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Management of Federated Information in Tele-assistance Environments

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ABSTRACT

An advanced tele-assistance environment for elderly care is being developed by the research carried out in the context of the TeleCARE project. This environment is a highly distributed collaborative network composed of heterogeneous and autonomous nodes. The analysis of information management requirements has identified both the modelling and functionality requirements at each node, as well as the information exchange/integration necessary for interoperation within the network. Based on the examination of these requirements, three key and innovative components were identified that together support the management of all information related to the TeleCARE environment. These components, namely the Federated Information Management component (FIMA), the Resources Catalogue Management component (RCAM), and the Dynamic Ontology-based data Structure Generator (DOSG) are introduced, and their implementation details are discussed.

INTRODUCTION

Tele-assistance services and remote supervision applications are progressively increasing to improve the efficiency and availability of care services (e.g. remotely operated appliances, remote homecare services, etc.). Ongoing advances in telecommunications, networking, artificial intelligence, safe communication facilities and information management provide the groundwork for emerging services, based on collaborative networked environments dedicated to tele-assistance. A collaborative environment as such, is usually a highly distributed network composed of heterogeneous and autonomous nodes that are interested in providing organised support and care provision to the clients. Each node individually plays an assisting role, however, many organisations involved in the collaborative network need to maintain their autonomy and their rights to both their proprietary data and local resources. Thus, the collaboration among different active organisations (e.g. care centres and leisure centres) in the network forms a Virtual

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Organisation (VO)[1], while the collaboration among active individuals (e.g. relatives' and friends' nodes) in the network forms a Virtual Community (VC)[2].

Interest in deploying tele-assistance services is global, with the perceived advantages of using emerging technologies to provide remote access at low cost. However, the development of tele-assistance services is extremely complex. Due to the growing number of technologies under development, new hardware (sensorial devices, appliances, etc.) are being deployed in a fragmented and non-interoperable way. Furthermore, a number of other advanced capabilities and features are required by the software managing the remote operation/access to resources. For instance, the secure transfer, reliability, safety and privacy of the information exchanged within the network should be assured. The design and development of an affordable infrastructure for tele-assistance is, therefore, a crucial requirement for the effective deployment of applications in such collaborative networks.

The TeleCARE project aims to design and develop a base infrastructure to support elderly care environments, whilst addressing many of the above challenges. A scenario for TeleCARE is depicted in Figure 1.

Distributed information management plays a fundamental role within the base infrastructure supporting the elderly care domain. Specificities of this domain

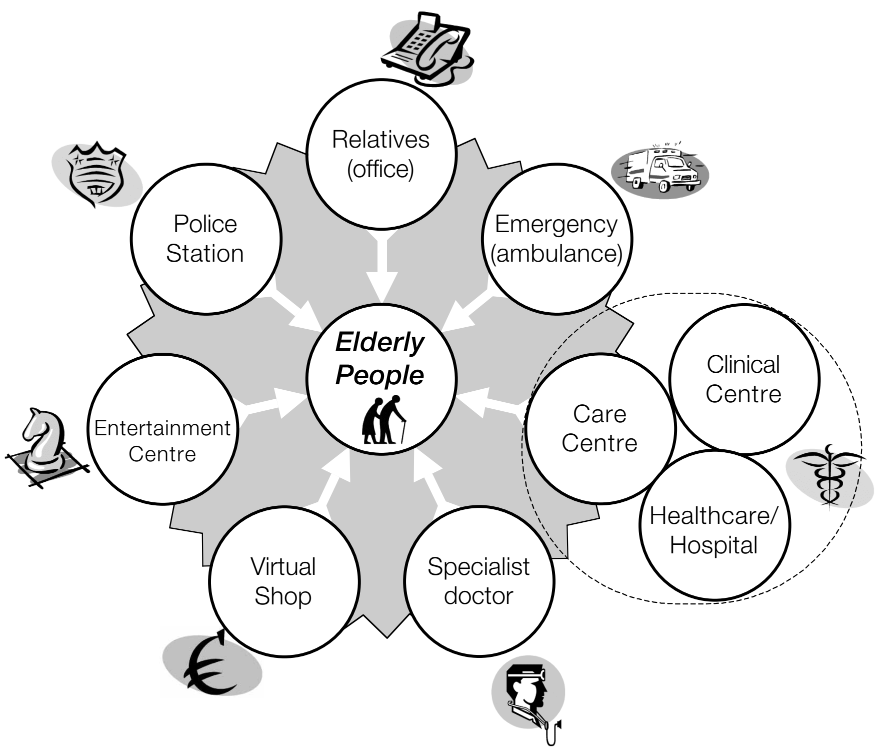

Figure 1. *The TeleCARE scenario as a collaborative networked environment*

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, many challenges are involved in handling their information. These challenges include the organisation, management and provision of retrieval facilities for both the heterogeneous data that is stored at the nodes, as well as the information regarding its hardware and software resources (i.e. devices and services), while preserving users access rights and authorisation.

In addition, considering the incremental development of the support services to be made available within the elderly care network, developers of such services require assistance to make their services interoperate with other existing systems and resources. 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. To avoid the need for expertise in database modelling, it should be sufficient for developers to use an 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's database.

This article first briefly describes the TeleCARE platform architecture and its main elements. It then presents the three main components developed in the TeleCARE project to support and facilitate the management of all the information related to tele-assistance for elderly persons in the tele-care environment. These components are:

- **FIMA —** *Federated Information Management*
- **RCAM —** *Resource Catalogue Management*
- **DOSG —** *Dynamic Ontology-based data Structure Generation*

Although the above components are currently developed to benefit the area of elderly care networks, these components are generic enough to enable a very large number of the designed and developed components to be applied to any advanced emerging collaborative network.

RELATED TECHNOLOGIES

Before describing the information management itself, it is pertinent to review some of the TeleCARE technologies that are most closely related to information management.

Multi-Agent Systems (MAS)

During the last decade, MAS together with *agent mobility* have advanced to the level that they can offer many potential advantages including robustness, efficiency, flexibility, adaptability, scalability, inter-operation of multiple existing systems, reliability and extensibility. The emerging field of mobile software has started to gain widespread acceptance, and nowadays is used for building applications in the area of collaborative networks, and to feature interactions among members[3,4]. A mobile agent is a program that acts on behalf of its user or another program creating it and is able to migrate from host to host within a network following its own itinerary. The mobile agent can choose when and where it will migrate and may interrupt its own execution and continue elsewhere within the network. Depending on its software implementation, a mobile agent can return results and messages in asynchronous fashion. Mobile agents can perform complex information gathering strategies autonomously; while stationary agents can collect and digest the information of interest and assemble a result report. Agents can be either reactive in performing services by responding to changes in their environment, or pro-active, by performing tasks to fulfil their goals. A mobile agent is also able to travel, searching for specific information across the network and retrieving it. As it performs these actions, a mobile agent can also deploy new applications or upgrade the software running at different sites. Key elements of an agent's mobility are *autonomy* and *behaviour*. Once goals are established, the mobile agent is guided by its own capacities to fulfil the action. Mobile agents can also hold some decision-making control. Thus, while searching its itinerary it can run independently from the interventions of the user who created it.

The TeleCARE infrastructure is based on Aglets[5,6], a multi-agent system, that supports agent mobility based on Java. The designed platform supports seamless interactions among stationary and mobile intelligent agents, with planning, error diagnosis, and recovery capabilities. Agents are able to recognise and self-adapt to diverse environments. At the same time, the mobile agent technology provides a rich base for information brokerage in networked environments[7] and a possible approach for implementing distributed/federated information management systems[8].

Ontology System

An ontology refers to the set of logical definitions that express the meaning of terms for a particular domain. These conceptual definitions make use of explicit assumptions and may include semantics as well. Ontologies are based on the understanding of the members of a particular domain, such as biomedicine, and help to reduce ambiguity in human and computer interactions.

An ontology definition constitutes a collection of concepts and interconnections that describe the information units of particular applications. For their application plan, the platform and vertical service developers, who are the experts on the semantics of data required, first design all information units that need to be shared in a collaborative environment. The semantic heterogeneity among the shared information is resolved by mapping it into an ontological definition. This ontology can be understood and consulted by both humans and software agents[9].

Essentially, developers describe their shared information through the use of ontologies. The ontology management system in the TeleCARE architecture supports this process, and the developers can transparently define their conceptual model. The ontology management system preferred for TeleCARE is Protégé[10].

Protégé-2000, or Protégé for short, is an ontology system developed by Stanford Medical Informatics Laboratory that can be used by software system developers and domain experts to develop their knowledge-based systems. This system assists its users with the creation of their knowledge base, since it supports the definition of structured classes and information storage. Originally, Protégé was designed specifically for the medical domain but it grew as a general-purpose set of tools for building knowledge-based systems in any domain. In TeleCARE related domains such as clinical medicine and the biomedical sector, where complex concepts need to be modelled, Protégé is already being used to define class hierarchies and to provide semantics on concepts[11]. A number of applications and ontologies in the particular domain of medical care have been developed with Protégé and used in problem-solving and decision-making. Examples of ontologies developed with Protégé include: Health Level Seven (HL7) Data Types, Top-Level Reference Information Model (RIM) classes, Biological Processes Ontology, Gene Ontology (GO), and GuideLine Interchange Format (GLIF) Ontology.

Federated Information Management

The federated information management and federated database mechanisms address the sharing and exchange of distributed information in a highly heterogeneous environment[12–14]. The federated approach to information management in networks of independent cooperative nodes is well suited to management of all local and distributed information handled in TeleCARE, while preserving the node autonomy and information privacy. The federated query processing mechanisms allow access to distributed information according to their defined access rights, where TeleCARE sites represent autonomous nodes in the federation. Namely, TeleCARE sites run independent of each other, and may evolve independently in terms of applications, devices, services and data models.

The establishment of federated schemas is a critical task during the set up and implementation of the federated information management. Information sharing is generally performed based on those schemas, and any misinterpretation of data during communication between information systems is called semantic heterogeneity. In TeleCARE, to avoid misinterpretations of data, the federated information system uses explicit data structures specified from ontological definitions.

The TeleCARE platform applies the results gained in previous research and development projects for federation of autonomous and heterogeneous expert systems. Federated information management has also been applied to virtual organisations to support the cooperation between the nodes in the federation to accomplish a common or global task, while the local autonomy and independence of every node is preserved and reinforced.

TELECARE AS A TELE-ASSISTANCE PLATFORM

The overall goal of the TeleCARE project is the design and development of a configurable framework solution for tele-supervision and tele-assistance, to support the elderly. The proposed solution has been seen as complementary to other initiatives, focused on the integration of the elderly into society to reduce their isolation[15]. The TeleCARE solution benefits from the merging of a number of technologies and paradigms in order to provide an open architecture supporting seamless future expansion. Specifically, it is based on the integration of:

- Multi-agent systems, including both stationary and mobile intelligent agents
- Federated database systems
- Secure communications
- Services likely to be offered by emerging ubiquitous computing and intelligent home appliances.

In essence, the core *horizontal* platform developed for TeleCARE provides the MAS, mobility, safe communications and the federated information management services. The TeleCARE consortium has further developed some *vertical services* on top of this platform, including status monitoring, as well as other forms of assistance such as agenda reminders, entertainment services and Time Bank. In addition a few *base services* for supporting virtual communities, Web access and a specialised elderly user-interface are also provided.

THE TELECARE REFERENCE ARCHITECTURE

The reference architecture for TeleCARE nodes provides cooperation/federation among different nodes of the elderly care network as depicted in Figure 2.

The designed architecture of the TeleCARE node is composed of a three-level platform. At the bottom, the *External Enabler Level* provides support for the external communication of the TeleCARE node and the interfaces with external resources. The *Core MAS Platform Level* is the major component of this architecture, and includes essential support for software agents. Finally, at the top, the *Vertical Services Level* is the open component where a variety of services can be gradually added to the node.

External Enabler Level

This level supports the remote communication with other nodes and provides interfacing mechanisms to the external devices. This level comprises two segments:

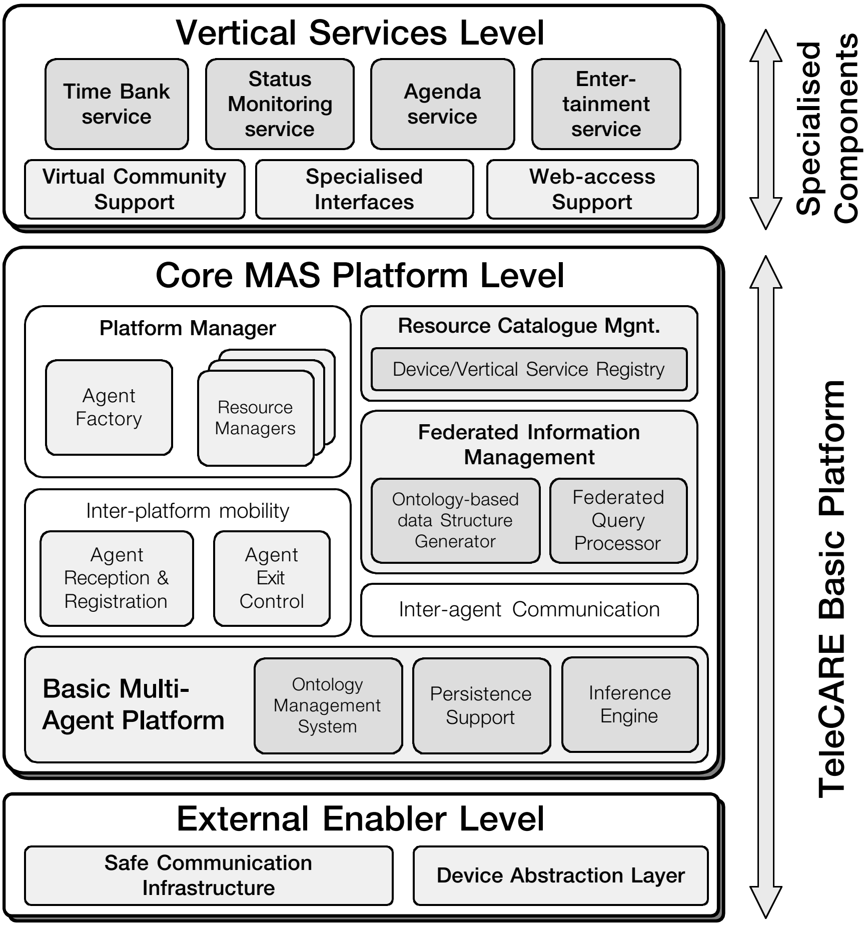

Figure 2. *The TeleCARE platform reference architecture*

- A **safe communications infrastructure** to provide safe communications and support both secure and reliable agent/messages passing among different nodes.
- A **device abstraction layer** that interfaces the sensors, monitoring devices, and other hardware (home appliances, environment controllers, etc.) to the TeleCARE environment.

Core MAS Platform Level

The platform level is the main component of the environment and offers fundamental services for agents as well as for their interactions. These services include the creation, launching, reception, user authentication, access rights verification, and execution of stationary and mobile agents. The main modules at this level include:

- The **Basic Multi-Agent Platform** that provides the essential multi-agent support, and is based on the Aglets framework[5] with the following extensions:
    i. *Ontology management system* — The Protégé 2000[10] is used in the platform for the definition of the ontologies.
    ii. *Inference engine* — For intelligent agent interpretation using a Prolog interpreter.
    iii. *Persistence support* — For basic recovery mechanisms.
- **Inter-platform Mobility** is an extension to the basic MAS platform to support generalised mobility of agents, including agent security mechanisms. This module includes the *Agent Reception and Registration* component, and the *Agent Exit Control* component, for administration of stationary and mobile agents.
- **Inter-agent Communication** is an extension to support credentials and coordination of agent communication, independent of the agent location.
- The **Federated Information Management** supports the management of information at TeleCARE nodes and provides the infrastructure for flexible processing of federated queries, data structure generation based on ontological definitions and preserving information privacy through access rights management. This component was developed using Java in conjunction with free and open source software, namely the SAP DB relational database system[16] and the Castor data binding middleware for Java[17].
- The **Resource Catalogue Management** manages the catalogue of resources, and registers the descriptions of all device and vertical services available at the site as well as their access rights.
- The **Agent Factory** supports the creation and specification of new agents.
- The **Platform Manager** configures and specifies the operating conditions of the platform at each site, including user administration and node management.

Vertical Services Level

The applications and Vertical Services Level focuses on the actual support for the elderly (who require specialised user interfaces), care providers, and relatives of the elderly (assuming that they are able to interact with normal computer interfaces). It is composed of two layers.

- **Base Services** that provide specific support to other value-added services.
    i. *Virtual Community Support* to assist the management of the Virtual Community (VC) for the elderly care environment.
    ii. *Specialised interfaces for the elderly* are designed to be easily used by people who are unfamiliar with computers, and also for assisting people with diminished physical abilities, such as poor hearing or eyesight.

  iii. *Web-access support* enables Web-based mechanisms to interface with the TeleCARE environment.
- **Vertical Services —** A number of specialised vertical services are implemented as specific TeleCARE applications, including a VC-based Time Bank, a living status monitoring service, an agenda reminder service, and an entertainment service.

MANAGEMENT OF INFORMATION IN TELECARE

The analysis of information management requirements for the TeleCARE network has identified both the modelling and functionality required to be supported locally at each node, as well as for the information exchange/integration and necessary interoperation among the sites. Based on the analysis of these requirements, the necessity of three main components was identified that together support both the management of all information related to the TeleCARE network. These components, namely FIMA, RCAM and DOSG are described below.

FIMA — FEDERATED INFORMATION MANAGEMENT

The Federated Information Management component of TeleCARE supports applications that may require a variety of data models and large numbers of users and agents accessing and retrieving its data, while supporting the pre-defined visibility rights to physically distributed and heterogeneous data. The federated database architecture of FIMA does not require any centralisation of data or control and thus supports the flexibility and extensibility aspects required for future use of the TeleCARE system. The database architecture can also support a variety of application architectures that may be used for development of different vertical services for TeleCARE, including both the client/server and the agent-based systems. The database repository of FIMA is developed using the SAP DB as the base. The SAP DB provides an open source and freeware database management system, and was one of the main reasons for selecting it for the TeleCARE project.

The two key functionalities offered by FIMA include:

- *Federated Data and Schema Management.* This handles all the data and schemas defined in the network while supporting the definition of adequate levels of information privacy for access by authorised agents and users.
- *Federated Query Processing.* This supports the collection of all necessary data from different distributed heterogeneous and autonomous nodes, through a single query issued by the user, as if all data distributed among different nodes are in fact available at the local site.

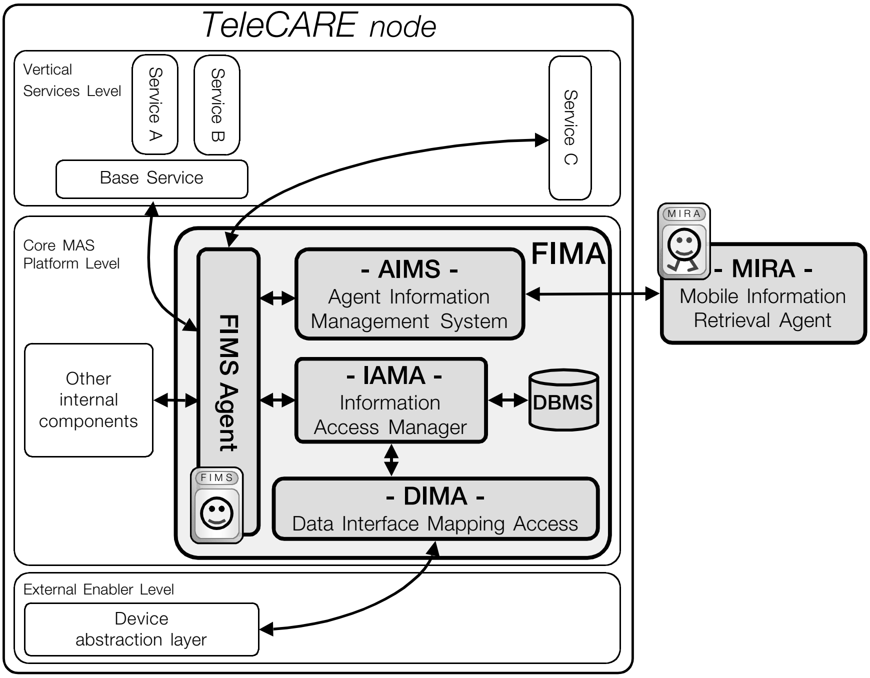

Figure 3. *Federated Information Management Architecture – FIMA*

Figure 3 shows a high level architecture of FIMA and its main software components. These components, depending on their role and functionality, are all implemented as stationary and/or mobile agents. Detailed description of all these agents is outside the scope of this paper. Below we focus on the Federated Query Processing (FQP) of FIMA and provide details on the stationary and mobile agents supporting this functionality, and how the query processing performance is improved in comparison to other agent-based approaches[8].

The processing of federated queries is a complex task, and it is briefly detailed as follows. First, the requester sends a query (which is in high-level format) to the FIMA interface, which generates an agent designed to handle this request. The query is then translated considering the internal structures of the stored data, and a set of sub-queries is established. These sub-queries are one by one assigned to mobile agents with the proper itinerary. After this step, these mobile agents are dispatched to the remote nodes to accomplish their mission, to perform the local query and to send the results back to the original node. Finally, the received results are merged at the node and returned back to the requester, see Figure 4.

What should be appreciated is that the main goal of the federated query processor component in FIMA is to enable TeleCARE agents and end-users to query the authorised information, without concern for all the details about database connections, agents creation, their travelling among nodes and processing of the data.

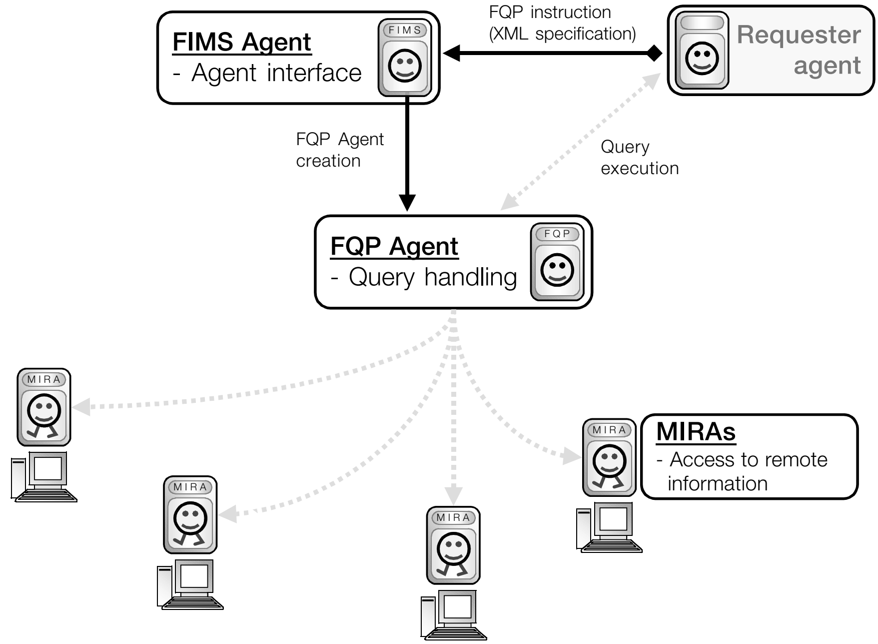

Figure 4. *Main agent components of Federated Query Processing*

Below are the main agents involved in federated query processing of FIMA:

- **FIMS Agent**: Federated Information Management Server Agent, acting as the FIMA interface agent.
- **FQP Agent**: Federated Query Processor Agent, acting as the query supervisor.
- **MIRA Agent**: Mobile Information Retrieval Agent, acting as the mobile component, transferring the jobs to other nodes, for this process.

FEDERATED INFORMATION MANAGEMENT SERVER AGENT

The Federated Information Management Server Agent (FIMS Agent) manages the interface to access the information in FIMA. It must be continuously available and running. It supports multi-users and thus can fulfil requests from numerous agents simultaneously that may have different purposes other than just executing a single query. However, in order to speed up the data retrieval process FIMS Agent does not handle all the query processing related operations. Whenever FIMS receives a request for a federated query, it generates another agent (FQP Agent) in a different execution thread, thus allowing it to maintain its primary operation. This mechanism provides the highest performance for query processing, since the new FQP Agent will focus only on the task of performing the query.

When the FIMS Agent summons the FQP Agent it also includes the credentials of the requester into this new FQP Agent. As a result, from that point on all query operations are bound to that FQP Agent, i.e. it will supervise the processing of a federated query, and thus the FIMS Agent is freed from the responsibility of the federated query execution.

FEDERATED QUERY PROCESSOR AGENT

The Federated Query Processor Agent (FQP Agent) is at the heart of the federated data processing in FIMA. It implements several advanced features particularly useful in the collaborative TeleCARE environment. Some of the mechanisms used for federated query processing of FIMA are also integral to the TeleCARE infrastructure (e.g., the multi-agent and the Java object oriented programming environments).

A number of techniques are used to improve the performance of the query processing, for example: (1) special multi-thread processing; (2) simultaneous execution of several queries and (3) reduction of communication costs by reducing the size (i.e. content) of the mobile agents involved during the query execution.

Table 1. Processing of federated queries

Query translation	The query that arrives in high level functional format in XML is first translated into internal handling structures.
MIRA creation	Depending on the type of federated query and on the targeted itinerary, appropriate Mobile Information Retrieval Agents (MIRAs) are created, e.g. if the query type is 'parallel' then multiple MIRAs will be created, one per target node.
Query decomposition	The original query is divided into a number of sub-queries according to the number of target nodes, and these sub-queries are assigned to the corresponding MIRA agents.
MIRA transmission	Each MIRA is sent to a remote node carrying the corresponding sub-query.
Query evaluation	The MIRA agent performs the MIRA-to-FIMS Agent communication of the remote node in order to execute and retrieve the requested information from that node.
Result transmission	The MIRA transmits the information resulted from the sub-query to the FQP Agent.
Information merge	Once all results arrive from the MIRA to the FQP Agent, the FQP merges the sub-results and sends the final results to the requester.
Resource release	When the execution of the query completes, the requester can agree to release resources generated by the FQP Agent, disposing all the MIRA agents involved in the query evaluation as well as the FQP itself. Note that disposing the FQP Agent at any stage of the query execution will effectively close the processing of the federated query.

All these mechanisms focus on the internal operations for the processing of federated queries. The number of these internal operations is large and they are grouped in several task categories, which are summarised in Table 1.

MOBILE INFORMATION RETRIEVAL AGENT

The Mobile Information Retrieval Agent (MIRA) is a mobile agent that transmits the federated query to other nodes. Being a software agent, it also guarantees the possibility of combining intelligent decision-making with the information retrieval tasks. Therefore, it can support a range of federated queries. For example:

- Gathering information from several specific nodes at once and merging the results at the originating node
- Searching all nodes one by one in an attempt to retrieve all possible answers, or to find the best answer
- Searching all nodes one by one until a certain condition is satisfied. For example, finding the first possible answer, or finding a satisfactory answer. In the latter case the answer is sent to the originator node and a 'satisfaction' response is required from the originator node to decide whether to continue the search or to stop. The search may also be modified to allow for finding a specific number of answers and then quitting.

Handling of MIRA agents is solely performed by the FQP Agent and it is completely transparent to the requester. Clearly, from the requester point of view, the proper execution of the query and its results is what really matters, and not how the query mechanism was implemented. This transparency noticeably reduces the system complexity since the TeleCARE application designers and developers are not concerned about internal details of the processing mechanism.

As part of the strategy to enforce the visibility levels and access rights on the information, FIMS Agent will also "*borrow* (from the TeleCARE platform system*) and check the credentials*" of the requester agent for creating the FQP Agent. The FQP agent in turn uses those credentials to create authorised MIRA agents. In general, this strategy is used in FIMA to validate the access rights to the information for requesters, no matter if the requester is local or remote. Visibility levels and access rights are further described later in this paper.

PROCESSING OF QUERY TYPES

The federated query processing mechanism of FIMA supports access and retrieval of data from multiple TeleCARE nodes, so that the data can be retrieved either from the same or different remote nodes. Three types of federated queries are supported in FIMA to allow retrieval from remote data stored in different nodes on the network.

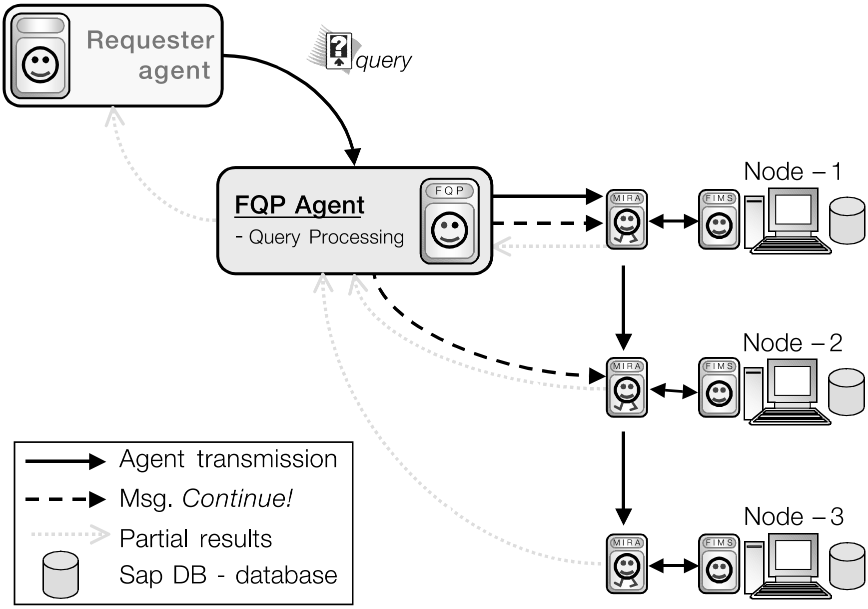

Figure 5. *Sequential query type in FIMA*

- **Parallel query type,** where speed of performance is the key consideration.
- **Serial query type,** where optimisation of resource usage is the focus.
- **Sequential query type,** which requires interactivity with the requester to control the information-processing overhead (see Figure 5).

One advantage of providing different types of query and access methods is that the requester can choose which of the three options to use. This allows him to control the general performance and overhead of the process and thus optimise performance of the federated queries for specific purposes.

The design of the architecture of FIMA carefully considers necessary data and agent traffic among the TeleCARE nodes. Two communication mechanisms between the nodes are properly supported. These are (1) inter-agent message passing and (2) agent mobility. They are respectively considered for supporting the cases of '*information push*' and '*information pull*' among the agents:

- *Information push*: A simple TeleCARE information exchange case is considered where a Care Centre site requires periodic sending of the sensed data from the home sites. In this case, the data collected at the home site is pushed from the home site to the Care Centre. The 'push' action is performed as 'messages' sent from one agent to another.
- *Information pull*: To illustrate the information pull, assume that an elderly person wishes to plan a special fun activity in his/her community and starts this planning through an 'entertainment service' at home. The corresponding 'elderly entertainment service' at the home site searches for relevant

data to be collected from the Virtual Community. Then, a MIRA agent that may contain a parallel, serial, or sequential federated query (depending on the kind of request, if it is to all, or, for instance, a specific number of people), can pull names from one or more leisure centres.

VISIBILITY LEVELS IN TELECARE

In federated information management networks, different autonomous nodes can have different visibility levels and access rights to other nodes' information. Thus, every node in the federation can decide what part of its local information should be available to each member in the federation[13,14].

In other federated database environments the approach for visibility levels is either based on individual export schema definitions, on the local schema for every external 'user', or based on the definition of a complete hierarchy of export schemas. However, due to the highly dynamic nature of the TeleCARE environment, where users and nodes are added and removed regularly, a different approach is adopted for defining the visibility levels. This approach is based on the credential of every agent, and specifically of the agent type, that also represents the role of the user generating the agent.

DOSG — DYNAMIC ONTOLOGY-BASED DATA STRUCTURE GENERATION

Typically, for building large systems and applications, the assistance of a database expert is required to define the structure for concepts and entities of the environment, namely the database schema. The DOSG component supports and assists both the TeleCARE component developers as well as its service developer, with their direct definition and modification of database schemas, for the data that needs to be processed by their code, while eliminating the need for database expertise. Namely, DOSG provides facilities for dynamic and automatic definition and modification of database schemas, so that they can be automatically stored in the database. As a consequence, the service developers of TeleCARE, can simply use the user friendly interface provided for the 'Protégé' ontology system to provide their data structure definitions.

The main focus of DOSG in TeleCARE is transforming the ontology definition provided for some information into the underlying information management model (based on the relational database system), as well as the Java objects specification. DOSG provides a highly innovative mechanism to leverage the object knowledge model in ways that vertical service developers can use to store, retrieve and manipulate information seamlessly through the federated information management layer of the TeleCARE platform.

DOSG is designed as a plug-in to Protégé. It extends Protégé's ontology editor with an interface that allows users to parameterise the automatic data structure

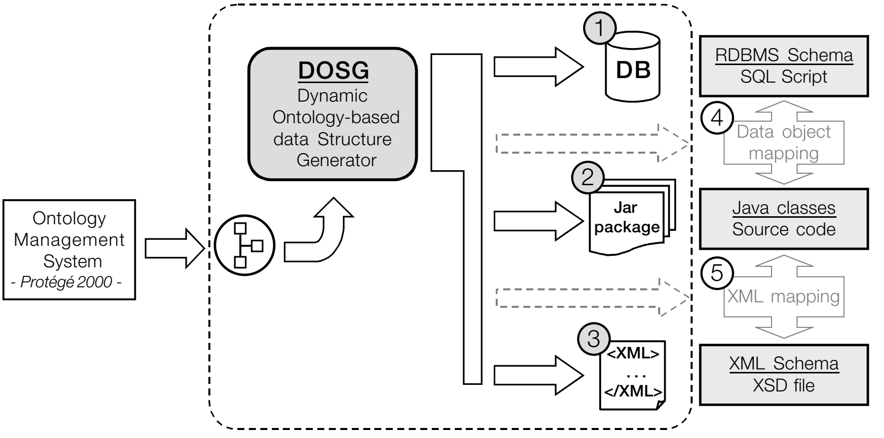

Figure 6. *Output format for Dynamic Ontology-based data Structure Generation — DOSG*

generation. DOSG benefits from the integrated Protégé environment by gathering online input related to conceptual schema, while allowing customisation of some parameters for this generation process through the DOSG interface. The implementation of DOSG is in Java and it also uses free and open source software, specifically Castor is used to produce the two mapping definitions[17], while Xerces is applied for the development of extensible markup language (XML) schema[18]. As shown in Figure 6, based on the ontological definitions provided by users, the DOSG tool automatically generates five different outputs, namely:

- **RDBMS schema** with the appropriate Structured Query Language (SQL) script for relational databases
- **Java classes** providing the source code of the data structures
- **XML schema** with the specification for proper handling of XML documents
- **Object-relational mapping** containing the mappings that govern the conversion between Java classes and the database system
- **XML mapping** that defines the translation between the Java classes and XML

RCAM — RESOURCES CATALOGUE MANAGEMENT COMPONENT

A complementary module to FIMA is the Resource Catalogue Management (RCAM) component. RCAM provides definition of the resource model, supports automated resource management and enables TeleCARE service developers to define, search and modify specific details of resources available through the TeleCARE environment. Resource descriptions in RCAM are based on widely accepted standards in order to allow current and future devices (e.g. household appliances) and/or emerging vertical value-added services to be more easily added to the TeleCARE platform. All hardware devices and software services in TeleCARE

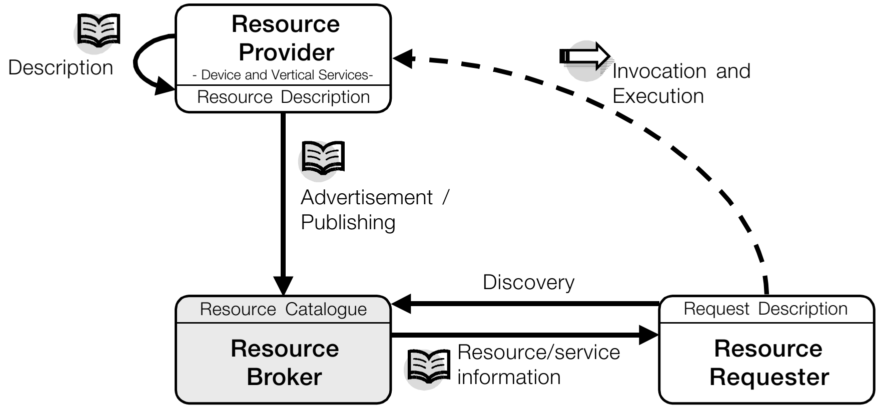

Figure 7. *Resource handling operations*

are treated as resources. Basically, RCAM acts like a registry for all resources, their internal service descriptions and interfaces. Namely, for every resource of the TeleCARE environment, RCAM manages three types of information:

i. The catalogue entry representing a definition of the resource
ii. The entries for the resource's internal services definitions
iii. The access rights to the resource

In order to support current and future devices, and emerging vertical services, TeleCARE resource definitions in RCAM are based on widely accepted standards. The hardware device definitions are based on the Universal Plug and Play (UPnP) specification[19], while the software vertical service definitions are based on Web Service Definition Language (WSDL) specification[20]. Furthermore, RCAM resources definition has been extended to better support users' access rights to resources, based on agent identification, part of the TeleCARE passport definition[21].

The *RCAM Agent* provides basic operations on the TeleCARE resource model. These operations can be grouped into the following categories: resource advertisement and publishing, resource discovery, resource access rights management (see Figure 7).

The suggested TeleCARE resource model involves the following actors: *resource provider*, *resource broker,* and *resource requester*. RCAM Agent acts as an automated *resource broker*. This resource broker provides a searchable (catalogue) repository of resource definitions through which resource providers can advertise and publish the functionality of their resources. Additionally, resource requesters search for appropriate resource services and obtain the necessary information to use them.

Furthermore, RCAM can store information about the access rights to TeleCARE resources based on the TeleCARE passport definition. As such, for every resource, related information regarding the Agent-type, User-role and User-id of its authorised users can be stored. Thus, every time that a Resource Manager agent receives a request to access its resource, the Resource Manager can first request the RCAM Agent to validate the authorisation of this access for the specific user. Therefore, usage of RCAM properly secures the access and usage of the vertical services and devices.

VALIDATION

The clearest and most direct way to validate and verify the applicability of the federated information management functionalities developed for the TeleCARE environment, is to study how the development of emerging tele-assistance services benefit from these functionalities. To illustrate this, two of TeleCARE's vertical services, *Agenda Reminder* and *Living Status Monitoring*, and one of TeleCARE's base services, *Virtual Community Support*, are used as examples. The full description of each of the application services has been previously reported[22,23]. The key characteristics of each of these three services is briefly described, together with a table summarising the contribution of the FIMA, DOSG and RCAM components in each situation.

AGENDA REMINDER

The *Agenda Reminder* is a vertical service allowing the management of individual agendas for elderly people. It provides the necessary hardware and software at the Care Centre, the homes of the elderly persons and the homes or offices of their relatives. Forgetfulness is common in elderly people and as a result they may miss activities and meetings that could improve their physical and social well-being. The agenda service aims to compensate for their loss of memory by reminding them of the activities and meetings they should attend to keep them healthy and socially integrated. Table 2 shows the key characteristics of the usage of the information management mechanisms in the Agenda Reminder service.

Table 2. *Information management for Agenda Reminder*

FIMA component	— Handling information of *Event*, *Proposal*, *Alarm* and *Event log*-e — FQP Agents are used to gather data contained in the remote nodes
DOSG component	— Concept definition for *Proposal*, *Proposal Type*, *Event* and *Alert* — DOSG transforms the concepts into appropriate data structures. No code by developers is required to define the structures in the database
RCAM component	— This service registers and establishes proper access rights through RCAM, when it is deployed on the elderly node.

Table 3. *Information management for Living Status Monitoring*

FIMA component	— The information managed for this service relates to parameters describing the normal life of the elderly. *Reading* and *Event* data originated from the monitoring sensors is also managed by FIMA component — Federated queries are applied to generate reports
DOSG component	— Concept definition for *Parameterisation*, *Response*, *Response type*, *Alerts* and *Alert type* — Translation of concepts into the primary data structures
RCAM component	— This service publishes its functionalities when it is deployed — Resource discovery is used when this service searches for audio/video and monitoring devices available at the elderly home — Access rights for monitoring devices are assured for authorised users

LIVING STATUS MONITORING

The Living Status Monitoring is a vertical service that proposes an innovative tele-assistance system for the elderly. The assistance is either requested manually, by the elderly through alarm buttons, hands-free communication devices, etc., or automatically, via the information generated by the medical equipment and hardware sensors. Moreover, the Living Status Monitoring service uses bi-directional information flows, together with complementary information sources (e.g. video cameras) in order to accurately assess the characteristics of the urgent situation to reduce the incidence of unnecessary travel of care personnel. Table 3 depicts the key characteristics of the usage of the information management mechanisms in the Living Status Monitoring service.

VIRTUAL COMMUNITY SUPPORT

The Virtual Community Support (VC Support) is a base service that provides its final users (the elderly) new approaches to socialise and improve their quality of life. The participation in virtual communities can be an important feature, playing a significant role in reviving personal experiences that may be impossible otherwise. In TeleCARE, a virtual community offers elderly people the feeling of belonging and a communication facility. It also makes it possible for elderly people to contribute and collaborate within a group. The VC Support service provides the base mechanism for administration and evolution of TeleCARE virtual communities. As such, this tool provides basic functionalities to support the creation, operation, evolution and maintenance of virtual communities in the TeleCARE environment. VC Support uses the functionalities of the federated management of information offered in the TeleCARE network. A summary of the

Table 4. *Information management for Virtual Community Support*

FIMA component	—	Handling information of *Virtual Community*, *VC Member*, *Interest Group*, *Message board* and *Contribution*
DOSG component	—	Concepts of the VC Support service are described with an ontology
	—	DOSG is used to construct the data structures at the Care Centre
RCAM component	—	This base service interacts with RCAM in order to publish its functionalities to support the creation, operation, evolution and maintenance of VCs

significant characteristics of the usage of the information management mechanisms for the development of the VC Support service is shown in Table 4.

CONCLUSIONS

A federated information management approach offers suitable mechanisms to cope with the required flexibility, heterogeneity, autonomy and privacy requirements for information handled within collaborative networks for elderly care. The combination of this approach with a mobile agent-based platform has proved to be an effective approach to developing a flexible infrastructure supporting a large variety of TeleCARE services.

The developed prototype system supports information interoperability between agent-based systems, contributing to an open plug-and-play philosophy involving a variety of hardware devices and appliances, as well as software vertical applications and services. The federated query processing in TeleCARE transparently provides access to remote data from several nodes and supports different types of queries. The dynamic ontology-based data structure generation facility offers system/service developers a new level of flexibility as they can focus on modelling their tasks at the ontology level using a user-friendly interface. Finally, a modular approach is introduced for resources (devices and services) to be integrated in TeleCARE via the Resource Catalogue Management component, thus making it possible for resources to be discovered and applied in the future service developments for this environment.

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