Federated management of information for TeleCARE

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Abstract. 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 actors, the critical data that is handled about individuals, and the variety of hardware/software resources supporting the elderly care environment. A federated information management system coping with these requirements is designed and integrated as a core component of a mobile agent-based infrastructure, to support collaborative networks for elderly care. Functionalities for: federated schema management, federated query processing, HW/SW resource management, specification and enforcement of visibility/access rights to data and resources, and an ontology-based automatic schema generation facility are introduced, and their implementation details are briefly discussed.

1 Introduction

A technologically advanced **elderly care environment** is a highly distributed collaborative network, composed of heterogeneous and autonomous nodes. Each node in the network (e.g. a care providing center, a leisure providing organization, a supermarket/shop in the neighborhood, a relative or a friend of the elderly person, etc.) is in one way or another interested in supporting the elderly person with his/her independent living style (see Fig. 1). Therefore, each node individually plays an assisting role, and further in collaboration with the other nodes in the network, provides certain **organized support and services** to the elderly.

The collaboration among different active organizations (e.g. care centers and leisure centers nodes) in the network forms a so called Virtual Organization (VO) [4], while the collaboration among active individuals (e.g. relatives and friends nodes) in the network forms a Virtual Community (VC) [10].

To develop an advanced elderly care environment, in addition to the Internet representing the communication facility for the network, some special base requirements must be satisfied for reliability, safety, and privacy of the information exchanged through the network. Furthermore, a number of other advanced capabilities and features are required, where among others, the remote operation/access to HW/SW resources (e.g. to home-devices and support-services), interoperation of heterogeneous information sources and software systems, tele-monitoring, federated management of the information and cataloging the HW/SW

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resources information, error recovery, and cooperative problem-solving for tele-assistance services, can be emphasized.

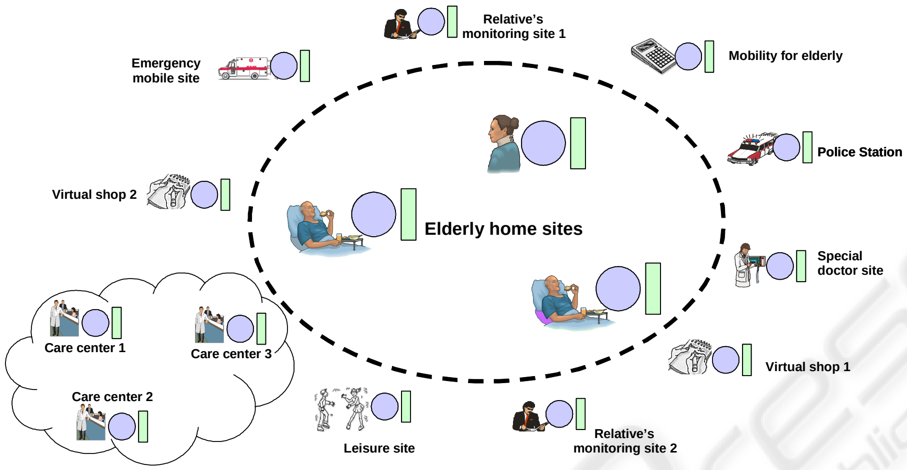

Fig. 1 – The TeleCARE scenario for virtual elderly support environment

The IST TeleCARE project aims at design and development of a base infrastructure to support elderly care environments, addressing many of the above challenges. A scenario for TeleCARE is depicted in Fig. 1. Proper handling and access to all related information within the elderly care environment, is of vital importance, and thus the information management constitutes a key element of the TeleCARE infrastructure. Considering the independence and autonomy of the network nodes, a main 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 HW/SW resources (i.e. devices and services) at each node* within the network, *while preserving their access rights and authorization.* Furthermore, 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 modeling on the network's database*, it should be sufficient for developers to use an editor through which they can define their data by its ontology, that shall in turn be automatically translated into proper database structures and get stored in the network database.

This paper first briefly addresses the TeleCARE platform architecture and its main elements. It then presents the three main components developed in TeleCARE project to support and facilitate the management of all the information related to elderly care environment. These components include: **FIMA** – *Federated Information Management component*, **RCAM** – *Resource Catalogue Management*, and **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, so that at least a very large part of the designed and developed components can be applied to any advanced emerging collaborative network.

2 TeleCARE as a tele-assistance platform

The overall goal of the IST 5FP 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 elderly in the society to reduce their isolation [14]. The TeleCARE solution benefits from the merge of a number of technologies and paradigms in order to provide an open architecture supporting seamless future expansion. In specific, it is based on the integration of: (i) *multi-agent systems* (MAS), including both stationary and mobile intelligent agents, (ii) *federated database systems*, (iii) *Secure communication*, and (iv) the services that are likely to be offered by the *emerging ubiquitous computing and intelligent home appliances*.

In a nutshell, the core *horizontal* platform developed for TeleCARE provides the MAS, mobility, safe communication, and the federated information management services. The TeleCARE consortium further develops some *vertical services* on top of this platform, including status monitoring, as well as other forms of assistance such as agenda reminders, entertainment services, time bank, and a few base services supporting virtual communities, web-accesses, and specialized elderly user-interface.

2.1 The TeleCARE reference architecture

The reference architecture for TeleCARE nodes providing cooperation/federation among different nodes of the elderly care network is depicted in Fig. 2. The main components of this architecture are briefly addressed in this section.

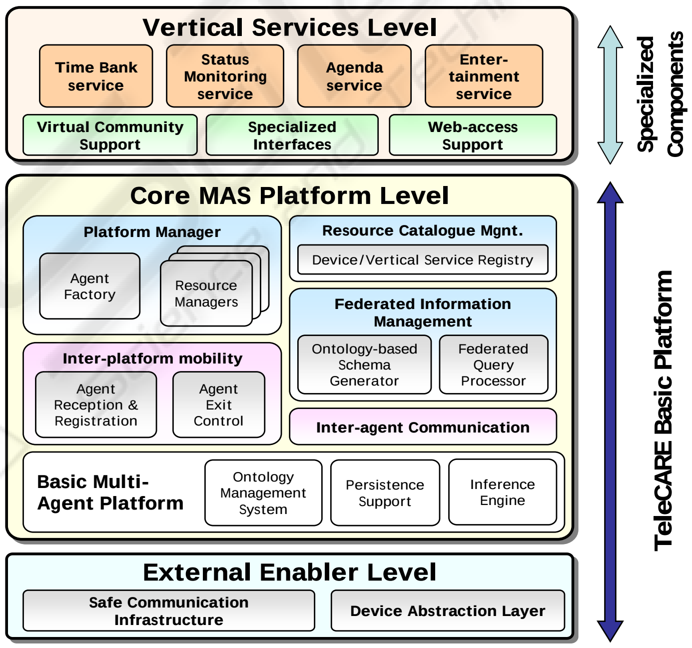

Fig. 2 - The TeleCARE platform reference architecture

The designed architecture of TeleCARE node is composed of a three-level platform. 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, 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 compromises two segments:

- **Safe communications infrastructure -** providing safe communications and supporting both secure and reliable agent/messages passing among different nodes.
- **Device abstraction layer -** interfacing 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:

- **Basic Multi-Agent Platform -** provides the essential multi-agent support, and it is based on Aglets framework [8] with the following extensions:
  - i. *Ontology management system* - The Protégé 2000 [13] 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 -** extension to the basic MAS platform to support generalized mobility of agents, including agent security mechanisms. This module includes the *Agent Reception & Registration* component, and the *Agent Exit Control* component, for administration of stationary and mobile agents.
- **Inter-agent communication -** extension to support credentials and coordination of agent communication, independent of the agent location.
- **Federated information management -** supporting the management of information at TeleCARE nodes and providing the infrastructure for *i)* flexible processing of federated queries, *ii)* data structure generation based on ontological definitions and, *iii)* preserving information privacy through access rights management. This component is developed using Java with free/open source software, it is built on top of SAP DB relational database system [11], and Castor data binding middleware for Java [6].
- **Resource catalogue management -** managing the catalogue of resources, and registering the descriptions of all device and vertical services available at the site as well as their access rights.
- **Agent factory -** supporting the creation / specification of new agents.

- **Platform manager -** configuration and specification of 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 (which require specialized user interfaces), care providers, and elderly relatives (assuming that they are able to interact with normal computer interfaces). Further, it compromises the two layers.

- **Base services -** set of base services on top of the horizontal infrastructure that each provides specific support to other value-added services.
    i. *Virtual Community Support* - To support the management of Virtual Community for the elderly care environment
    ii. *Specialized interfaces for elderly* - Suitable computer interfaces for the use of elderly person
    iii. *Web-access Support* - Web-based mechanisms to interface with the TeleCARE environment.
- **Vertical Services -** A number of specialized vertical services are implemented as specific TeleCARE applications, including a VC-based time bank, an elderly status monitoring service, an elderly agenda reminder service, and an elderly entertainment service.

2.2 Management of information in TeleCARE

The analysis of information management requirements for the TeleCARE network has identified both the modeling and functionality required to be supported local to 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 were identified that together support both the management of all information related to TeleCARE network. These components, namely FIMA, RCAM and DOSG are briefly described in this paper.

3 FIMA - Federated Information Management component

The Federated Information MAnagement (FIMA) component of TeleCARE supports applications that may require 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 centralization of data or control and thus supports flexibility and extensibility aspects required for future use of 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 DBMS, and was selected for TeleCARE among many considered options for this purpose.

The two key functionalities offered by FIMA include:

- *Federated data and Schema Management*, that handles all the data and schemas defined in the network, while supporting the definition of adequate levels of information privacy for access by authorized agents / users.

- *Federated Query Processing*, which 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.

Fig. 3 shows a high level architecture of the 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 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 [9].

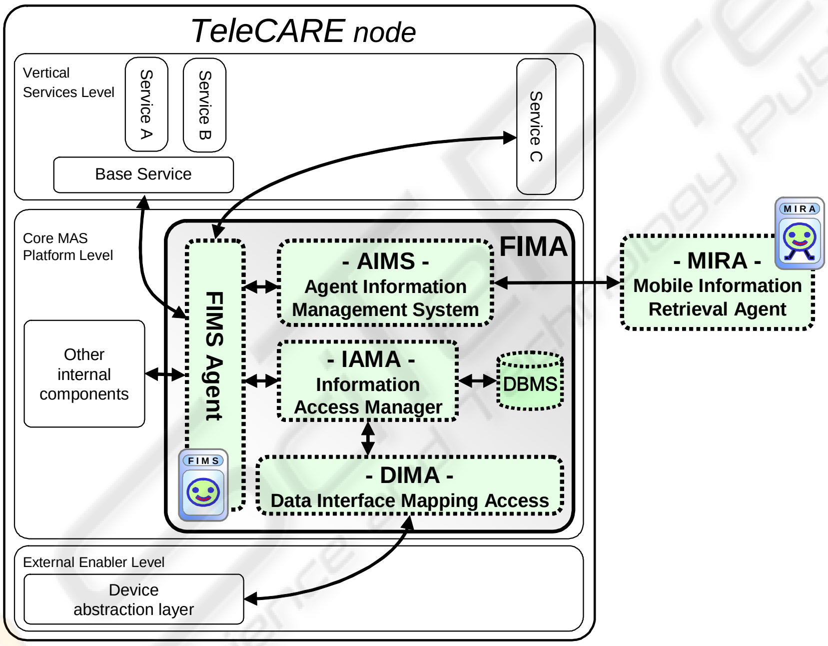

Fig. 3 – Architecture of Federated Information MAnagement – FIMA

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 Fig. 4.

What should be noticed here is that the main goal of the federated query processor component in FIMA is to enable TeleCARE agents and end-users to query the authorized information, while hiding all the details about database connections, agents creation and their traveling among nodes, and processing the data.

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.

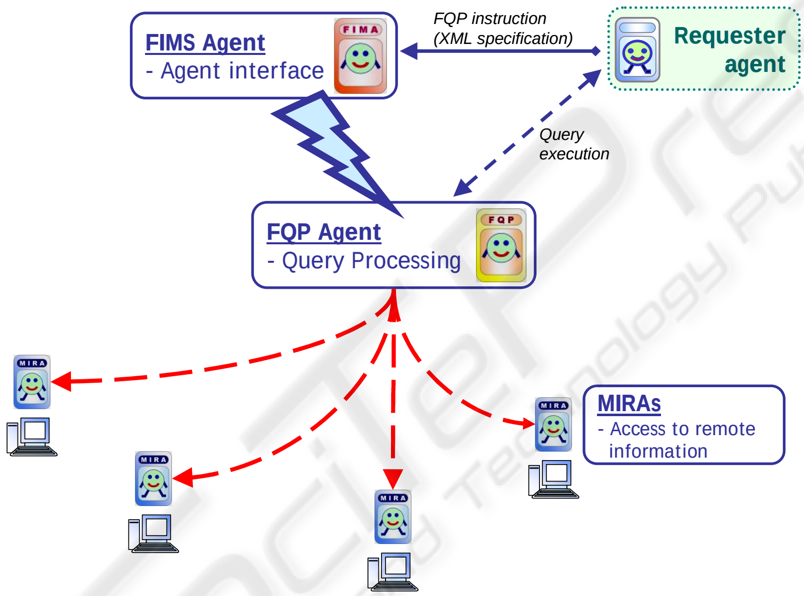

Fig. 4 - Main components of the federated query processing

3.1 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 fulfill requests from numerous agents simultaneously, that may have different purposes other than just executing a single query. FIMS Agent does not handle however all the query processing related operations, otherwise it will too overloaded. Whenever FIMS receives a request for a federated query, it generates another agent (FQP) 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 be focused only on the task of performing the query.

When the FIMS Agent creates an FQP Agent to supervise the processing of a federated query, it also provides the identifier of this FQP Agent to the requester. As a result, from that point on, all query operations are bound to that FQP Agent, and the FIMS Agent is freed from the responsibility of following the federated query execution.

3.2 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 techniques, particularly useful in the distributed TeleCARE environment. Some of the used mechanisms 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 in FQP. 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 can be summarized as follows:

- **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, 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 communication MIRA-to-FIMS Agent of the remote node, in order to execute and retrieve the requested information from that node.
- **Result transmission**: The MIRA transmits to the FQP Agent the information resulted from the sub-query.
- **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.

3.3 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:

- the case of gathering information from several specific nodes at once and merging the results at the originating node,
- the case of a query that "crawls" from one node to another to search all nodes, e.g. retrieving all possible answers, or to find the best answer, or,
- the case of a query searching all nodes one by one, trying to satisfy certain condition. One example is the case of finding the first possible answer, or to find a satisfactory answer (e.g. by sending the answer to the originator and waiting for a "satisfaction" response from the originator node, in order to decide either to continue the search or to quit), or even the case of finding a specific number of answers and then quit.

The FQP Agent creates MIRA agents and their handling is completely transparent from 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 processing mechanism that they need to invoke.

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 authorized 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. Section 3.5 refers more on visibility levels and access rights.

3.4 Processing of query types

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

- **Parallel query type,** where the performance in speed is the key consideration.
- **Serial query type,** where the optimization of resource usage is the focus.
- **Sequential query type,** that requires interactivity with the requester to control the information-processing overhead, see Fig. 5 below.

One advantage of providing different types of query/access methods is that for instance the requester (for instance the vertical service that accesses some data from the network database) can choose among the three options, to control the general performance and overhead of the process and thus easily optimizing the performance of the federated queries for specific purposes.

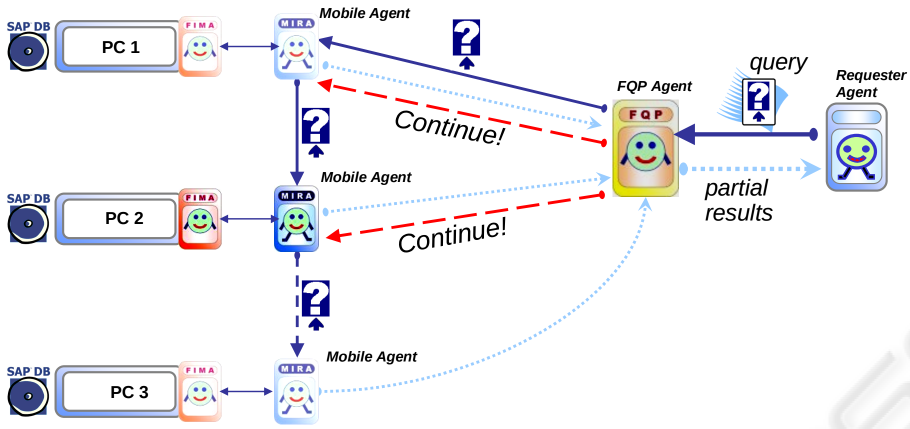

Fig. 5 - Sequential query type in FIMA

Furthermore, the design of the architecture of FIMA carefully considers necessary data / agent traffic among the TeleCARE nodes. Therefore, two communication mechanisms between the nodes are properly supported, namely (1) the inter-agent message passing and (2) the agent mobility, 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 center site requires the 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 center. The "push" action is performed as "messages" sent from one agent to another.
- *Information pull*: To illustrate the information pull, assume that an elderly 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 inquires some 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 specific number of people), can pull some names from one or more leisure centers.

3.5 Visibility levels in TeleCARE

In federated information management networks, different autonomous nodes can have different visibility levels and access rights on 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 [1, 3, 12].

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 such as in [7]. However, due 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 on the agent type, that also represents the role of the user generating the agent.

4 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/modification of database schemas, so that they can be automatically stored into the database. As such, for this purpose the service developers of TeleCARE, can simply use the user friendly interface provided for the ontology system "Protégé" 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 object knowledge model in ways which 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 parameterize the automatic data structure generation. DOSG benefits from the integrated Protégé environment by gathering online input related of conceptual schema, while allowing customization of some parameters for this generation process through the DOSG interface. The implementation of DOSG is in Java and, it also uses free / open source software, in specific, Castor is used to produce the two mapping definitions [6], while Xerces is applied for the development of XML Schema [2]. As shown in Fig. 6, based on the ontological definitions provided by users, the DOSG tool automatically generates five different outputs, namely:

- **RDBMS Schema** with the appropriate 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 governs the conversion between Java classes and the database system, and
- **XML mapping** that defines the translation between the Java classes and XML.

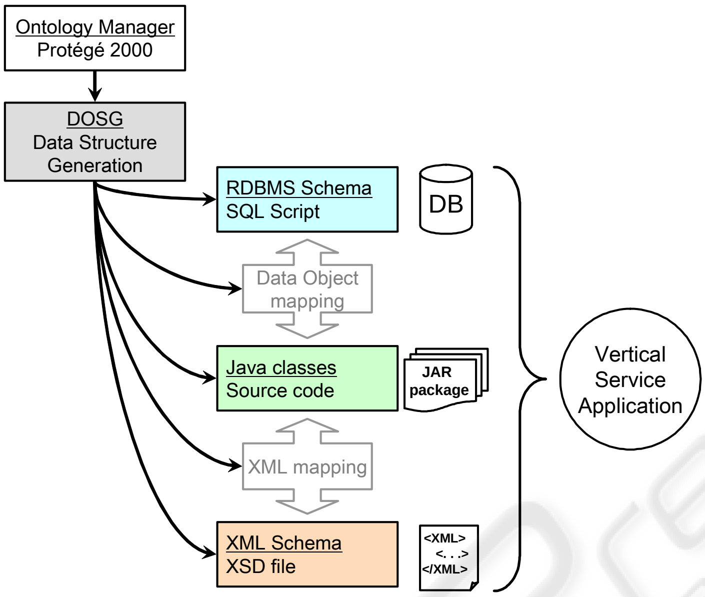

Fig. 6 – Output format for Dynamic Ontology-based data Structure Generation - DOSG

5 RCAM - Resources Catalog Management component

A complementary module to FIMA is the Resource CAtalog 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. house hold appliances) and/or emerging vertical value-added services to be easier added to the TeleCARE platform. All hardware devices and software services in TeleCARE 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:

a. the catalogue entry representing a definition of the resource,
b. the entries for resource's internal services definitions and,
c. the access rights to the resource

In order to support the 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 UPnP (Universal Plug and Play) [15] specification, while the software vertical service definitions are based on Web Service Definition Language (WSDL) specification [16]. 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 [5].

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 Fig. 7.

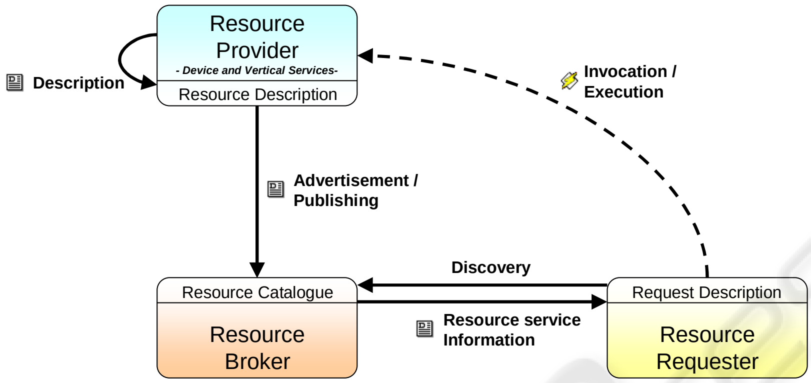

Fig. 7 - Resource handling operations

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/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 authorized users can be stored. Thus, every time that a Resource Manager agent receives a request to access its resource, the Resource Manager can first access RCAM to validate the authorization of this access for the specific requester. Therefore, usage of RCAM, properly secures the access and usage of the vertical services and devices.

6 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 platform has proved to be an effective approach to develop 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 resource 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 modeling 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 Catalog Management component, and thus making it possible for resources to be discovered and applied in the future service developments for this environment.

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