USING MOBILE AGENT TECHNOLOGY FOR DISTRIBUTED HEALTH-CARE TELEEXPERTISE SYSTEMS

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Abstract: This paper describes a novel approach to the analysis and the development of distributed healthcare Teleexpertise systems.

Mobile agent is an autonomous, social, reactive and proactive entity that has the ability to move from host to host in heterogeneous networks. Since healthcare Teleexpertise is grounded on cooperation and sharing of resources, mobile agents are suitable for its analysis and implementation, and we adopted them for developing a system prototype.

Keywords: Mobile Agents, Telemedicine, Cooperative systems.

Introduction

Health-care teleexpertise is considered as the use of telematic tools to share, look for and ask for (a) medical expert(s), sited in distant location or country, in order to have (an) external opinion(s) and advice. Teleexpertise systems may be described as communities of interacting entities, aimed at supporting collaboration and resource sharing in the medical field. This process involves massive transfers of patient's medical information which cause considerable strain on network throughput. Then, the construction and the development of the proposed distributed teleexpertise system will require new approaches of design. In fact, the traditional paradigms (centralized client-server and remote evaluation) present certain difficulties such as: (1) excessive use of network, (2) interactions are synchronous and (3) inefficiency of results.

In recent years, the mobile agent paradigm emerges as a new research area in distributed computing. A mobile agent is a software component that has the ability to move from host to host in heterogeneous networks. Their mobility allows it to move across an unreliable link to reside on a wired host, next to access to the resources that it needs to use.

Healthcare Teleexpertise is grounded on cooperation and sharing of resources. Thus, mobile agents are suitable for their analysis, design and implementation. For this reason we have adopted them for developing a system prototype to face the traditionnal paradigms problems.

The aim of this paper is to describe the use of mobile agent for the analysis, the modeling and the development of healthcare teleexpertise systems.

The rest of the paper is organized as follows. Section 2 provides an overview of Health-care Teleexpertise systems. Section 3 presents the importance of mobile agents to the Teleexpertise distributed system. Section 4 presents the mobile agent-based Teleexpertise system architecture. Then it presents the specification and the design of this system. An overview of a prototype implementation is presented in section 5. Finally, a conclusion is made in section 6.

Health-care Teleexpertise systems

Health-care teleexpertise is considered as the use of telematic tools to share, look for and ask for (a) medical expert(s), sited in distant location or country, in order to have (an) external opinion(s) and advice. Teleexpertise is essentially based on the transmission via networks of a full or part of electronic patient records and also complementary information necessary for expert diagnosis and advice. It helps to allow consultations with specialists worldwide working at excellence healthcare centers in order to evaluate unusual or 'difficult' cases presented in regions and countries with less developed healthcare services [1].

Typical teleexpertise scenario involves two health-care parties: the Requestor (source of request) and the Advisor (expert) centers. The data concerned by the exchange during a teleexpertise scenario may include all patient documentation, as examination results, and clinical data, the identification of the requestor and the advisor and the expert diagnosis and advice. The interchange shall be open, asynchronous and not proprietary. A basic node may include: hosts, communication environment, databases, and users.

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The host may be any intelligent computer system being able to communicate with the other elements. It may be part of an Intranet or a hospital information system and should be able to connect to patient records databases.

The communication environment is the means of transfer of patient records and related teleexpertise data. It should follow the state of the art of the computer network field, using standard protocols and services. It should be linked to the host via a communication interface.

The database is used for efficient storage and retrieval of patient records and related teleexpertise data.

The user interaction should be viewed as part of application scenarios for teleexpertise data transfer. The user may be the source of request or an advisor. Both the sender and the recipient must have precisely the same understanding of any messages which are exchanged between them.

Figure 1 shows the scenario of interactions between the main components of a teleexpertise system.

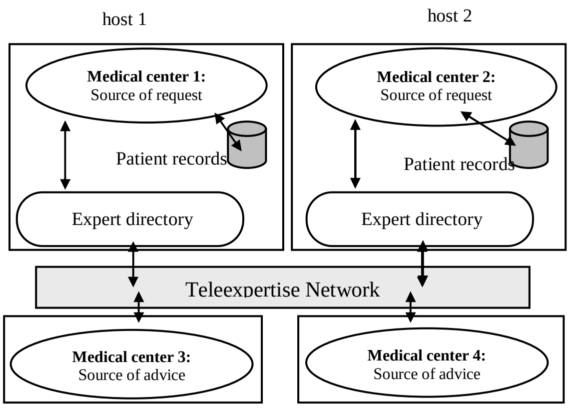


Figure 1: Architecture of a Distributed Teleexpertise System

Rationale for using mobile agent technology

Teleexpertise system may be described not only as single workstations eventually able to intercommunicate, but also as communities of interacting entities, aimed at supporting collaboration and resource sharing in the medical field. This process involves massive transfers of patient's medical information which cause considerable strain on network throughput. Then, the construction and the development of the proposed system will require new approaches of design.

In recent years, Mobile Agent (MA) is an emerging paradigm that is gaining momentum in several distributed systems. We have adopted mobile agent technology in response to difficulties described above and we have proposed a mobile agent-based teleexpertise system. A mobile agent is a software component that has the ability to move from host to host in a network of computers. Their mobility allows it to move across an unreliable link to reside on a wired host, next to access to the resources that it needs to use. Autonomous mobile agent could be used to enable health-care teleexpertise systems to achieve their intelligent information retrieval and expertise delivery objectives. With these capabilities, a human user or an agent can delegate tasks to another agent with minimal supervision/intervention. Therefore, mobile agent technology offers a number of capabilities such as:

- Mobile Agent (MA) can execute asynchronously and autonomously, that make MA in the teleexpertise system acts independent without intervention from the requestor. The MA performs its task and saves results until its connection to the requestor is established. So, MA provides a reliable transport between a requestor and an expert without necessitating a reliable underlying communications medium.
- Teleexpertise system is essentially based on the transmission via teleexpertise network of a full or part of electronic patient records and also complementary information necessary for expert diagnosis and advice. A MA in teleexpertise system can reduce the network traffic since it encapsulates and transports with it data, code and context.
- The mobile agent supports the heterogeneous environments of expert centers.
- In the teleexpertise system, experts directories change usually (for example the expert availability ratios). During its travel, MA has the ability to learn and react to changes, and then it updates its itinerary that includes the expert centers to visit. This makes teleexpertise system more adaptive to the changing situations of the environment.
- The ability for a MA to decide when and where to move, is of critical importance. In fact, if a network routing problem occurs, a MA can update its travel schema.

The proposed mobile agent-based Telexepertise system: architecture and design

In this section, we present at first the requirements and the architecture of the mobile agent-based teleexpertise system that we have designed and implemented. Then, we present the system design using the UML (Unified Modeling Language) [2], the AUML (Agent UML) [3] languages and some extensions to UML and AUML that we have proposed in [4] [5]. The design of the system includes some AUML sequence diagrams describing interactions between different agents and objects of the system and the design of mobile agent model.

Requirements and considerations

The system design has been influenced by the following constraints:

- It should take into account the delays of computing, transmission and propagation of the Requestor queries, the Advisor responses and their notifications.
- The responses should not overcome a limit of time specified by the Requestor on the basis of the case emergency.

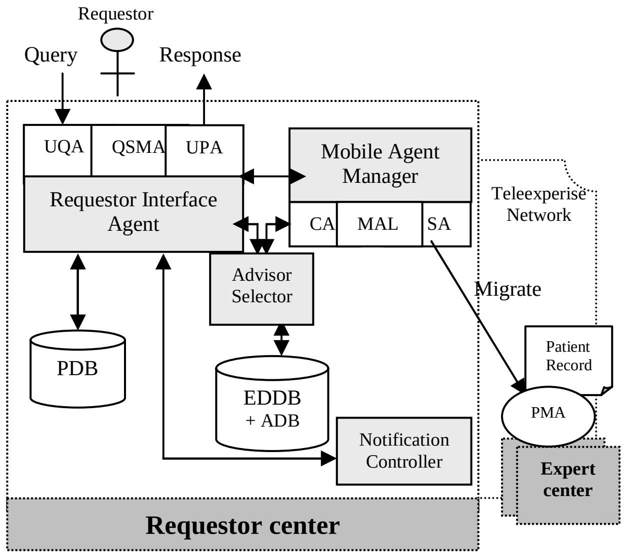
- The experts directories should be updated automatically taking into account the recent information brought by the agents.
- The expert can refuse or not be able to respond to a query.
- In order to facilitate the experts diagnostics, the information related to a query and sent to the experts should be as complete as possible.
- For security purposes, the system should ensure the authentication of both the requestor and the advisor, and also the integrity and the confidentiality of the interchanged data.

System Architectures and design

Based on the specifications and requirements presented above, we describe the architecture of mobile agent-based teleexpertise system (figure 2 and figure 5). The proposed teleexpertise system consists of four major components: (1) a Requestor Center, (2) an Expert Center, (3) a Teleexpertise Network, and (4) a Patient Mobile Agent.

Requestor center

Requestor center is composed of six main components: (1) a Requestor, (2) a Requestor Interface Agent (3) a Mobile Agent Manager, (4) an Advisor Selector, (5) a Notification Controller and (6) several databases. Figure 2 presents Requestor center architecture.



Legend:
EDDB: Expert Directory Data Base MAL: Mobile Agent Launcher
UQA: User Query Agent PDB: Patient Data Base
UPA: User Presentation Agent ADB: Advice Data Base
QSMA: Query State Manager Agent CA: Constructor Agent
PMA: Patient Mobile Agent SA: Security Agent

Figure 2: Requestor center architecture

Requestor is a user that confronts a difficult case and needs to take an advice of an expert.

Requestor Interface Agent **(RIA):** provides a front end to the end user, for deposing query, interpreting query, and displaying results. There are three kinds of RIA:

- *The User Query Agent* (UQA) is responsible for holding a user's request. It gives the user the possibility to construct, save, delete and send Query.
- *The Query Status Manager Agent* (QSMA) allows the requestor to display the query status. Based on the automatic notifications sent by the experts, this module displays the list of experts that are processing the query and the date and time they have received the query and the deadline date for their answers.
- *The User Presentation Agent* (UPA) enables to visualisation of answers according to the user's choice and environment.

Mobile Agent Manager **(MAM)** which is responsible for handling of the mobile agents. MAM is composed of the following three agents:

- *The Constructor Agent (CA):* it creates, defines the itinerary of PMA, and delegates a set of PMAs that will be sent around the teleexpertise network seeking for medical advice. The number of the created agents depends on several parameters specified by the requestor, including the expert availability ratio, the query emergency, the maximum time allocated to the query, etc. After receiving the list of the available experts from the advisor selector sub-module, the CA applies one of the following two strategies: (1) the broadcast strategy consists of creating a number of agents equal to the available experts. (2) The selective diffusion strategy consists of creating a number of agents less than the available experts. Figure 3 shows the AUML sequence diagram describing what happens when requestor depose a query.

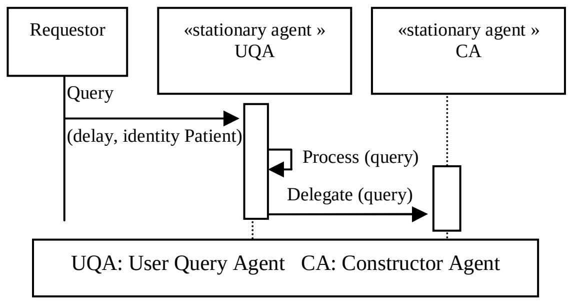


Figure 3. AUML sequence diagram corresponding to the query of requestor

- *The Mobile Agent Launcher* (MAL) is responsible for launching the mobile agents, monitor and control the network situation, and processing the data collected by the mobile agents.

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Figure 4 shows the AUML sequence diagram describing what happens when CA receive the delegated query and process of sending PMA.

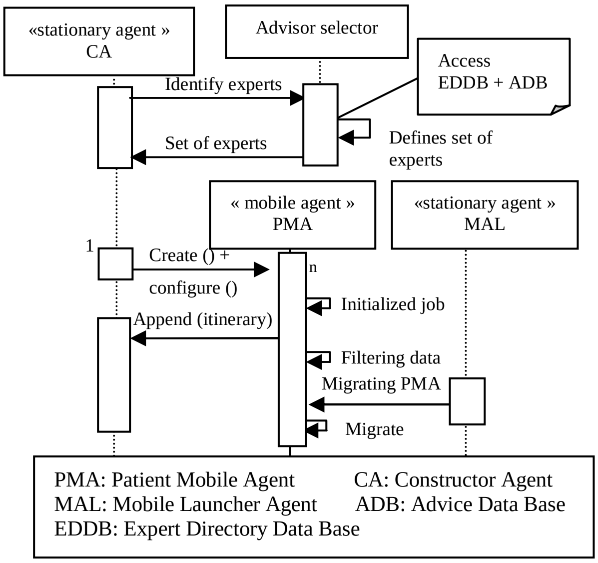
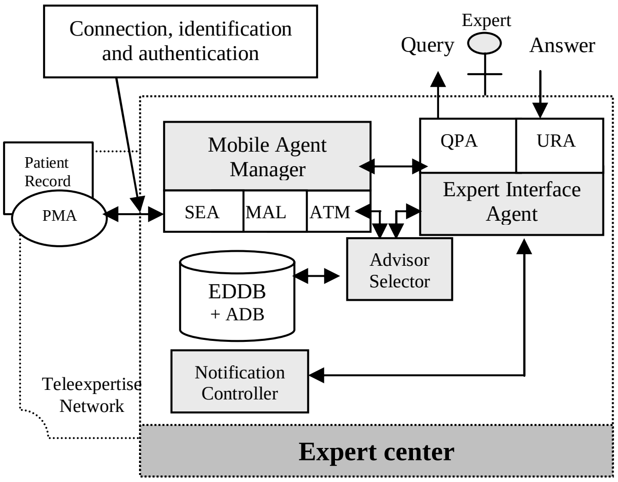


Figure 4: AUML sequence diagram describing the initialisation and sending patient mobile agent

- *The Security Agent* (SA): after receiving a PMA, the SA verifies if PMA has become a malicious agent. If PMA has changed his behavior, the SA destroys this agent, else it allows PMA to run and depose his response.

Expert center

Expert center is composed of six main components: (1) an Expert, (2) an Expert Interface Agent (3) a Mobile Agent Manager, (4) an Advisor Selector, (5) a Notification Controller and (6) several databases. Figure 5 presents Expert center architecture.



URA: User Response Agent	ADB: Advice DataBase
SEA: Security Expert Agent	EDDB: Expert Directory Data Base
MAL: Mobile Agent Launcher	QPA: Query Processor Agent
ATM: Agent Task Manager	PMA: Patient Mobile Agent

Figure 5: Expert center architecture

Expert *is a user that* is capable to provide answers to requests of expertise.

Expert Interface Agent **(EIA):** provides a front end to the end user, for interpreting query and deposing answers. There are two kinds of EIA:

- *The Query Processor Agent* (QPA) checks periodically the incoming queries and makes the necessary actions to present the query to the experts for analysis and interpretation. The expert is given the possibility to view more information on the patient (patient medical record) by using other mechanisms such us the web resources.
- *The User Response Agent* (URA) allows the expert to enter his corresponding answer. The expert response includes the query identification, the expert identification, the patient identification and the textual answer.

Mobile Agent Manager **(MAM)** which is responsible for handling of the mobile agents. MAM must be capable for receiving and authenticate Patient Mobile Agent and providing a local resources access mechanism to perform its tasks (memory, CPU, …). The MAM is composed of the following three agents:

- *The Security Expert Agent* (SEA): After receiving a new Patient Mobile Agent (PMA) and before performing any tasks, the SEA verifies the authentication of the incoming PMA. SEA uses the information encapsulated in the PMA (name, authenticate key, ...) in order to decide between the following tasks: (1) refused the PMA if it is not authorized to run on this center ; (2) kills the incoming agent if the latter is malicious agent ; (3) accept the PMA if it is authorized to run on this expert center.

Figure 6 shows AUML sequence diagram describing the process of receiving new PMA in expert center.

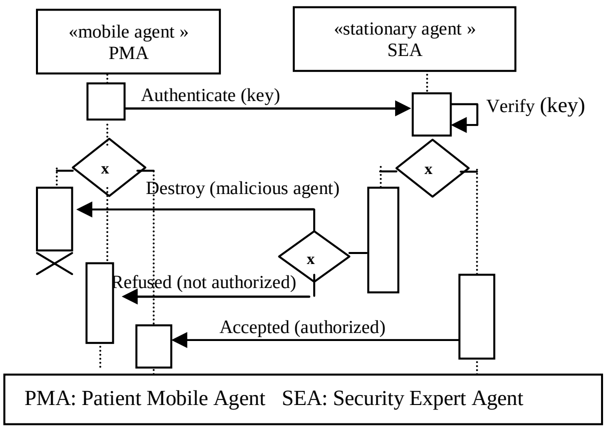


Figure 6: AUML sequence diagram describing reception of patient mobile agent at expert center

- *The Agent Task Manager* (ATM): After reception of the incoming agents and checking the availability of local experts, the ATM uses the information encapsulated in the PMA in order to decide between the following tasks: (1) presents the received request to the QPA in order to be processed by the local

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experts; (2) kills the incoming agent if the latter has reached its death state; (3) updates the local EDDB using the incoming agent data.

- *The Mobile Agent Launcher* (MAL) is responsible for launching the mobile agents. It defines the mechanism and primitives that transfer agents from system to system; headers, methods, format, etc.

Figure 7 shows the AUML sequence diagram describing the process when sending PMA from expert center.

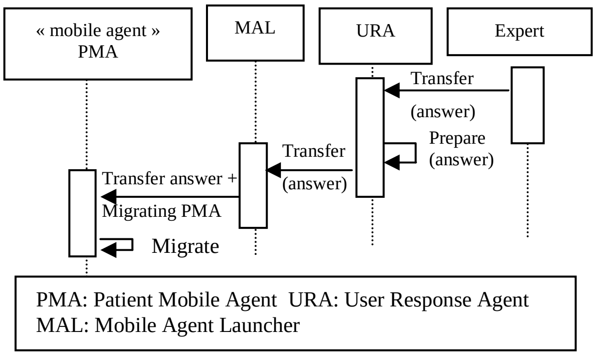

Figure 7: AUML sequence diagram describing collect answer and the process to migrate PMA

Advisors Selector: the Advisor Selector is a module, when given the specialty of the requested experts; extracts from the Experts Directory database the set of experts (and their related information) that are eventually able to answer to the submitted query. The obtained list is transmitted to the constructor agent.

Notification Controller: this module is responsible of the automatic notifications of the requestors and the experts (Non- repudiation service). The Requestor Notification will be sent to the expert when a requestor receives the expert answer. This notification could be useful for several purposes: acknowledgement, payment, etc. On the other hand, the Expert Notification which will be transmitted when an expert accepts to process a query is used to the follow-up of the queries. The notification controller allows also the update of both the Advice and the expert directory databases.

System Databases: the Teleexpertise system we have designed is based on three relational databases: (1) The *Patient Records database* is the principal database where the patients and their medical data are stored. (2) The *Advice Database* classifies the expert and requestor notifications by their identifiers. (3) The *Expert Directory database* is used to store and retrieve the expert related information such as expert name, identification, the electronic address, the availability ratio, the availability date which represents the last time the availability ratio has been updated and the time zone of the expert region.

Patient Mobile Agent

Patient Mobile Agent (PMA) is a software program, which migrates among Expert Centers to collect Experts answers based on the patient's medical record transported with it. We present hereafter the design of PMA model.

Mobile Agent model design: this model defines the internal structure of the PMA. It defines PMA characteristics and information. We present hereafter some information transported with PMA:
- Requestor Identification: it is a set of information needed to identify the requestor such as the requestor identifier, his name and his medical.
- Patient data: it includes two kinds of information, the patient identification and the patient medical data that are extracted from the Patient Record Database.
- Experts Information: extracted from the Experts Directory Database, this information contains a list of experts (and their related data) that a specific agent may visit during its trip around the teleexpertise network.
- Times mission parameters: they include the mission starting time, the mission ending time, the propagation delay, the agent transmission delay, the estimated processing and decision times. Based on those times, the agent computes its time to live (TTL) and if this time comes to elapse, the agent moves to its death state.
- Response data: it is a field which is initially empty and will be filled when the agent reaches a server where the associated expert proposes a response to the given query.

To model PMA model, we have proposed some extension to AUML class diagram in [5]. Figure 8 shows a simplified PMA structure.

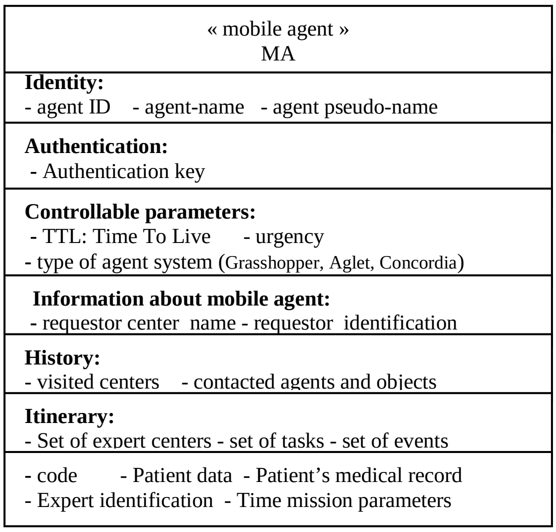

Figure 8: A simplified Patient Mobile Agent structure

Implementation of Mobile Agent-based Teleexpertise application

A prototype of the teleexpertise system described above is developed using the Java programming language and the *IBM Aglet* development environment [6]. We use Tahiti as the servers for creation and execution of the agents. In this environment, an agent (an *aglet*) is an object that can move from one host to another over the teleexpertise network. That is, an *aglet* that executes on one host can suddenly halt execution, dispatches to a remote host, and resumes execution there. When the *aglet* moves, it takes along its program code as well as its state. For easy access to the different system functionalities, we are trying to develop a user-interface that is layered on top of the Java language.

We present hereafter a scenario that describes the developed teleexpertise prototype.

When the requestor needs (an) external opinion(s) and advice, he must fill the form of request for medical expertise. Then, he must specify his related information (name, center, etc.), the patient data (name, date of birth, symptom, clinical examinations, etc.), the specialty of the expert, and the deadline of this request (figure 9).

When the requestor specifies the specialty of the expert, the system determines the list of expert centers to visit from the expert directory data base. This list represents the Patient Mobile Agent (PMA) itinerary.

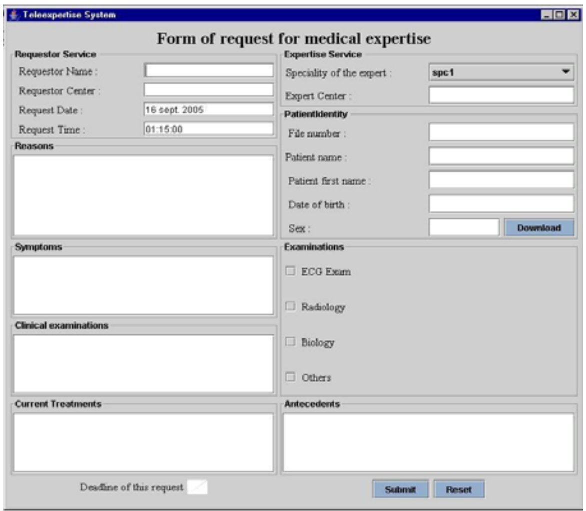

Figure 9: Form of request for medical expertise

By clicking on the submit button, the PMA travels from expert center to expert center within the teleexpertise network until it has visited all expert in its itinerary.

Once the PMA arrives at the expert center, the expert is informed. If the expert accepts to treat the request proposed by the PMA and based on the patient records transported by the PMA, he must specify the proposed treatment and the comment (figure 10). Then the PMA saves this answer and it decides to visit the next Expert.

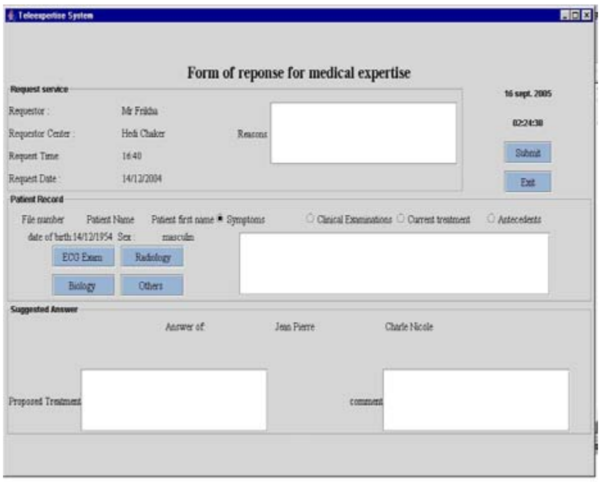

Figure 10: Form of response for medical expertise

After visiting expert centers and achieving its mission, the PMA returns to its requestor center. When arriving, it posts experts answers (figure 11).

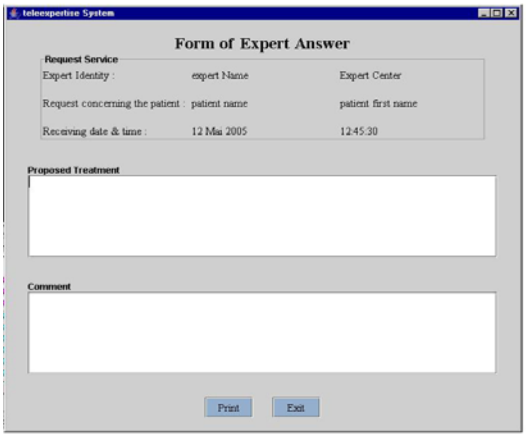

Figure 11: Form of consultation on the corresponding answers

Conclusion

Teleexpertise systems are distributed systems that will be able to exchange the full or part of patient's medical record and data. Traditional models of distributed computing present some difficult to support such complex services. Nowadays, Mobile agents are increasingly being seen and used as a suitable technology to support distributed computing applications. In this paper, we have proposed to use mobile agent paradigm for the development of a Teleexpertise system. First, we have presented the mobile agent-based Teleexpertise architecture. Second, we have presented the description and the design of this architecture. Finally, we have briefly reported on the status of our implementing system.

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