# Towards the Definition of a Multi-Agent Architecture For Ambient Assisted Living: The Virtual Carer Project

**Paolo Sernani, Andrea Claudi, Luca Palazzo, Gianluca Dolcini and Aldo Franco Dragoni**

Dipartimento di Ingegneria dell'Informazione (DII)
Università Politecnica delle Marche
Via Brecce Bianche, Ancona, Italy
{p.sernani,a.claudi,l.palazzo, g.dolcini,a.f.dragoni}@univpm.it

## Abstract

Ambient Assisted Living (AAL) is trying to respond to the ageing process of the population, aiming at the extension of the time in which older people can live in their home environment and giving support to them and to their families. This paper highlights the importance of Artificial Intelligence to provide intelligent and adaptive solutions to assist an elderly patient with his daily activities, while his health conditions are monitored, in order to ensure his security. Thus a Multi-Agent architecture, based on Belief-Desire-Intention (BDI) paradigm, is proposed, modelling an AAL system. The adoption of BDI paradigm tries to represent the behaviours and the tasks of a human caregiver. The paper presents a software implementation of the proposed architecture: the Virtual Carer. By means of a simulation scenario, the main features and capabilities of the system are shown.

**Keywords:** *Ambient Assisted Living; AAL; Ambient Intelligence; AmI; Virtual Carer; Multi-Agent System; MAS; Belief-Desire-Intention; BDI.*

## 1. Introduction

It is a well-known fact that a demographic shift is ongoing in the so called First World countries: the portion of their population being middle aged and over is increasing [1]. As an example of this trend, the tendency of the old-age dependency ratio (i.e. the ratio between the portion of population with 65 or more years and the portion between 15-65) can be considered [2,3]. The increasing of the median age of the total population results in the rise of chronic diseases causing the increasing of emergency situations over the years [4]. Ambient Assisted Living (AAL) focuses on these themes and aims at extending the time in which older people can live in their home environment assisting them with activities of daily living, promoting the use of intelligent products and Information Technology (IT) tools to provide remote care services [5].

The basis for AAL systems are in the developing of pervasive devices typical of Home Automation and in the use of Ambient Intelligence (AmI) technologies to integrate devices together to construct a safety environment [5]. AmI develops new paradigms where computing devices are distributed everywhere (ubiquity) to allow intelligent and natural interactions between the humans and the physical environment [6]. The main goal of AmI is to enhance people building around them an unobtrusive, interconnected, adaptable, dynamic, embedded, and intelligent environment [7]. AmI-based systems interact with human using forms of natural communication like speech and gestures: the ideal system is that one permitting the users to interact with it as they would do with other humans [4].

Following those researches indicating Artificial Intelligence as the most promising direction for AAL and AmI [8,1], we present a Belief-Desire-Intention (BDI) agent system: the Virtual Carer (VC). It is basically a Multi-Agent System (MAS) modelling a reliable, distributed and modular network, formed by ambient and biometric sensors and integrating one (or, possibly, more) BDI agents, i.e. the Virtual Carer. Its main goal is to model logical structures, reasoning and behaviours similar to those of a human being, transforming data from other agents in logical predicates representing its knowledge base. So the VC has to collaborate with other agents not only to monitor health conditions of an elderly individual, rising alarms when something is wrong, but also to interact with the monitored person, in order to facilitate his daily activities, like opening a window or answering the phone.

The rest of paper is organized as follows. Section 2 deals with some related works on MAS and AAL. In section 3 the core the proposed architecture is described. In section 4 a simple simulation scenario highlights some features of the VC. In the last section conclusions are drawn.

## 2. Related Works

As stated in [9], an agent is anything that can be viewed as perceiving its environment through sensors and acting upon that environment through actuators. In [10] the main properties of an agent are outlined: autonomy, social ability, reactivity and pro-activeness indicate that agents operate without intervention of human or others, interact with other agents using some kinds of Agent Communication Language (ACL), perceive the environment responding to changes and are able to exhibit goal-directed behaviours by taking the initiative. Thus MAS can be a suitable solution for the need of AAL systems to adapt themselves autonomously to context changes resulting from user activities, device failures, and the addition or loss of devices and services [11]. BDI agents act on the basis of practical reasoning [12]: their intentions, i.e. the set of actions of agents, originate from the intersection between beliefs, i.e. the knowledge of world held by agents, and desires, i.e. the set of states representing world as desired by agents. So MAS and BDI agents, with their knowledge base, seem perfect to respond to guidelines of AAL and AmI indicating the need of unobtrusive, adaptable and dynamic intelligent environments [7] and requiring technical solutions that are flexible and adaptable to individual and changing needs [13].

Many researches deal with MAS applied to AAL. In [14] a warning system to monitor patients suffering from dementia is presented: a Risk Assessment Agent, through its knowledge base and information provided by other agents responsible for various ambient sensors (like a Temperature Analyzer Agent and a Door-Window Analyzer Agent), uses fuzzy logic to predict risk assessment and to rise suitable alarms. Instead in the system described in [15] each agent uses its knowledge base to rise an alarm and collaborates with other agents to carry out specific tasks like calling the medical personnel in dangerous situations. In [16] the focus is on the interaction with the user rather than in monitoring. The work in [17] is rooted in Home Automation and describes a small society of BDI agents to cope with energy efficiency issues when different devices are available.

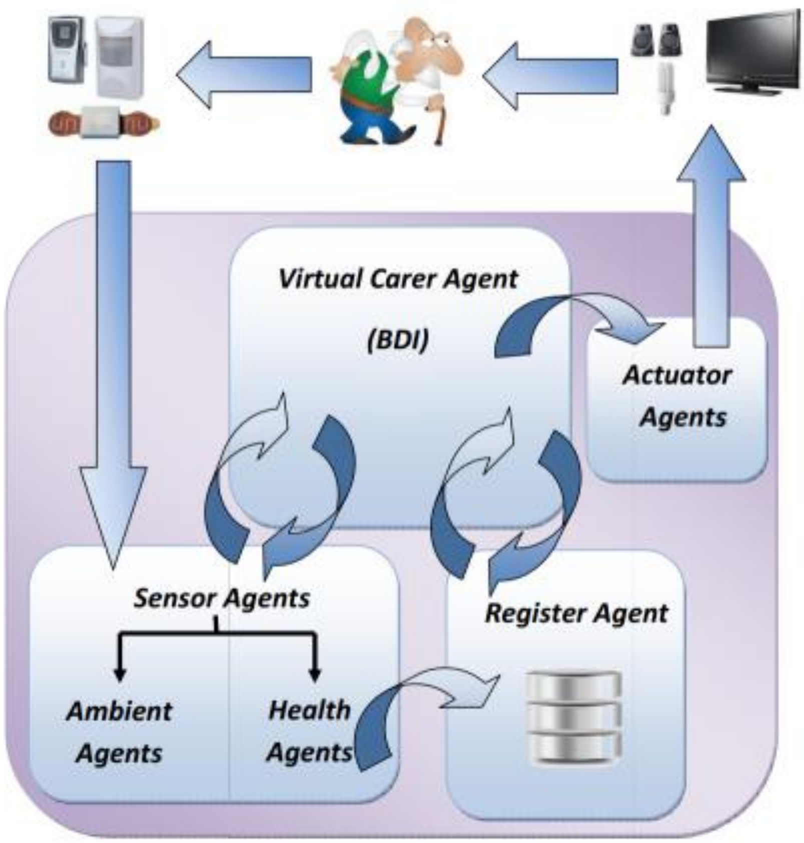


**Fig. 4. Virtual Carer Architecture.**

## 3. System Architecture

The main idea of this work consists of a MAS modelling a distributed, reliable and modular network composed by biometric and ambient sensors, integrating a BDI agent: the Virtual Carer. It has to be understood as an IT system being able to communicate with an elderly or disabled person, to monitor his health condition and to control the environment around him. Following the BDI paradigm, VC models reasoning mechanisms and behaviours similar to those of a human being to cope with events from a highly variable environment. The great amount of information used by VC is represented by logical predicates, forming its Knowledge Base (KB). VC chooses the right actions to perform on the environment with an inference engine applied on its KB. Thus the VC works as follows:

- it analyses data provided by sensors and devices forming the system (i.e. by other agents controlling them) and updates its KB;
- when its KB is updated, VC generates new knowledge using its inference engine;

- with backward reasoning rules applied on its KB, VC selects the main goal and chooses (through backtracking) the plan to satisfy it.

VC carries out the actions of chosen plan collaborating with agents responsible for actuators, in order to directly act on the environment.

Fig. 1 shows the basic architecture of the proposed system. Around the BDI agent representing the VC (i.e. the Virtual Carer Agent), there are some Actuator Agents, a Register Agent and a number of Sensor Agents. The Actuator Agents are responsible for the activation and deactivation of the devices in the environment like speakers, lights, monitors and so on. They have to be able to receive requests from other agents and to execute on/off commands on the devices. The Register Agent has to store in a database all the information provided by sensors and the anomalies detected by the VC. Sensor Agents can be distinguished in two types: Ambient Agents and Health Agents. Ambient Agents are responsible for reading the value of ambient sensors, for example the temperature of a specific room. It has to verify if the read values are in a predetermined range: if the verification fails the Ambient Agent has to communicate the anomaly to the VC. In this category also Agents for presence sensors, like Passive Infra-red (PIR), can be considered: PIR agents only inform the VC about the presence of someone in the monitored room. The Health Agents have the same tasks of Ambient Agents but with respect to the health conditions of the monitored person, for example reading values from a heartbeat sensor. The arrows in fig. 1 highlight the information flow characterizing the system. The Virtual Carer Agent receives from Sensor Agents alarms when a value is out of the predetermined range; in addition the VC can directly require values, for example because the chosen plan requires it to satisfy the goal. The Register Agent receives from Sensor Agents the read values and from the VC the anomalies that have to be registered. The VC can also requires old values to Register Agent. The VC Agent sends request to the Actuator Agents in order to execute actions of the plan. For example the VC can send a request to turn the light on in the living room because the PIR agent detects the presence of the monitored person.

Sensor and Actuator Agents are implemented using the JADE framework [18] whilst the BDI agent representing the VC and the Register Agent are implemented using JASON platform and Agent Speak language [19]. It is important to notice that the use of JADE framework permits the communication between agents with FIPA-ACL messages, ensuring the modularity of the system: different devices can be added any time simply integrating more agents. JASON is used for the VC Agent and for the Register Agent, permitting to store beliefs directly in the database.

The adopted frameworks also provide recovery techniques to meet fault tolerance requirements: the DF Persistence and the Main Container Replication Service avoid the presence of single points of failure for the traceability of agents' services and for the agent management.

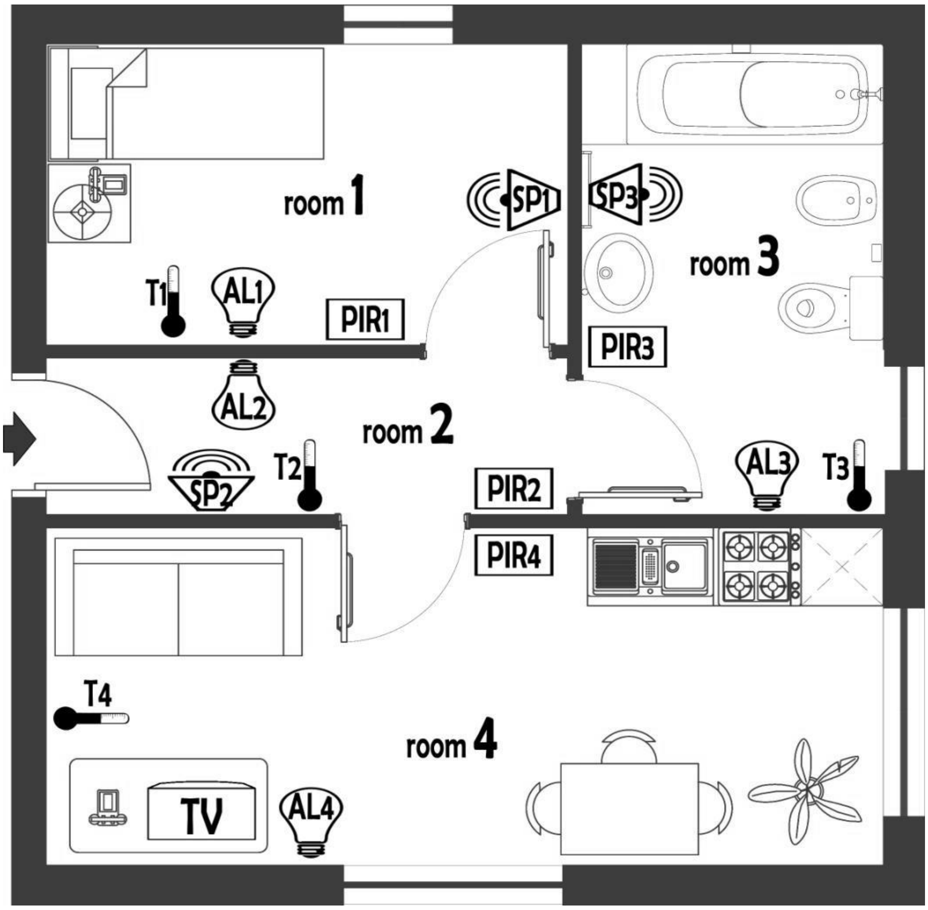


**Fig. 5. The fictional home map used for simulation scenarios.**

## 4. Simulation Scenario

Another agent is necessary to build a first preliminary simulation in order to test the proposed architecture: the Elderly Agent. It is a BDI agent representing the various behaviours of the human being monitored by the VC. For simulation reasons the Elderly Agent has to send messages to other agents of the system: for example it informs the PIR agent of a room when it moves in that room or it can send a request to Health Sensors to know the value of a specific health parameter.

The image in fig. 2 shows the home map describing the simulation scenario, highlighting the arrangement of the available devices in the environment. There are 4 rooms corresponding to the bedroom (room 1), the hallway (room 2), the bathroom (room 3) and the living room (room 4). For each one there is a temperature sensor (T1, T2, T3, T4), a PIR sensor (PIR1, PIR2, PIR3, PIR4) and a device to turn on/off the light (AL1, AL2, AL3, AL4). In addition there are a speaker (SP1, SP2, SP3) for each one of the first three rooms and a device (TV) to visually communicate with the monitored person in room 4. Furthermore there are pressure sensors in each place where the person can sit or lie down (e.g. couch, bed, seats) and window sensors to verify the open/closed state. An health sensor controls some parameters of the elderly like heartbeat and body temperature. For each sensor and device of the described scenario the right Ambient, Health and Actuator Agents are created.

In this simulation the VC Agent has two emergency plans: the first, shown in fig. 3, is executed when an Ambient Agent, responsible for a temperature sensor, read a value out of the predetermined range. In this case the VC Agent sends the anomaly to the Register Agent and activates the plan "notify" in order to evaluate if the monitored person has to be advised with some alarms.

```
+emergency1(V)[source(A)] : true <-
         .print("Room temperature out of range");
         .print("from sensor ", A);
         .print("value ", V);
         .time(H,M,S);
         .send(register,tell,anomaly(A,V,H,M,S));
         .print("Information sent to Register Agent");
         ?em1(N);
         New = N + 1;
         -+em1(New);
         !notify;
         !canc.
```

**Fig. 6. Emergency plan for the room temperature**.

To simulate different behaviours adopted by the monitored individual, the Elderly Agent has different plans. For example one of these plan includes the transition from the hallway to the bedroom, and the request of the body temperature value.

First of all, the Elderly Agent initializes the VC Agent, giving the information about its initial position; then, after 5 seconds (i.e. the time necessary to get to bedroom), it informs the PIR Agent of its presence in the final position. As a sort of cascade mechanism, the PIR Agent of the bedroom communicates to the VC Agent the detection of an individual. Thus the VC Agent has a new belief (i.e. the presence of the elderly person in room 1), that activates the plan to turn the light on in the bedroom and to turn it off in the hallway. In the end the Elderly Agent send a message to the VC to know its body temperature value. The activated plan includes those actions to require to the Health Agent the desired parameter and to communicate it to the Elderly Agent. Beside plans similar to the one just described, we simulated plans without an explicit request by the Elderly Agent, but in which the VC Agent had to infer the right actions. For example, when a window remains open in the bedroom with the elderly person sleeping, the decreasing of room and body temperature should activate the plan to wake up the individual and to advise him to close the window. So the Ambient Agent corresponding to the bedroom window informs the VC that the state is "open". At a later stage the Ambient Agent responsible for T1 sensor communicates to the VC Agent that a detected value is out of the predetermined range; a similar message is sent by Health Agent. The VC Agent updates its KB with these new beliefs and the activated plan ends with a message to the Elderly agent to close the window.

Even if the ideal test for the proposed approach should include a real AAL scenario with sensors and devices developed in the field of Home Automation, the simulations we carried out are adequate to underline that MAS and BDI paradigm are useful applied to an AAL context: the MAS approach guarantees modularity to the system, in order to cope with the extension of available devices, while the BDI paradigm permits to quickly respond to a dynamic environment.

## 5. Conclusions

We described an expert system for AAL to deal with a dynamic environment monitoring the health conditions of an elderly or disable person. The heart of the system is a BDI agent modelling the behaviours of a human caregiver, i.e. the Virtual Carer. The VC Agent uses the information provided by other agents controlling various sensors and devices, in order to simplify the daily activities of the elderly and to rise alarms when something is wrong with his health conditions. Thanks to the JADE framework, the communication is implemented through FIPA-ACL messages, ensuring the flexibility of the system: new devices can be added in a transparent way, with the integration of new agents in the proposed platform. We tested the system considering a simulation scenario and representing the elderly individual using another BDI agent. Several plans were taken into account, modelling different actions performed by the Elderly Agent (e.g., movements, direct requests, changing of health parameters). Tests confirm the tendency of AAL and AmI researches towards Artificial Intelligence and MAS. The Multi-Agent approach guarantees the modularity of the system, whilst the BDI paradigm permits to respond to changes of the environment and of the needs of the monitored person.

As a future work the integration of further technologies and devices in the Virtual Carer system could be considered: for example those for video surveillance described in [20] could be useful both with their original purpose and to monitor the patient conditions, ensuring its security.

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