Infrastructures for collaborative networks
- An application in elderly care

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Abstract
Applications of collaborative networks are increasingly emerging in diverse domains such as, for instance, elderly care. The growth in the elderly population imposes an urgent need to develop new approaches to care provision. Integration of a number of technologies such as multi-agent systems, federated information management, safe communications, hypermedia interfaces, rich sensorial environments, and increased intelligence in home appliances represents an important enabling factor for the design and development of virtual elderly support community environments. In this paper, the experience in developing an infrastructure based on mobile agents combined with federated information management mechanisms is described, as well as its initial evaluation as a basis to support the development of vertical valued-added services.

1. Introduction
A large variety of collaborative networks have emerged during the last years as a result of the challenges faced by the business, social, and scientific worlds and enabled by the fast progress in the information and communication technologies. Advanced and highly integrated supply chains, virtual enterprises / virtual organizations, virtual (professional) communities, virtual laboratories /e-science, represent some manifestations of a major trend in which organizations seek complementarities and joint activities that allow them to participate in competitive business opportunities and new markets. A large number of research projects in this area are carried out worldwide and a growing number of practical cases on different forms of collaborative networks are being reported. Many similar cases can be found in other domains, namely in the service sector. For instance, the concepts of virtual organization and virtual community are entering the elderly care sector [2-4] as a way to facilitate a smooth interaction and collaboration among all actors involved in an integrated elderly personal wellness system.

One of the key challenges facing modern societies is the increasing speed at which the population is aging. In Europe for example, during the last three decades the number of people aged 60 years or more has risen by about 50%. This will inevitably place a considerable strain on resources and finances [12]. To deal with this challenge, new ways of providing elderly assistance and care must be found, including the creation of a new technological infrastructure. Although technology is certainly not the solution to all problems in this domain, it will play a fundamental role in the creation of a new concept for an integrated elderly care system. This system will consist of a number of organizations such as care centers, day centers, health care institutions, and social security institutions acting in cooperation with involved personnel e.g. health care professionals, social care assistants, elderly people, and their relatives. When based on computer networks and adequate supporting tools, collaboration among care institutions may evolve towards operating as a long-term virtual organization and the various involved humans will become part of a virtual community.

Advances in computer networks and ubiquitous computing suggest the opportunity for more advanced care approaches including comprehensive status monitoring, other forms of assistance such as agenda reminders, but also the creation of the opportunity for the elderly to become better involved in the community, and thus reduce their feeling of loneliness – a new generation in elderly care systems (Fig. 1). To achieve these objectives, the TeleCARE project has aimed at the design and development of a configurable framework focused on virtual communities for elderly support.

![Figure 1. Generations in elderly care systems](image-url)
One of the innovative conceptual contributions of TeleCARE is the introduction of the concepts of collaborative networks (virtual organizations, virtual communities) into the elderly care sector. A virtual organization approach to elderly care will allow a more integrated and smooth interaction / collaboration among the various entities, being public and/or private, that have a role in this domain. The concept of collaborative network in elderly care is an important instrument to support the active aging concept.

2. TeleCARE platform

The idea of using new technologies to support elderly care provision is not new and there are many initiatives taking place, in a variety of areas, to address the challenges ahead (see, for instance, [14], [15]). However, these initiatives have been carried out independently of each other. With different organizations developing different products and services, in a variety of different areas, there is a need for a common platform into which all these developments may be plugged so that interoperability is possible (Fig.2). Vertical (application) services can then be plugged on top of this platform.

![Figure 2. The role of a horizontal infrastructure](image)

The TeleCARE approach for providing a technological infrastructure to enhance collaborative virtual elderly support communities is based on using the Internet and mobile-agent technologies (Figure 3). The Internet, although appealing as a base infrastructure, raises some difficulties. These include:

- In application domains such as elderly care, high levels of heterogeneity are expected in the sensorial and equipment richness of the remote places (e.g. elderly homes). This demands appropriate solutions to guarantee the necessary levels of flexibility and scalability.
- The Internet is characterized by long and variable time-delays and very often suffers from low levels of availability. This raises new challenges in assuring the reliability of the implemented system and its dependence on the characteristics of the network.
  - The emergence of mobile and ubiquitous computing raises the importance of wireless connections where the actual connection to the network may have to be reduced to short periods.
  - The execution environments, involving legacy components, are potentially unstructured and uncertain. This means that it is difficult to cope with these environments by resorting to deterministically programmed systems.

The mobile agents paradigm offers interesting characteristics that in fact directly address several of the above issues [7]:

- Moving the code to the place where actions are required enables real-time response, autonomy and continuity of service provision with reduced dependency on network availability and delays.
- Since new mobile agents can be built and sent for remote execution whenever needed, higher levels of flexibility and scalability are achieved.

In developing such a system, whilst preserving the elderly person’s independence, it is clear that a number of sensitive issues must be addressed. One such important issue is privacy and special care must be invested in developing a system that will protect the elderly person’s privacy. Considering the distributed and autonomous nature of the implementation sources to be handled in a TeleCARE community and the need to specify privacy / access rights at different levels of abstraction, the federated information management paradigm was adopted as one of the key approaches in the project development. Another perspective of security and privacy is related to the safety of communications in a potentially hostile environment such as Internet. Advanced techniques to support safe communications (e.g. Private Virtual Networks) and the evaluation of biometric identification technologies were part of the TeleCARE approach. A recent project [16] shares similar concerns and approach but it is in a much earlier stage than TeleCARE.

Figure 3 shows a block diagram of the TeleCARE infrastructure to support collaboration in the elderly care virtual organization [2], [5], [6]. The Basic Platform is intended to be installed at each node of the TeleCARE network. This infrastructure comprises:

- **External Enabler Level:** This layer supports the communication over the network and interfacing to the external (local) devices. Specifically it includes:
  a) A **safe communications infrastructure** that provides safe communications, supporting both agent mobility and inter-agent message passing [10]. A virtual private network (VPN) approach is adopted.
  b) A **device abstraction layer** interfaces to the sensors and monitoring devices and other hardware (home appliances, environment controllers, etc.). These
interfaces represent the bridge to any “intelligent home” [8], [9] or “local network”, hiding aspects such as low-level protocols, wire-based or wireless communications, etc. The Universal Plug and Play (UPnP) [13] is one of the approaches adopted to interface devices.

Figure 3. The TeleCARE platform architecture

- **Core Multi-Agent System (MAS) Platform Level**: This is the main component of the basic platform. It supports the creation, launching, reception (authentication and some rights verification), and execution of stationary and mobile agents as well as their interactions. It supports the storage and manipulation of data and information to be handled within TeleCARE. It provides a catalog of all devices and services available at each site. Some of these innovations, namely in the areas of agent migration, mobile-agent based infrastructure led to a number of important results in terms of agent technology. These achievements include both scientific and engineering developments provided by TeleCARE software developers.

   a) **Basic multi-agent system (MAS) platform** (based on Aglets).

   b) **Inference engine** (based on a Prolog interpreter).

   c) **Ontology support** (based on Protégé). A facility is developed providing the basic mechanisms for dynamic schema description by TeleCARE service developers.

   d) **Persistence support** as an extension to the MAS platform to provide some basic recovery mechanisms in case one node goes down.

   e) **Inter-platform mobility** is an extension to the basic MAS platform and supports generalized mobility of agents, including security mechanisms. This module includes the Agent Reception & Registration component (for incoming mobile agents) and the Agent Exit Control component (for outgoing mobile agents).

   f) **Inter-agent communication** is another extension to the basic MAS platform and supports communication between and coordination of agents independently of their current location, via FIPA ACL messages.

   g) **Platform manager** specifies and configures the operating conditions of the platform in each site. It assists in recovery from errors, monitoring the operation status, etc. It includes:

      - An **Agent factory**: A module that supports the creation / specification and launching of new agents.

      - **Resource manager agents**: To provide a common and abstract way of dealing with devices and appliances.

   h) **Federated information management** supports the necessary management of information while preserving information privacy and careful control of access rights to local data for external users. This module, installed in each site, is the local component of the Federated Information Management Architecture (FIMA), which includes:

      - **Federated query processing** that provides the ability to retrieve information from a number of TeleCARE nodes.

      - **Federated access control** to assist with querying and providing access to the stored information.

      - **Automatic ontology-based schema generation** which generates database schemas from the ontology definitions provided by TeleCARE software developers.

   i) **Resource catalog management** to manage the catalogue of resources including support for their specification, discovery, and access proxies of all devices and services available at each site.

The design and implementation of the TeleCARE mobile-agent based infrastructure led to a number of important results in terms of agent technology. These achievements include both scientific and engineering innovations, namely in the areas of agent migration, communication, reliability / security, service continuity, and the access to resources and appliances. Some of these results are:

**The passport concept.** When agents travel, hosts must have means to efficiently recognize and verify the true identity of mobile agents. In TeleCARE, correct authentication is very important for procedures such as the entry in a platform, running in the execution environment, and authorization of access to local resources. Without such means, unknown malicious agents could enter and damage the system. To deal with these aspects, it was necessary to implement the passport concept. The passport is the “proof of identity” of any agent. It is the official
“travel document” recognized by any TeleCARE node of the community (see the details in Figure 4). Therefore, any mobile agent that intends to migrate to another platform must have a valid passport. The use of passports has been attempted by other authors but TeleCARE extends the concept namely in what concerns agent/user identification and provides the following facilities:

- A flawless mechanism for mobile agent identification, common to all TeleCARE sites.
- The secure agent migration through the TeleCARE network.
- The protection of the TeleCARE platforms from incoming malicious agents that could damage their execution environment or have access to non-public information or resources.
- The possibility for denying the entry of agents from unknown/un-trusted origins.
- To allow/deny the entering agents the access to the local resources in TeleCARE platforms.

The passport mechanism proved also effective in the case of interchange of messages between agents located in different platforms. Both in the case of mobile agents, when an agent arrives at one node, and for remote (inter-node) agent communication, it is important to know who the agent is as well as which user (under which role) it represents. Having the sender’s passport associated to a received message, the receiver can better decide on what to do with the message.

**Figure 4. The passport structure**

The extended Inter-platform Mobility concept. This module constitutes an extension of the basic Aglets platform responsible for the management of the migration process of the agents between the TeleCARE nodes. It keeps a registry of all agents that live inside or entering in a platform (see Fig. 5). It also controls the reception or exit of the mobile agents, depending on the contents of their passports. An important achievement is that this module provides a lightweight, federated/distributed agent localization mechanism that allows the localization of any local or remote agent that was created in any node of the TeleCARE network.

**Figure 5. The Inter-platform Mobility manager**

Inclusion of agents’ persistence support. Persistency is a mechanism that allows storing information about the running activities of the agents and, whenever a system crashes to allow them to be resumed when the system is restarted. Aglets provides a method called **snapshot**, which saves a snapshot of an agent into a secondary / non-volatile storage. For persistency purposes, every TeleCARE agent can invoke the **tcSave** method, which does a call to snapshot, for storing information about its execution status when necessary. If there is a system failure, the last snapshot of the agent is restored and its execution can be resumed with the information stored in that snapshot. However the effectiveness of this process still depends, to a large extent, on the agents’ programmer.

**The Abstract Resource Manager Agent.** The **Resource Manager Agents** provide a generic and open mechanism for the definition and utilization of devices and appliances in TeleCARE. They provide a way to deal with the disparate number of interfacing methodologies contributing to the materialization of the concept of plug-and-play at this level. A resource manager acts as a broker responsible for providing the access to the hardware resources and appliances whenever requested by upper level Vertical Service agents, as seen in Figure 6. The resource manager also verifies their access rights whenever they request access to the resources. The structure was inspired in the **UPnP** (for devices) and web services (for vertical services) specifications. To enhance interoperability within the remaining components of the platform and contributing to a form of implementation of ubiquitous computing, these managers use FIPA ACL. The resource managers work in collaboration with the **Resource Catalog Management Module**.

**The Resource Catalogue Management (RCAM)** enables TeleCARE service developers to define, search, and modify specific details of resources available within the TeleCARE environment.
Distributed information management plays a fundamental role within the base infrastructure supporting the elderly care domain. Specificities of this domain include the autonomy and independence of its involved personnel, the critical data that is handled about individuals, and the variety of hardware/software resources supporting the elderly care environment. Considering the independence and autonomy of the network nodes, a major challenge here is the organization, management, and provision of retrieval facilities for both the heterogeneous data stored at the nodes, as well as the information regarding its hardware and software resources (i.e. devices and services) at each node within the network, while preserving their access rights and authorization. One problematic issue here is that in order for services to be connected to the elderly care network, their developers must structure and store all their data within the network’s database. However, the need for developers to obtain database modeling expertise must be reduced. One way to avoid the need for expertise in database modeling for the network’s database, is for developers to apply a user-friendly editor through which they can define their data by its ontology, which in turn can be automatically translated into proper database structures and stored in the network database. The Dynamic Ontology-based data Structure Generation (DOSG) component supports and assists both the TeleCARE component developers as well as its service developers in terms of ontology definition and automatic generation of database schemas. Based on the ontological definitions provided by users, the DOSG tool automatically generates five different outputs, namely:

- Relational database schema, in form of a Structured Query Language (SQL) definition
- Java classes providing the source code of the data structures
- XML schema with the specification for proper handling of XML documents
- Object-relational mapping with details for the conversion between Java classes and the DB system
- XML mapping that defines the translation between the Java classes and XML.

Other safety aspect. Safety and privacy is a primary concern in the elderly care domain. In addition to the mentioned passport mechanism and the access rights definition (supported by the federated information management system), safety and security also involves communications and user authentication. In order to provide a safe communications environment over Internet, a VPN approach was integrated with the multi-agent platform. A finger print biometric identification device was also integrated with the platform providing a mechanism to implement safer user identification. This is particularly useful in the care centers where different users (e.g. nurses, doctors, care workers), with different information access rights, can have access to the system. A taxonomy of users and roles is therefore associated to the biometric-based login process.

3. TeleCARE services

In order to validate the TeleCARE architecture, a prototype platform is developed in Java that integrates and resorts to various open source or freeware supporting technologies, e.g. Aglets mobile agents platform [1], Protégé ontology manager, SAP DB management system, and Castor.

Figure 3. An implemented demonstrator system

On top of the TeleCARE platform a number of application-oriented services can be implemented. Current prototype implementation includes two sets of specialized services (Fig. 3):

a) Base horizontal services – This is a set of specialized base services that provide specific functionality for the other (vertical) services, including the following:
- Specialized interfaces for elderly – Specialized interfaces are required to enable elderly people to use the system in their homes as many of them are not...
skilled in the use of computers. The ultimate goal is to make the usage of the system pleasant and easy, and thus the TeleCARE infrastructure "invisible" to the elderly.

- **Virtual Community Support** – To support and facilitate the creation and operation of community-based services designed for the elderly. For this purpose, specific virtual community management functionalities are supported within the service development environment of TeleCARE.

- **Web service access** – To allow remote access to some services via a web browser. This functionality is particularly useful to allow relatives of elderly people to have access to the TeleCARE network from their working places or their own homes.

In the TeleCARE environment each vertical service can be implemented in different ways as a set of distributed stationary and/or mobile agents. For instance, a monitoring service might involve a stationary agent in the care centre (interacting with the care worker), a number of stationary agents in the elderly home (agents in charge of monitoring local sensors, e.g. temperature sensor, presence sensor), and some mobile agents sent from the care centre to the elderly home.

People using the system will exhibit a diverse range of computer skills. Consequently access to the TeleCARE platform and services has to be made accessible through a variety of user interfaces. In particular specialized interfaces have to be provided to make the system easy to use for elderly people with little or no computer skills (via a TV set, for instance). For users with good computer skills (e.g. care center workers or relatives having access through a web browser) the interface can be Windows-based. For most elderly the interface shall make the infrastructure as transparent as possible.

In order to validate the general approach and functionality of TeleCARE, an extensive and controlled field assessment was performed. For this assessment four interest groups were selected:

- **Elderly people and their relatives**, who are the end users of the possible horizontal and vertical services on which TeleCARE is initially focused.
- **Care Providers**, including those people, institutions, and companies concerned with care for the elderly and especially tele-care.
- **Decision Makers**, that is, all of those with the power to make decisions, since they belong to public organisations in the sphere of social care.
- **Software Developers**, i.e. people and companies developing applications for elderly care.

The field assessment involved the realization of several demonstration and hands-on events organized for the various target groups. Of these events, four were held in Sanlucar la Mayor, a town in the province of Seville (Spain), each of which was targeted at one of the four user groups described. Another took place in the town of Castilleja de la Cuesta, just outside Seville, aimed at elderly people and their relatives. Two more took place in Gelves, also near Seville, for relatives and developers, and one was held in Pamplona (Province of Navarra, northern
Spain), in which the attendees belonged to the three user groups directly related to assistance to elderly people. Together with these events, another meeting was held with a NGO (GRAAL) that promotes and manages the Time Bank concept in Portugal, which also produced some interesting feedback. Final a special session for developers was organized in Porto, Portugal.

The results of these events showed the appropriateness of the TeleCARE approach and helped in the identification of areas for improvement and further development.

Firstly, the elderly people, the relatives, the Care Providers and the Decision Makers all noted the possible difficulties which elderly people might have to use the system, given their lack of technological knowledge. The general recommendation in this respect was to improve the specialised interfaces for elderly people and especially to add voice recognition tools as an interface between the elderly person and the system, which would avoid most of the knowledge barriers existing at present.

One lesson learned, although not expressed by the users, is the need to include training, awareness and motivation activities in any possible implementation of the system, to familiarise elderly people with new technological advances. In any case, we must not lose sight of the fact that this problem is likely to gradually improve in the future, since new generations will be more familiar with technology and will thus not view it as something hostile.

The opinion of the Decision Makers is very positive towards TeleCARE, and the only barrier they see to the use of the system by elderly people is fear, reticence and a lack of training in the use of technology, but they show great interest in the future development of the system and possible cooperation. With regard to Care Providers, they confirm the barrier described above, and add the lack of economic resources of elderly people, at least in some countries, to afford the cost of telecare services. With regard to the technical aspect, the approach, the architecture and the implementation of the platform were well received by the domain experts, who considered it to be a very innovative system. Nevertheless, there were recommendations to make the system more intelligent, not as regards the approach, with which they agree, but as regards the implementation and integration of intelligence in the services developed for the prototype.

4. Further challenges

As a result of this development and field assessment effort it was possible to identify major trends and further R&D needs. Some of the challenges ahead include:

- Further development and implantation of the Collaborative Networks concept among the organizations/individuals involved in this domain: Understand and support the specificity of virtual organizations for elderly care; Extend support for Virtual Communities, considering both informal and formal care giving networks.
- Progress towards the materialization of “personal wellness systems”: Highly individualized support for home based care; Maintaining wellness.
- Exploit new approaches to make the infrastructure “invisible” for both the end-users and the service developers.
- For end-users: New mechanisms for user interface and pervasive computing (e.g. Voice); New additional assistance mechanisms (advanced help); “Independence of where people are” (mobility).
- For service developers: Web-service based infrastructure to assist the developments of future services; Incremental and semi-automatic development of common ontology for the environment; Visualization of data in meaningful ways, e.g. “disease signatures”, “behavior patterns”. Putting the emphasis on “accessibility”, a typical approach in many research programs in this domain, is too limiting. The issue of user interfacing and “immersion” is more general and it involves basic research issues and engineering and technology issues.
- Increase the level of intelligence of vertical services, namely by adding intelligent monitoring functionalities (e.g. fall detection and other advanced interpretation of multi-source sensorial information).
- Develop an extensive program for training and raising awareness - creating a new mind set for tele-assistance and tele-monitoring.
- Further analyze and support the security, legal, and ethical issues involved in remote monitoring. The issue of accountability (in what regards access and use of sensitive information) needs to be further researched and supported.
- Better support the collaboration among autonomous nodes and pre-existing legacy systems. Innovative approaches must be developed for federated information/knowledge management, in order to support the dynamism/evolution, and integration/inter-linking of existing schemas, with semi-automatic tools and mechanisms.
- Exploit the applicability of the main concepts and technology of TeleCARE to other domains including tele-health care.

Many of these requirements are now being addressed in the ECOLEAD integrated project funded under the 6th framework program of the European Commission. ECOLEAD is not focused on elderly care but rather addresses collaborative networks in general.

5. Conclusions

The growing numbers of elderly population impose an urgent need to develop new approaches to care provision.
Recent developments in a number of technologies such as multi-agent systems, federated information management, safe communications, hypermedia interfaces, rich sensorial environments, and increased intelligence of home appliances represent an important enabling factor for the design and development of virtual elderly support community environments. In order to support the smooth development and integration of new services, a flexible and open infrastructure is needed. Nevertheless, the specific characteristics of the elderly population, who are not very open to deal with new technologies, requires a careful integration of the infrastructure with traditional home appliances including Television sets. Furthermore, the tuning and eventual acceptance of the technology can only be determined when reliable prototypes are tested in the field with real users.

The results of TeleCARE prove the feasibility of the approach and clearly point to a new vision of the elderly care systems. It is however clear that the introduction of a new approach and new tools in this domain requires a new mind-set from many of the actors in the field. Therefore, further developments in the area need to be accompanied by intensive training of care workers and initiatives to raise awareness of the involved stakeholders.

The TeleCARE Basic Platform comprising the mobile-agents platform and the federated information management system, although designed and developed to cope with the requirements defined for the elderly care domain, shows the potential to be applied in other domains. In fact, several other applications with similar characteristics – geographically distributed, requiring high flexibility and openness regarding the addition of new resources and services, multi-level security / privacy mechanisms – can benefit from a platform such as TeleCARE. Examples include remote monitoring and maintenance applications, distributed supervision systems (in automation, environment monitoring, etc.).

Regarding the use of mobile agents it was experienced that this paradigm provides adequate flexibility but it is still a complex and somewhat immature technology when it comes to implementations on top of Internet, namely with respect to issues of persistence support and safety. Nevertheless most of the architectural features of the TeleCARE platform are relatively technology-independent. The development of systems that are not biased to a particular technology is one of the main goals of the new ECOLEAD project.

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