are embedded on the person or on the robot. So, the agents associated to the embedded CO act in the same way as the others (that are embedded). They participate to the coalition formation. Note that the robot is not agentified. The robot has a particular role; it is able to move, it should need some services (i.e. locate itself). Because the agents encapsulate CO, they are called ambient agents. Each ambient agent decides in a local and proactive way how to contribute to the required service to the person. In fact, we have introduced a more general notion than a service, which we have called an effect. An effect can be a particular lighting at a precise place of the residence or the localization of a robot. The MAS configures itself for providing a solution according to the availability of the CO and the respect of criteria. The adaptation to the context is inherent to the multi-agent modeling, strengthened by coalitions and negotiation mechanisms. Note that the goal is not to find the optimal solution but a solution close enough to the required effect. In our coalition formation protocol, the obligation to respect the result and an intrusion level depending on the urgency of the situation, are the most important considered criteria. These criteria are also used during the reorganization of the agents while trying to achieve a desired effect. The obligation result criteria is used in priority, while the level of intrusion is modified only if needed, i.e., to acquire new data and thus to activate the sensors (ex. tilt-camera) likely to cause discomfort to the person.

As shown in the Figure 2, several kinds of components are necessary to deal with the complexity of our ambient assistive application. These components are described hereafter.

A. *Knowledge modeling*

An effect is modeled in the form of a triple σ = <t, c, f> where t $\in$ T, c $\in$ C and f $\in$ F and:

- T is a set of tasks labels: localize a robot or a person, enlighten, cognitive stimulation.
- C is a set of criteria: accuracy, efficiency, time constraint, neighborhood.
- F is a list of influencing factors: intrusion level, urgency degree.

The criteria are assigned by the designer (programer) of the system in a static way, while the influencing factors are dynamically fine-tuned by the end-user. Since the criteria concern the capabilities of the CO, they are stored in the ontology in a static way for each CO. But the addition of CO allows new capabilities to be dynamical stored in the system. The influencing factors are directly related to the degree of freedom that the end-user (person at home or the caregiver) want to give to the system.

B. *Agents environment*

The ambient agents operate in an ambient environment consisting of habitat model within which the patient and the robot are together. They argue according to the different measures and relevant information that smart objects provide.

1) Ontology: Information handled by the system is classified into two types. This so-called persistent information, related to the application domain, puts together data about the structure of the residence and the features of the CO. The second type concerns volatile data mainly the measures provided by the sensors and the orders sent to actuators. The information types are handled differently. The volatile data are distributed in each agent, while persistent data are instances of an ontology named AA (Ambient Assistance) [16], [17]. The AA ontology contains four categories of information related to the application domain: The Home category for defining the structure of the environment, the CO category for knowing their characteristics and their operating mode, the User category for defining the user profile and the Task category that puts together the tasks and services that the system is able to achieve (see

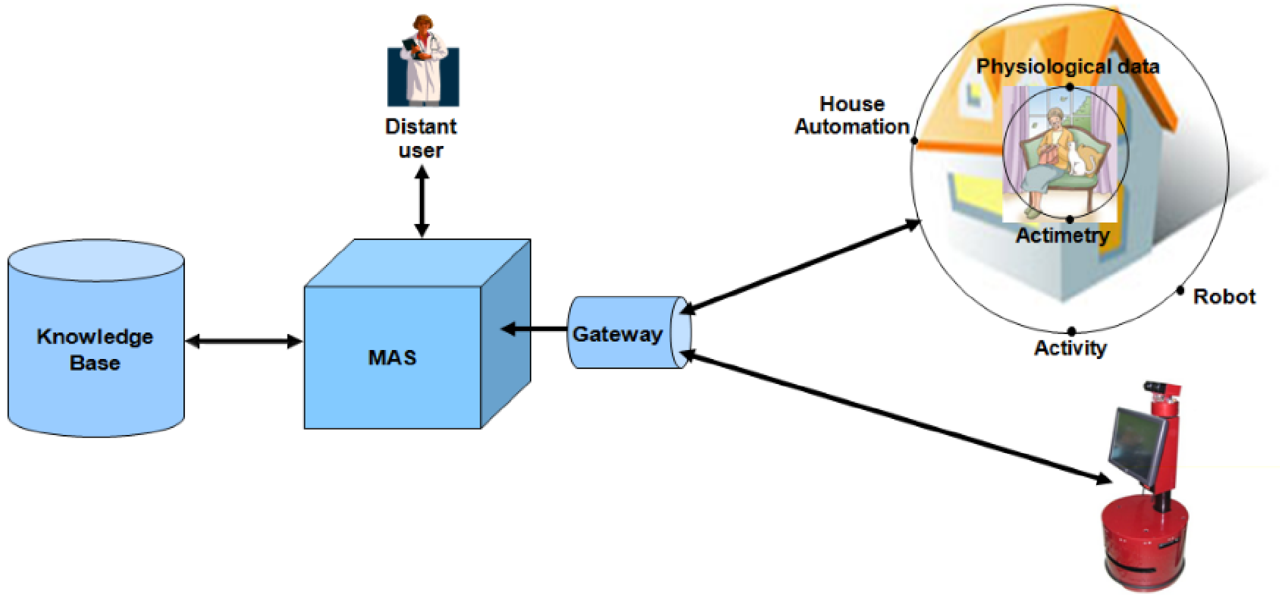

Fig. 2. Integral architecture of Coalaa

Figure 3). These categories define the four concepts of the ontology that are implemented for the studied usage scenario. But the ontology can easily be extended with new concepts if new CO were installed in the environment allowing new services to be offered. Our system needs to set up links between members of the same concept such as a topological relationship between two parts of the residence. Links are also needed between members of different concepts. For example, to process a measure provided by a sensor, the system has to locate the sensor in the residence. These links are referred to as ontological properties. We have defined three types of properties: relationship, use, and attribute. The ontological property relationship defines a logical relationship, generally of ownership, which links concept members between each other. The ontological property use defines the function of an object. The ontological property attribute refers to the features of a concept or a concept of an individual member of the ontology. It specifies the operating mode of the object, for example, a camera can be used to perform the localization task.

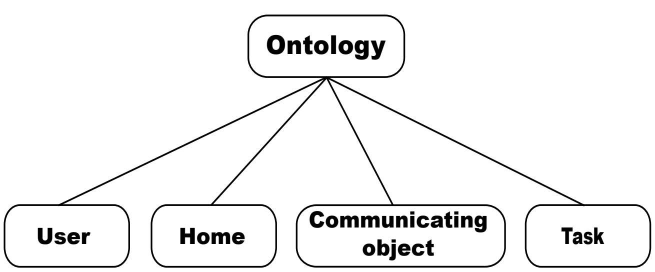

Fig. 3. Ambient Assistance Ontology

In this ontology, a property named topological distance is defined as the number of hops between two instances. The hops are relations as defined above in the ontology. If the structure of the ontology is defined by a graph, the topological distance is the number of nodes which separate two individuals minus one. This topological distance is used by agents of the MAS to determine their neighborhood during the coalition formation. This knowledge base is complemented by the dynamic information from the ambient environment through the gateway.

2) Gateway: The gateway is a module for the standardization of information exchanged between the ambient environment the MAS. Its role is to make the agents manipulating a common information format. This standardization is necessary because of the heterogeneity of the protocols from different manufacturers. Thus, the MAS receives and acts on the ambient environment through the gateway without worrying about the format of the collected data.

C. Agent internal architecture

Figure 4 represents the internal architecture of an ambient agent. The decision making module takes in charge the agent adaption and reactivity by using three main parameters that are neighborhood, history, and ability. The neighborhood sets the list of agents that are close to this agent at a given time, according to the topological distance. The history stores previous perceived information which comes from the sensors. This is a simple succession of perceived data which helps to consider the timescale during the process of coalitions formation. At last, the ability identifies the skills of the agent which are directly related to the encapsulated CO.

D. Agent behaviors

In the process of the coalition formation, an agent may be either initiator or candidate. Any agent whose ability can

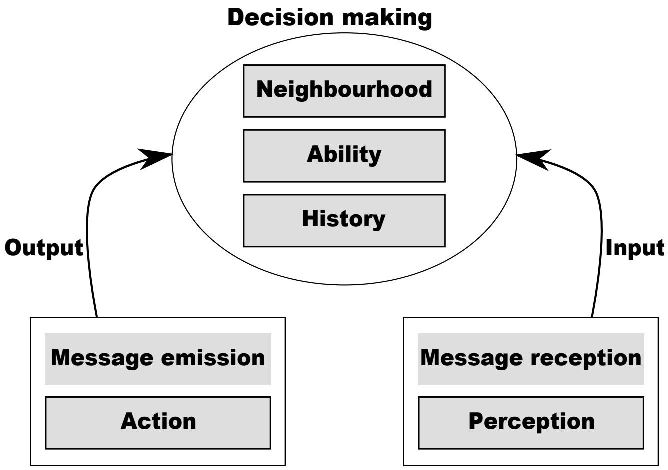

Fig. 4. Agent internal architecture

partially meet the desired effect can be a coalition initiator. The initiator exchanges messages with other agents, potential members of the coalition, called candidate agents. The Protocol is based on exchanges of messages between the initiator agent and candidate agents. As soon as the overall ability of the coalition is close to the desired effect, the initiator agent is pending the negotiation phase. The measure of closeness to the desired effect is performed according to an interval that is, in the case of a localization task, the precision of the task. At the end of the coalition formations, each initiator agent that is the referent of a coalition is negotiating with other initiators agents to choose the winning coalition. The coalition whose ability is the closest to the desired effect is the winning coalition.

The concept of ability is generic. In the localization application example, it is instantiated by the measures precision. The principle is simple. Each initiator agent sends a message that contains the ability obtained by its coalition. On receipt of this message, each initiator agent compares the ability of the coalition it received to its own one. If its ability is lower than that received, the coalition will be no more considered, otherwise, it is a winning coalition up to receiving a new message. Apart from the desired effect, the formation of coalitions uses other criteria such as the topological neighborhood to reduce the response time or the obsolescence of a measure when the desired effect depends on sensor data. Thus, the first step is the identification of candidate neighbors according to its own location in the environment (defined by the topological distance) and the desired effect. The aim of this strategy is to respond in the shortest time to the desired effect by forming coalitions. For that purpose, the first selection criteria considered is the topological distance. Once all candidate agents are known, each initiating agent continues the selection of candidates based on the recent measures criteria. When no coalition is able to meet the desired effect, a new search for a successful coalition is restarted after having relaxed the constraints on certain criteria. Indeed, it is possible to increase the level of intrusion of the system despite of the tranquility of the person at home. This authorization increases the level of intrusion allowing, for example, to operate a pan-tilt camera of the robot to acquire new measures. Then, the system is restarted hoping that the chances of finding a winning coalition is increased.

The MAS protocol is defined as a set of rules that ambient agents follow to find out a solution. The protocol of coalition formation is composed of two distinct steps. The first step consists in forming coalitions of agents according to their ability. The second step is a negotiation and refining phase so that the best coalition, in satisfying the desired effect, is chosen. In summary, after initialization, these exchanges follow three main actions:

1) Formation of all possible coalitions for each referent.
2) Selection of the best coalition according to the coalition precision.
3) Deployment of the winning coalition.

To make decisions and follow the protocol, each agent executes the appropriate behavior and starts in a state corresponding to the behavior adopted.

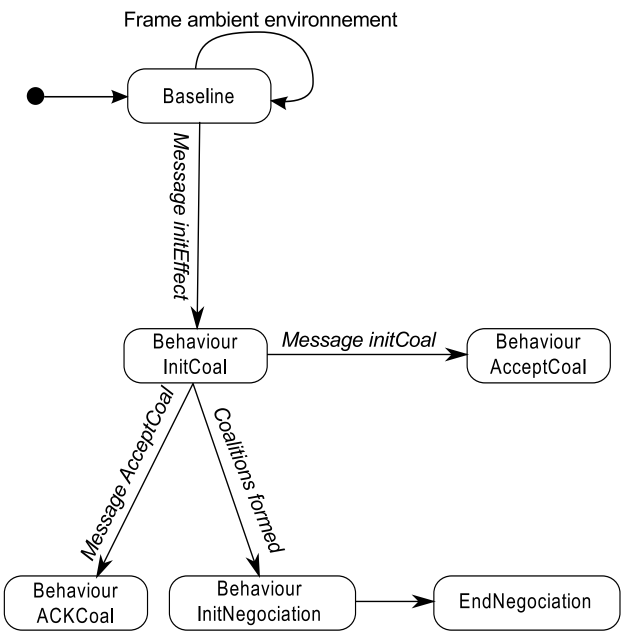

Fig. 5. Behaviors of an agent

Figure 5 shows the state transition diagram of the behaviors of an ambient agent. Each ambient agent includes six parallel and cyclic behaviors. The Baseline behavior represents the minimum treatment of an agent. Upon receipt of a frame from the environment (by the mean of the gateway), the agent must recover the sensor ID associated with it, therefore it can access the ontology and updates the ability attribute. InitCoal Behavior, AcceptCoal Behavior, ACKCoal Behavior and InitNegociation Behavior include the process of coalition formation and negotiation. For the formation of coalitions, the first behavior to be executed is sending InitCoal following receipt of a InitEffect. Running an InitCoal behavior consists in sending a message, containing the ability of the agent, to the neighborhood agent. All agents that receive this message accept or refuse to be part of the coalition. Agents that accept must then execute the AcceptCoal Behavior and then send an acceptance message or refusal message. Initiators that receive an acceptance reply with a confirmation. Finally, the EndNegociation Behavior runs when a winning coalition has emerged. This is a behavior that allows the deployment of the coalition.

E. Interaction between agents

The interaction between the agents is performed by sending messages. For the formation of the coalitions, two types of messages are defined: Request message and Response messages. For the messages exchanging, we have defined a semantic that is based on speech act theory, introduced by John Searle [18]. Such a semantic allows the agents to define message subtype as outlined below.

Initialization: Initialization messages subtype is used in two situations: by the Interface Agent (AI) to send an effect to achieve (InitEffect) to the agents of the system and, the initiator agents after all coalitions have been formed so that it is possible to initiate the negotiation (InitNegociation).

Coalition: A Coalition message type is sent in response to the reception of a desired effect.

Acknowledgement: A confirmation message (ACKCoal) or a refuse message (RefuseCoal) is an Acknowledgement message subtype.

Reaction: This subtype includes two main messages that are AcceptCoal and ArgNeg. AcceptCoal is a message Reaction subtype that is sent by an agent when accepting an InitCoal proposal. The second message Reaction subtype is ArgNeg that is sent by an agent to respond to a request for negotiation. Each message type contains the ability of the sending agent while forming the coalitions, and the ability of the coalition during the negotiation step.

F. Agent genesis

The initialization step of the MAS is performed by a particular initialization module. It is to trigger a behavior that scans the environment of each agent and creates the agents. Each created agent is initialized by loading locally, a data set from the ontology and information from the physical environment (the gate).

G. Robot localization scenario

In this scenario, three sensors of the environment are used: a robot pan-tilt camera, a fixed camera and a presence detection sensor. These three communicating objects are encapsulated by three respective ambient agents: a Presence Detector Agent (APD), a Fixed Camera Agent (AFC) and a Pan-Tilt Camera Agent (APTC). Visual markers like Datamatrix are associated with each camera. Figure 4 shows a sequence diagram of the different agents that are involved in the scenario already described in Section II.A.

Following the fall of the patient, a request for a localization effect is generated in the form of a triple σ = <t, c, f> (cf. Section IV.A). t is the localization task which matches with the localization effect, c matches with a singleton containing the precision criterion needed for the localization task and f matches with a set containing two influencing factors that are: the intrusion level and level of urgency. In the considered scenario, we have considered a precision equal to 0.1, a level of urgency equals to 3 (three levels of urgency are considered: low=1, medium=2, high=3) and an intrusion level initialized to 0 (the lowest intrusion level). So, the triple becomes: <Locate; f0:1g; f3; 0g>. The Interface agent (AI) has received the desired effect and then broadcasts the request InitCoal (<Locate; f0:1g; f3; 0g>) to all the agents of the MAS. Each agent which received the desired effect checks its ability. As all sensors in the environment have a precision that is not better than the desired effect, each agent initiates a coalition with immediate neighborhood. In this figure, only interactions with APD agent are shown. Assuming that all agents are topologically close, APD broadcast a coalition formation request by sending an InitCoal message. Each agent receiving the initialization message checks if its ability is adequate with the request of coalition formation. If yes, it sends an acceptance message labelled AcceptCoal to be a candidate. Such a message contains the precision of the agent. APD adds progressively answer acceptance, and accumulates the abilities which are the precision in the considered localization task. By this way, it calculates the overall ability of the coalition until it reaches that of the desired effect. Then, it sends ACKCoal acceptance to confirm the membership of the candidate to the formed coalition.

The next step is to activate the coalition. The robot moves to the place designated by the coalition and guides its pan-tilt-camera to the remote caregiver. First of all, the distant user has to verify that the person is in his field of vision, so he can perform a correct diagnosis of the situation and adopt an adequate action.

Conversely, if the person is not well located the system restarts searching for a new result, after having increased the intrusion level. This allows the cameras to be moved randomly so that the chances of getting a visual marker are increased. The consequence will be improving the precision of result (coalition).

This simple scenario shows that the management of the criteria is critical. Indeed, the result (a successful coalition) depends on the order in which the criteria are considered. In the above scenario, if the level of intrusion was considered before the precision, the first result would have been the correct one. Then, the question could be the following: why can one not have a management criteria step integrated in the coalitions formation process?

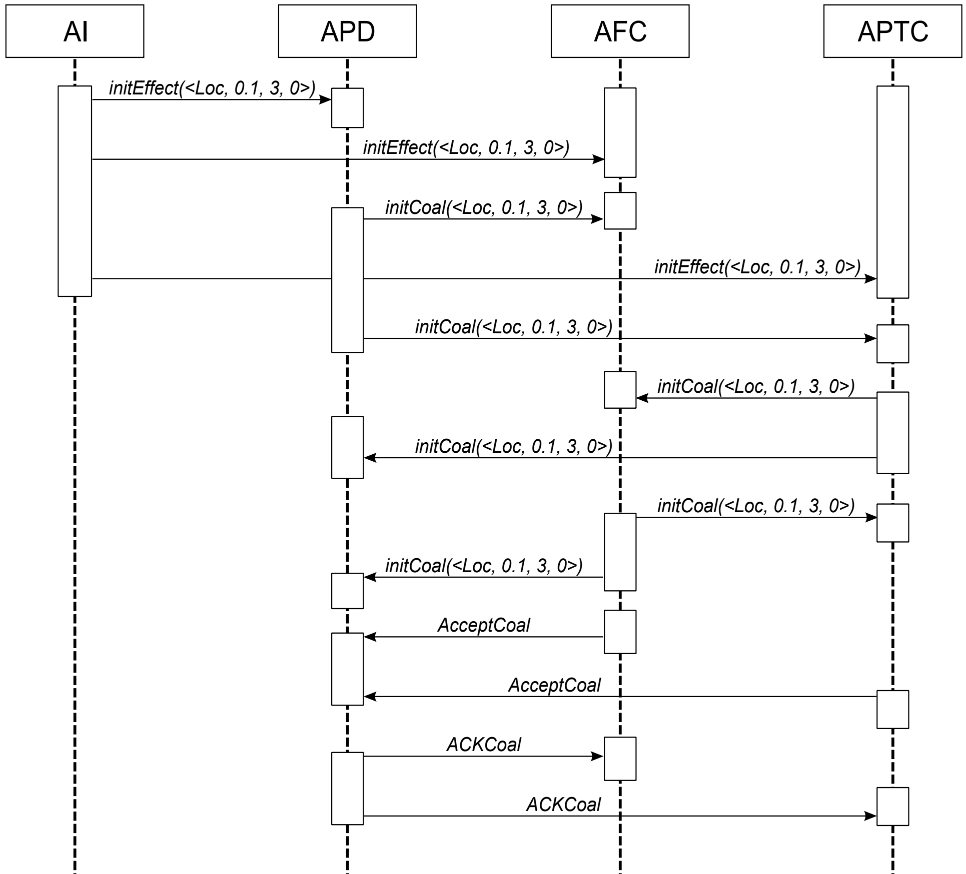

Fig. 6. Usage scenario example

V. Agent rule-based module

In order to introduce some degree of intelligence in the coalitions formation process, the agent architecture has been provided with a rule-based system able to reason to fixe a priority for the criterion. On the other hand, such a rule-based system is used to interleave the execution of the behaviors of the agents in a dynamic way. A rule-based system is composed of a set of rules named knowledge rules, a set of facts named knowledge facts and an inference engine. The rules are given in the form of implications. The knowledge facts describe the state of the world and the inference engine is a special interpreter that controls when the rules are invoked according to the knowledge facts. The syntax of a rule is:

IF <antecedent> THEN <consequent>

The <antecedent> is the condition that must be satisfied to trigger the rule. The <consequent> is the action that is performed when the rule is triggered. The antecedent is satisfied if the condition matches the knowledge facts. Some examples are given below.

A. Dynamic behaviors triggering

Instead of having a procedural control (such as described in section IV D), each behavior is modeled in a production rule whose activation condition is precisely the context of the execution of the behavior. The behaviors of the agents are associated with trigger conditions. These conditions represent the context that makes behaviors possible to be executed. Explicit chaining between the behaviors is no more needed since the rules are performed by the inference engine embedded in the agents. For example, the AcceptCoal behavior is chained with the InitCoal behavior. So the InitCoal behavior is executed once the AcceptCoal behavior is terminated. Expressing this assertion in a production rule will give the rule below:

IF (Message InitCoal Locate) and (Ability Locate) THEN execute the core of the behavior AcceptCoal

This rule expresses the fact that if the agent has in its working memory (knowledge facts) a message with certain attributes and if the agent has the ability of locating an object or a person, so the rule can be triggered. In this case, the core of the behavior associated with the rule is executed.

Note that all behaviors are not controllable. Some of them, such as the message reception behaviors are supposed to be generic and are automatically executed to threat the reception

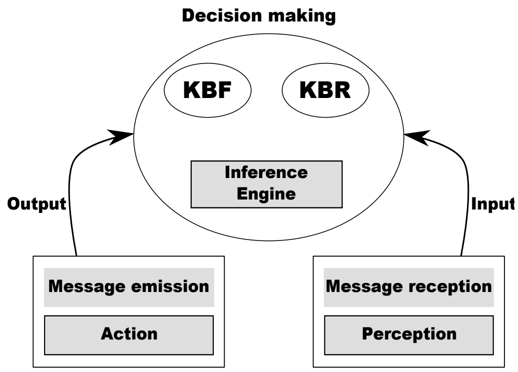

Fig. 7. Extended Agent Architecture

of the messages.

B. Flexible criteria management

In the first version of Coalaa, the priority of the criterion and the criterion themselves were fixed. Two main criteria were considered during the coalition formation process; the most prior is the topological distance and the second is the precision. When the result is not correct, a new search for a successful coalition is restarted after having relaxed the constraints on certain criteria. In the last case, the intrusion level is increased so that this increases the likelihood of finding a new satisfying coalition. In the version presented in this paper, the architecture of the agents has been modified with an embedded RBR (rule-based reasoning) module responsible of a declarative reasoning process.

In the new agent architecture, as it is is shown in the Figure 7, the inference engine replaces the procedural algorithm which implemented the decision module. The knowledge base facts (KBF) represents the knowledge extracted from the ontology, the perceived data and the exchanged messages between the agents.

For that purpose, a set of rules is defined to determine, depending on the context, the most relevant criteria to consider first at each step of the coalition formation process. On the other hand, when the coalition proposed by the system is not a correct one, the RBR is in charge of determining the most relevant criteria to relax. The rules involved in this case are some kinds of heuristics that guide the coalition process in managing the criterion. For example, if a CO involved in the coalition does not include a CO whose precision is sufficient (such as a camera), it is advisable to relax the intrusion level. This increases the degree of freedom of the system regarding to its actions allowing, for example, the cameras to be activated or lights to be switched on. Another use of the RBR for the management criteria concerns the addition of new criterion such as the time or more precisely data freshness. It is sometimes more relevant to consider not sufficiently precise data if they are very recent. For example, a presence detector can only inform that the person is situated in a particular room. Suppose that a particular presence detector says that the person is in the room R1 and a camera says that the person is in the right corner of the room R2. Of course, the information given by the camera is more accurate, but if it is too old it should be obsolete and will not help correctly locating the person. What is suggested here is to consider the date of perceived information while determining the priority of the criteria. So the system is able to deal with conflicting information. Providing such a reasoning to the system is done by adding a new rule to the set of criteria management rules, without any other change in the system.

VI. Contributions and results/outcomes

The results are obtained in a real environment composed of heterogeneous sensors and markers. The platform includes several sensors obtained of the market and dedicated sensors developed by the laboratory. The environment is composed of a room equipped with a set of sensors and the robot with its own sensors. The localization is based on goniometric measurements provided by robot on-board sensors and environment sensors. These can provide localization information to obtain the localization of the robot in its environment using real-time data either from the robot on-board sensors or from the sensors in the environment. Coalaa has been implemented using a multi-agents system platform: Jade ([16]). Jade provides generic behaviors, which facilitates controlling the execution of the agents. The RBR is implemented using a Java Expert System Shell: Jess (see [19].

Thanks to the RBR, the adaptiveness of our system has been broaden, so a fourth dimension is identified[1]:

1) Computational level: during the coalition formation process,
2) Functional and methodological level: while service modeling,
3) Ethical level: intrusion level of the system which is integrated in the behavior of the system,
4) Control level: for behaviors triggering and criteria management.

A. Computational adaptiveness

To validate the protocol used in Coalaa, a comparison to a well known protocol which is the Contract Net Protocol (CNP) has been performed. The CNP was the first approach used in MAS to solve the problem of tasks allocation. Proposed by Smith in 1980 [20], it is based on an organizational metaphor. The agents coordinate their work based on building contracts. There are two types of agents, a manager agent and contracting agents. The contractor agent must complete a task proposed by the manager. The manager breaks down each task into several subtasks, and then announces each subtask to a network of agents by sending a proposal. Agents contractors that have adequate resources respond by sending their submission. The manager agent analyses all received bids and based on the result of this analysis assigns the task to the best contractors. The contractors commit with the manager to perform the

[1] Indeed, in the previous version of this work, only three dimensions of the adaptiveness had been considered

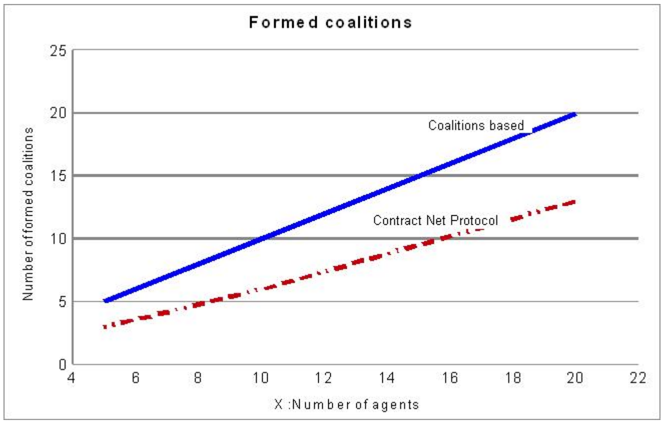

Fig. 8. Formed Coalitions

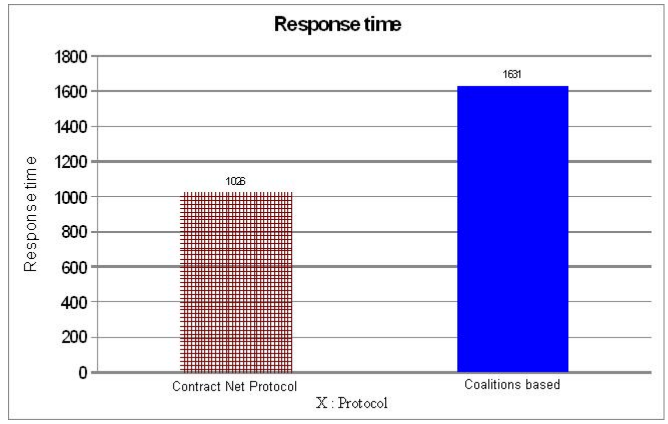

Fig. 9. Response time

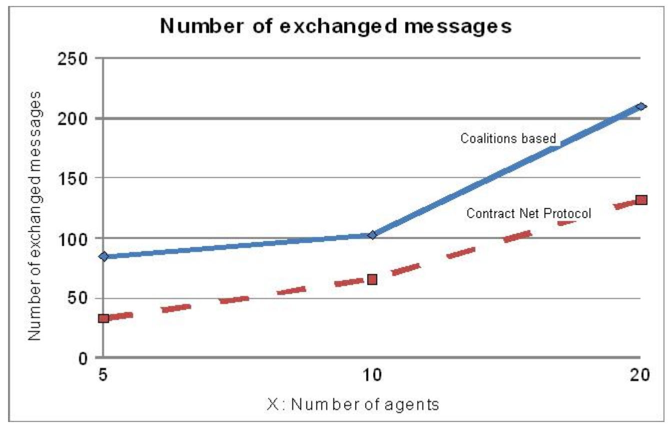

Fig. 10. Exchanged messages

assigned subtask. From the methodological point of view, there are two main differences between Coalaa the CNP. First, in Coalaa there are no commitments between the agents, they just do heir "best" to achieve the desired effect. Second, an agent can leave the coalition during the coalition formation process. Second, there is no fitness function that the coalition must achieve.

The CNP and the Coalaa protocols have been tested with a dozen scenario using in each scenario, different values for the criteria. Each scenario has been executed with both protocols. The showed results represent an average of the results of the scenario. Evaluations have been performed on a MAS whose cardinality varies. The results are broken down into three categories:

1) The number of coalitions for an initiator with cardinality greater than or equal to 2,
2) Comparing the response time of each protocol,
3) The number of messages exchanged during the formation of coalitions.

Figure 8 shows the number of formed coalitions depending on the number of agents present in the MAS. The preferred strategy in our approach is to obtain a maximum number of coalitions that meet the selection criteria. The goal is to maximize the number of solutions to meet the request to increase the chances of securing a result. The number of coalitions is always equal to the number of initiators. In terms of the number of formed coalitions, the Contract Net protocol is less efficient than Coalaa protocol.

The response times are compared (see Figure 9). This time corresponds to the time spent in calculating the coalitions, including the message exchanges.

The fact that the number of coalitions that the CNP can form is lower than the number of initiators has a direct effect on the response time. It also impacts the number of exchanged messages represented by Figure 10. The curve representing the number of exchanged messages follows the same rate for the two protocols. However, Coalaa shows a higher number of exchanged messages. Unlike the CNP, Coalaa avoids system crashes, by a progressive coalition formation which in contrast increases the number of exchanged messages. In terms of performances (time response and number of exchanged messages) measures, Coalaa and CNP are almost similar, CNP is slightly better in terms of response time. But in terms of obtained results Coalaa is better. Indeed, a failure can be catastrophic and thus the few milliseconds delay in the response time may be insignificant, if success to complete the task is assured. This is explained by the fact that Coalaa continues to reorganize itself until finding a solution (even with deteriorated criteria), while with CNP, the system can fail and do not offer a solution.

B. Methodological and functional adaptiveness

The genesis of the MAS is done automatically. In spite of the fact that this has not been detailed in this paper, this is a very important feature of the system. In fact, modifying the ambient environment, by adding or suppressing CO, automatically updates the ontology Habitat and triggers automatic MAS reconfiguration. In case of such modifications, the user does not need to do any specification to make the system adapting its architecture to AE dynamic updating. This ability of the system is qualified by methodological adaptiveness. We refer to functional adaptiveness when dealing with services that the system can offer to the user. The description of the ability of the CO used by the agents to construct services according to the ”effect description” is included in the ”ask” ontology part. This allows the agents to perform an automatic detection of their ability to perform an effect.

C. Ethical adaptiveness

An original specificity of our system is its dealing with an ethical dimension, which is the level of intrusion of the system. In fact, the system is able to adapt the intrusion of the robot, the CO and the embedded software according to the urgency of the situation and be allowed to cause discomfort for the person or its entourage only if needed.

D. Control adaptiveness

The fact that an inference engine has been employed instead of a procedural algorithm has a direct effect on the intelligence of the system. The behaviors of the agents are involved only when their associated rules are triggered, which are themselves triggered when some declarative conditions are met. Since the conditions of the rules can be modified without any procedural modification, the control of the execution of the behaviors is completely adaptive. The user can control and modify the execution of the behaviors even during the execution of the system itself. The system is also able to detect missing information which can lead to the execution of a particular behavior. So, if more generic rules are more the system intelligence can be improved. If it is easy to convince that adding new rules does not imply to modify the implementation of the system, suppression of rules is not trivial. The process of suppressing rules has to deal with consistency of the remaining data because of the possible inference which are related to the rule to be suppressed.

The convergence of the coalition formation process and the MAS itself have not been adressed from the conceptual point of view. A time out makes the system to stop if a coalition has not been emerged. This well be held in a future version of the system.

A last long term perspective concerns the construction of our AA ontology. While the utility of the ontologies is now well established, their construction, updating and using raise several scientific challenges, especially in new domain such as ambient intelligence.

VII. Conclusion and perspectives

An adaptive approach has been presented for an assistive ambient alarm detection by implementing the Coalaa system. Coalaa is a coalition-based multi-agent system in which the adaptiveness is considered from multiple dimension. The computational, the methodological, the ethical and control points of view of adaptation have been considered.

The advantages of Coalaa in comparison with a simple system in which: *a patient with alarm key and mounted on the ceiling movable video camera with a zoom lens that is controlled by a care provider*, are various. One can mention:

- Minimizing the number of zoom cameras that are more expensive and more intrusive than simple ones.
- Temporar or reversible installation of ambient environments.
- The robot is intended to be able to offer different kinds of services to the person.

The feasibility of this approach has been widely demonstrated on a usage scenario to remove the doubt of a false alarm. The first results illustrated with the robot localization application are promising. The validation of the system with a great data size has been performed by the generation of statistical distributions of data that provide more meaningful results. Moreover, comparing our protocol to the contract-net protocol has shown that even more time is spent with Coalaa, the number and the diversity of the solutions is greater.

In spite of conclusive results, several improvements of Coalaa are under consideration. The efficiency of Coalaa can be improved by making the initiator agents revising the way of choosing their partners during the coalitions formation process. This can be based on past obtained results. The agents can infer the capabilities of their potential partners through repeated interactions such as done in [21].

Another perspective is to implement more flexible way to calculate the cardinality of the coalitions. This could be done by the agents by evaluating their behavior and self-adapt for improving the overall model of criteria evaluation [22].

At a short-term perspective, we plan to apply our approach to other services such as cognitive stimulation and the detection of the person activity. The rule-based reasoning implemented in the second version of Coalaa can be used to infer information about the activity of the person. This can be done by making inferences based on the dating of information that are available during the activity of the agents. For example, if at t_i the person is in her/his bathroom and at $ti + n$ she/he is at the kitchen and now (at $ti + n + m$) she/he is in the dining room, one can infer that after having fixed herself, the person has prepared the meal and now she/he is feasting the meal she/he prepared. Indeed, a rule-based reasoning can be easily detect the rules that are linked and construct reasoning paths that lead to the description of the activity of the person.

At a long-term perspective, we will propose to wrap an agent in each communicating object, so that no time is spent to acquire information from the gate.

An original application of Coalaa could be to calculate an optimal deployment of the sensors in the houses so that to improve the services that the system can provide to the person. On the other hand, we are thinking about further development of our approach so that it can be extended for everyday life. An interesting challenge is to cope with large number of needed sensors if everyday applications are considered. Despite the inherent modularity of MAS, it will be necessary to improve the localization algorithm in such cases.

Another challenge would be comparing the solution not only with CNP but also with other coalition formation approaches (i.e., learning based ones). This can lead to a computational environment for experimenting coalition formation algorithms.

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