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Collaborative Tele-Neurology for Remote Diagnosis

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Abstract: This paper presents the TENECI (Collaborative tele-neurology) project which allows practitioners to use telecommunication technologies to provide medical information and services for neurological diseases. Specificities of remote neurology are described and the CAliF multimedia platform on which TENECI relies is presented. In the last section we present our implementation of TENECI. This software is composed of several services, such as a DICOM explorer, a DICOM viewer, a security service… Tests performed on this first TENECI release have given good results, and allow us to hope for a large experimentation between French and Swiss hospitals using secured connections.
Keywords: Telemedicine, Collaborative work, remote diagnosis, DICOM

1 Introduction

Over the past 10 years, the concept of working remotely (teleworking) has been in rapid development. This phenomenon is due in large part to the parallel growth in high performance networks and processors. Teleworking is used in such various ways as distance learning, remote maintenance and even telemedicine. The principal areas of research of the Distributed System team in the Computer Science Laboratory of Franche-Comté (LIFC – Besançon, France) includes all aspects of the middleware supporting these tele-applications from user interfaces and distributed algorithms through to networks. With the support of European/INTERREGIII funding (with Switzerland), this team has been working in close collaboration with the Federation of Neurosciences in Besançon on the creation of the TeNeCi project (cooperative teleneurology). Involving engineers from the LIFC and from the Swiss Federal Institute of Technology Lausanne (EPFL – Switzerland) and neurologists from the University Hospitals of Besançon and Lausanne, this project will enable neurological expertise to be improved through the Emergency Neurology Network (RUN), which is already established in Franche-Comté hospitals and coordinated by the University Hospital in Besançon. It also seeks to promote a collaborative network structure coordinated by the Lausanne University Hospital, which will gradually develop in hospitals in the Swiss cantons of Vaud and Neufchatel. In the long run a veritable regional cross-border centre of excellence will be created serving the border region.

The second part of this paper presents the issue of neuro-telemedicine. Finally in the last section we present the TeNeCi platform (supported by European funding), the first demonstration of which will take place at the end of 2005.

2 Remote Neurology

2.1 Definition

Telemedicine is generally used in a nonacute setting for patient monitoring or education and has only recently been introduced into emergency care. In neurology, telemedicine can be defined as the use of telecommunication technologies to provide medical information and services for neurological diseases. More specifically, “neuro-telemedicine” is the process by which electronic, visual and audio communications are used to support practitioners at distant sites with diagnostic and consultation procedures, such as distant clinical examinations and image transfers.

2.2 Need for Remote Neurology

The impact of a neurological inpatient assessment on diagnosis, patient management and treatment in the emergency room (ER) has been clearly demonstrated

[EAHCG96, Mou00]. Recent advances in neuroimaging techniques and new therapeutic imperatives make it necessary to establish prognostic factors as soon as possible in order to select the right treatment for any given patient [Mou96]. The role of the neurologist in the ER is therefore crucial in defining, confirming and implementing patient management as exemplified in stroke. Unfortunately, emergency neurology is mostly dealt with by non-neurologists in the majority of general hospitals. Telemedicine supports can therefore help to organize distant neurological expertise.

2.3 Media involved

The diagnostic process includes the neurological clinical examination and also the analysis of several other associated sources of data. These include CT-Scan, MRI and ultrasound static and moving images, neuro-physiological studies and biological examinations, such as blood tests.

2.4 Medical Images Specificities

With the introduction of computed tomography (CT) followed by other digital diagnostic imaging modalities in the 1970's, and the increasing use of computers in clinical applications, the American College of Radiology (ACR) and the National Electrical Manufacturers Association (NEMA) recognized the emerging need for a standard method for transferring images and associated information between devices manufactured by various vendors. This Standard [DIC04], which is currently designated Digital Imaging and Communication in Medicine (DICOM) defines a method of communication for the various equipment of digital medical imaging devices/software.

It facilitates interoperability of medical imaging equipment by specifying :

- For network communications, a set of protocols to be followed by devices claiming conformance to the standard.
- The syntax and semantics of Commands and associated information which can be exchanged using these protocols.
- For media communication, a set of media storage services to be followed by devices claiming conformance to the Standard, as well as a File Format and a medical directory structure to facilitate access to the images and related information stored on interchange media.

Information that must be supplied with an implementation for which conformance to the Standard is claimed.

3. TeNeCi: an Adaptive Tele-Application Proposal for Neurology

3.1 CAliF Multimedia Platform

The design of a multimedia cooperative application incorporates various domains including networks, distributed systems, multimedia, data consistency and Human-Machine Interfaces. It is therefore useful to create a platform combining the functionalities common to all types of cooperative applications [Hon98]. Such is the case of the CAliF Multimedia platform [Gar99, Gar01] which allows cooperative applications to be created without the constraints associated with problems of communication management, consistency, synchronization and multimedia management. TeNeCi is based on CAliF

3.2 TeNeCi platform

The objectives of the TeNeCi network (figure I) are to establish and develop an expert solution and support in neurological decision-making and in emergency neurology management. The TeNeCi project contributes to a better organization of the management of neurology emergencies thanks to the development of new techniques, which assist in emergency neurology diagnosis and treatment as well as in the field of neurological pathologies as a whole. These new techniques operating through a telecommunication network provide practitioners with real-time remote access to relevant information. Medical decision-making is thereby facilitated thanks to the cooperative nature of the application. This latter aspect will contribute to real-time group-based work.

TeNeCi will ensure improved neurological expertise through the activities of the RUN network. This network, coordinated by the University Hospital of Besançon established between the hospitals in the Franche-Comté region, is dedicated to facilitating the diagnosis and treatment of neurological emergencies. In the long term a veritable centre of cross-border and regional excellence will be created.

The structure of the project depends upon the completion of the following stages:

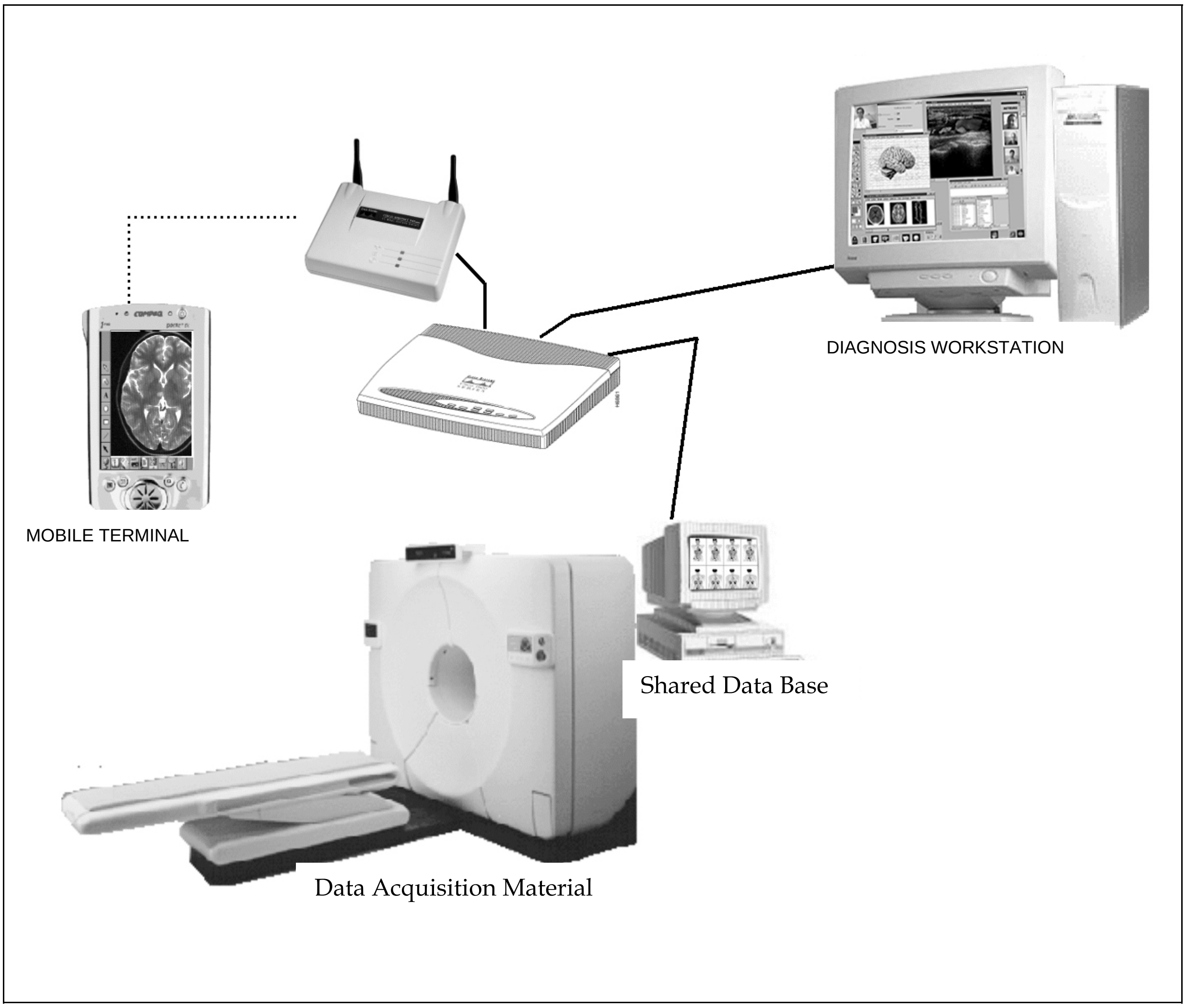

Figure I . *TeNeCi Scheme*

1. Development and consolidation of networks of emergency neurology care especially concerning acute stroke and head injuries coordinated by the University Hospital in Besançon. These operate within the framework of multidisciplinary cooperation to structure diagnosis and care procedures and to improve the quality of management through technical proficiency in video data techniques (patients and medical personnel) as well as in neuroimaging and neurophysiology.

2. Providing the various medical health professionals access to a rapid and multidisciplinary collaboration using neuroimaging (therapies and transfer of 3-D imaging) as well as neurophysiological techniques and their secure and accurate real-time interpretation in both regions in order to facilitate cross-border collaboration.

3. Encourage an exchange of information in order to establish an information database which will allow the creation of an expert system in the specific management of stroke cases.

3.3. Implementation

3.3.1. Introduction

TENECI collaborative tele-neurology application works with two complementary modes:

- Asynchronous mode: one person performs the diagnosis with the tools provided by the application. This mode can be composed of an image search stage to establish a diagnosis, followed by an emission stage to ask for an opinion, for example. This opinion can be given a few days after reception. For this mode, the interface must provide the necessary tools to create a package which must allow the expert to view

Images and final diagnosis and also to reconstruct how the diagnosis was posed (annotations, image settings, treatments).

- Synchronous mode: it uses the same tools allowing real-time collaboration among several people. This mode provides mechanisms to manage concurrent access to particular commands, e.g. contrast and zoom etc. It is composed of an image search stage, not in order to pose the diagnosis directly and to broadcast information to each person involved in the real-time collaborative diagnosis.

For this kind of application, graphic interface and additional tools must facilitate actors' capacity to disregard distance and time in order to reconstitute a virtual examination room. Software and network architecture have to be optimal to improve interactivity and fault tolerance. Our aim is to obtain a secure environment to exchange medical data, diagnoses and opinions.

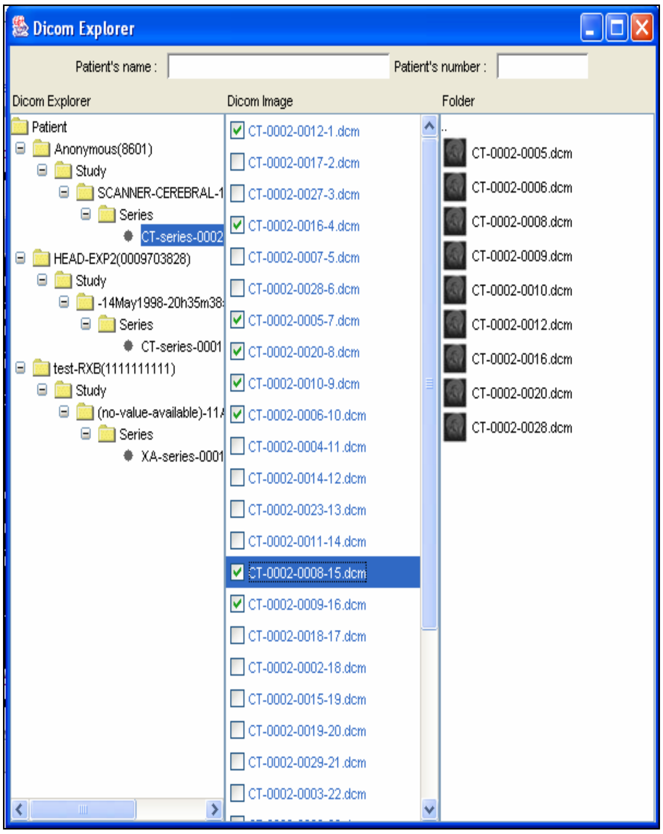

Figure II . *DICOM Explorer*

3.3.2. Implementation of General functionalities

The first tool; the DICOM explorer, is used in asynchronous as well as in synchronous mode, (figure II) allowing physicians to search and download to their computer terminals images from different medical equipment (MRI, PET…).

A radiology service uses 2 types of computing systems: the RIS (Radiological Information System) and the PACS (Picture Archiving Communication System) both of which are databases.

The PACS is an electronic management system of medical images with archiving and communication functionalities. It is compliant with the DICOM standard (communication and image description). It makes it possible to perform image acquisitions on modalities (CT scan, MRI, PET…), to archive produced images, to use the network and to consult images produced. Our DICOM explorer exploits these two last points to access the images stored on the PACS.

After the data download stage, the use of the viewer (figure III) becomes possible. This viewer is not only a simple image editor; it allows us to integrate specific tools used in tele-neurology such as data manipulation tools (contrast, brightness, zoom, scroll, geometric transformations, pattern recognition…). For example, a modification of contrast and brightness settings may highlight particular lesions (figure IV).

It is also possible to integrate textual (final diagnosis), audio (recorded message) or video (video of patient's exam) data into the session.

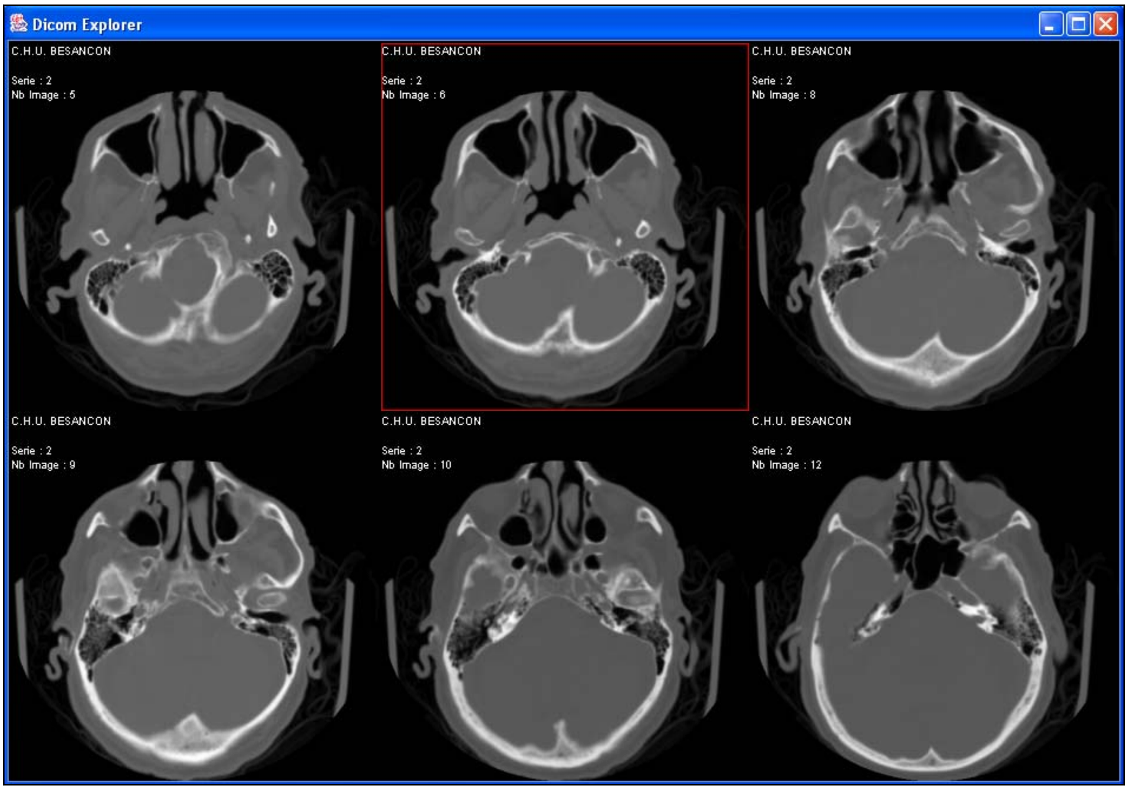

Figure III. *DICOM Viewer*

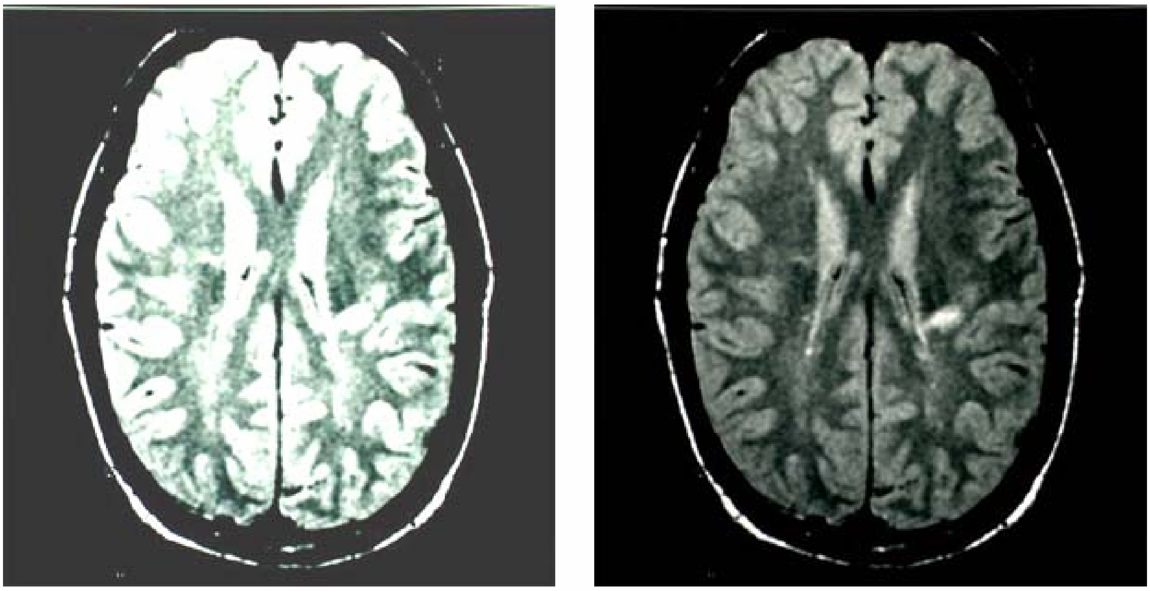

Figure IV. *Brain Lesion in MR images*

Asynchronous mode

This mode involves a search and download stage using our DICOM Explorer. After this stage, the doctor can perform a diagnosis by using TENECI tools (annotations, drawing, settings modification…).

The HMI provides a packing option to create an archive (package), which contains downloaded images, patient information, modifications, performed on images, files (text, diagnosis, audio/video…). This package can be stored for later examination and it can be sent to an expert or used to enrich a knowledge database.

In the case of emission, it is possible to specify the addressee. The message will be sent to the TENECI mailbox of this person who will open this package at a later stage. The opening process (unpacking) loads the file on the interface giving a precise view of the how the colleague posed the diagnosis. The expert contacted can display operations performed and results obtained and he can also work on the data. He gives his opinion by replying (packing and reply) to the original correspondent. Packages can be sent to several people.

Synchronous mode

Packing and unpacking operations are also used for real-time interactions directly after the session instigator has downloaded data from the PACS. In this case, receivers (users registered in the session and chosen by the instigator) obtain an automatic display of the entire file on their graphic interface. Each one could then act in real time (according to permission and priority policies in order to keep a good order in the collaboration).

For this mode, we distinguish several types of functionalities:

- The Visio conference tool ensures a human aspect is maintained during collaboration,

- The geographic and software topology representation makes it possible to geographically locate each person involved and to distinguish the communication architecture used. This feature is very useful in visualizing the access rights and activity of people involved in posing the diagnosis [Gar04],

- The DICOM Explorer tool used only by the instigator in order to search and download images,

- The file transfer tool allows users to broadcast a video file of the patient during the collaborative diagnosis for example,

- Groupware functionalities:

  - The tele-pointer can indicate areas on images and it is equipped to take on different shapes according to the operations to be performed,
  - The tele-annotations (text or drawing) enable inscriptions to be made on medical images,
  - Tele-setting operations allow users to modify images and to broadcast each operation to session members. These operations can be zooms, rotations, treatments, contrast and brightness modifications…,
  - The observation tele-diagnosis tool allows several persons to fill out a questionnaire during the observation of patients' reactions. At the end of the observation, the TENECI application performs a comparison of different doctors' evaluations and gives a summary report. This is an important time saving device when compared to rereading results at the end of a consultation.

For this particular mode, HMI and permissions are very important in order to manage collaborative work without breaking the collaborative feeling of the virtual examination room.

This requires the implementation of a visible hand taking system on different operations in order to determine precisely the initiator of an action. We use a marker for each functionality, which allows a physician to modify the brightness while another, draws on the image for example (the entire platform is not locked for one person). The TENECI platform has to control group members while avoiding the impairment of each member's initiative. This can be difficult, however, the Visio conference tool can help to overcome this obstacle allowing sessions to be organized as in a classical meeting where participants are physically present in the same place.

Inclusion of future functionalities

Moreover, with this architecture, it is also possible to integrate advanced computer-assisted diagnostic tools. For example, one of the most important indicator of stroke is the brain blood perfusion, which is diminished or even stopped in stoke areas in the brain. This brain perfusion can be measured by image processing techniques applied on some image modalities. As an example, a radio-opaque contrast agent can be injected in the blood of the patient. When reaching the brain, it causes an increase of contrast in CT images in regions where the cerebral blood volume is high, while it does not increase the contrast where the blood does not flow, i.e. in the stroke area. Figure V shows the same CT slide at two different time points, before the injection of the contrast agent, and when it flows in the brain, showing the arteries, veins and well perfused tissues.

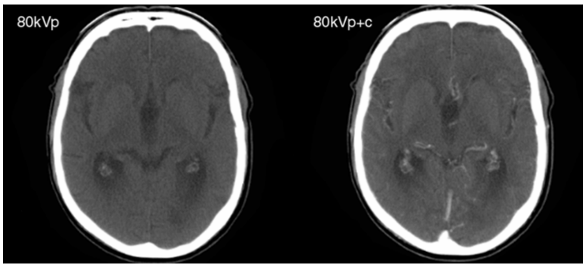

Figure V: *perfusion CT: left: one slice before (left) and after (right) injection of contrast agent.*

In order to assess the regional cerebral blood flow, image processing algorithms are use to measure the flow of contrast agent at each pixel of a dynamic CT image, i.e. of a sequence of CT images acquired at a fast rate after injection of the contrast agent. The contrast evolution curve at each pixel allows to derive the regional cerebral blood flow (rCBF) map [Win02]. Figure VI shows such perfusion map.

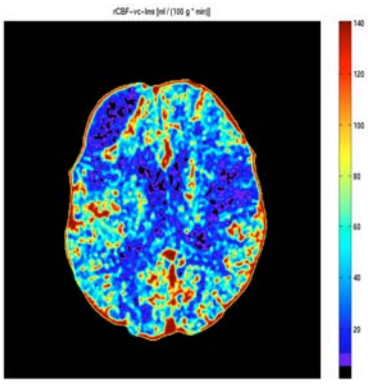

Figure VI: *perfusion map. The dark areas have a low perfusion.*

Such results can easily be integrated in the TENECI platform, and shared between the participants of a tele-neurology meeting. Other examples of tools that can easily be integrated include image segmentation and quantification techniques.

3.3.3. Tests and implementation

Software architecture

The TENECI application is composed of several modules presented in figure V. The TENECI server is the core and contains:

- The repository (profile?) (name, login, password, access control, picture, options…) of authorized persons,

- The connection server registers connected persons and maintains a list of IP and port numbers,

- The TENECI mail server contains the list of received packages for each user. These archives can be stored on the server as for POP3 protocol in case of ordinary e-mail,

- The observer stores all performed actions,

- The coordinator, a kind of proxy, will be detailed later in this paper.

TENECI applications provide the different tools we have presented after an authentication/inscription stage through the TENECI server (figure VII) in order to be enrolled in a cooperative diagnosis.

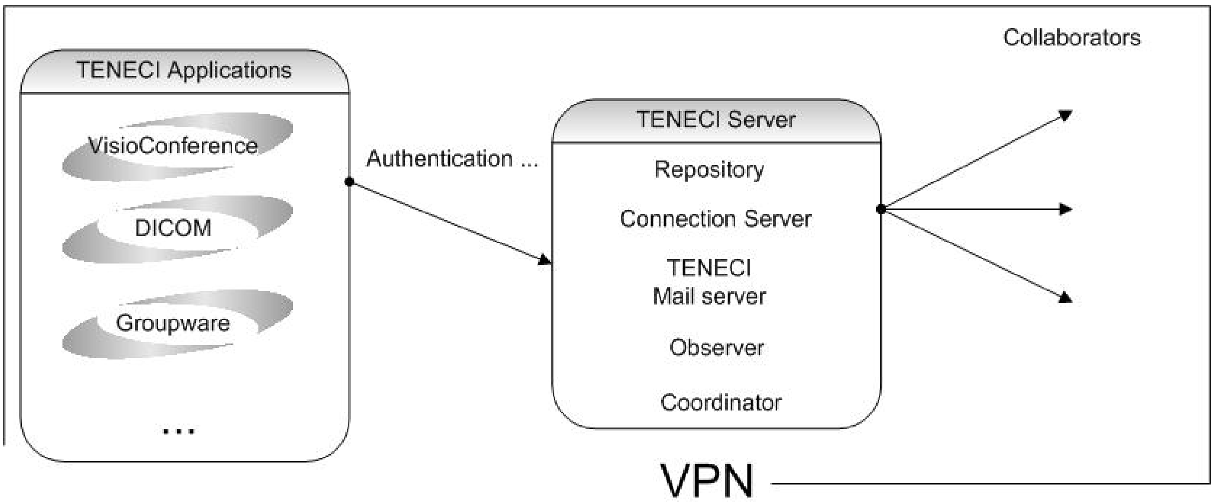

Figure VII. *TENECI Architecture*

Different communication modes (centralized, token based…) between applications are usable, according to different parameters. These parameters; advantages and disadvantages of different communication algorithms are detailed in [Gar04]

This communication layer lies on a secured network, indeed, during users' inscriptions; an IPSec VPN is created in order to avoid the transmission of unencrypted data. The registration stage is also secured. All data stored on computers (packages…) are also protected.

The network architecture of the TENECI platform (Switzerland-France) offers a real 8Mb/s throughput (tests performed in 2004). This bandwidth makes it possible to use each of the platform's tools and guarantees the performances required for the synchronous mode.

Network Architecture

For a good understanding of possible problems generated by the network, it is important to know its architecture. The TENECI platform relies on a high speed network. On French side (figure VIII), hospitals are linked by a regional network (E-BELIN 3) and Besançon sites by a metropolitan network (Lumière). This last one is linked to the regional network by the university network (UFC).

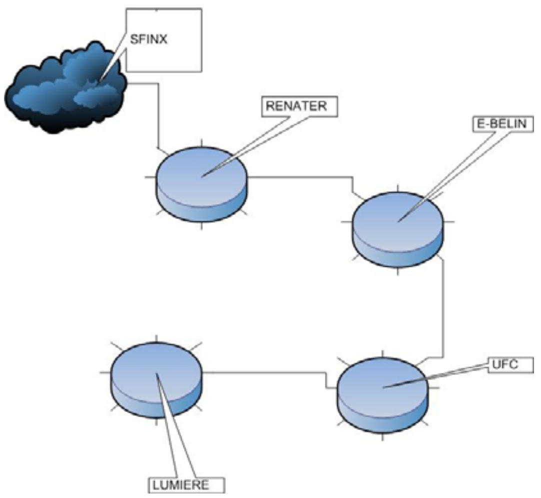

Figure VIII. ***French Network Architecture***

Swiss hospitals are connected on the GEANT network, which is connected to RENATER (through Paris using the SFINX network) for the link with France. This architecture allows to obtain 10 Mb/s throughputs (tests performed in 2004) between Lausanne (Switzerland) and Besançon (France). This throughput allows us to use all TENECI platform tools and ensures sufficient performance for the application interactivity in synchronous mode. All these networks are in continuous evolution and permit to envisage a generalized use of our platform. Furthermore, we can envisage a project extension which is not limited any more to a French-Switzerland cooperation.

Tests

The TENECI platform, in its current version, is programmed in JAVA (JDK 1.4.2). Synchronous and asynchronous modes are implemented, as well as image setting functions, packing and unpacking operations and transfer tools.

The DICOM tool [Dro04] implemented using Java, uses JDCM (JavaDicom) API and is compliant with the DICOM 3.0 norm. It includes an API to access implemented DICOM services (verification, storage and Query/Retrieve services). In order to ensure the compatibility between DICOM modalities and our explorer, all transfer syntaxes described in the DICOM 3.0 standard have been implemented (Big Endian, Little Endian…). Finally, trials have been carried out at the regional hospital (University Hospital Besançon) in order to test communication and compatibility between DICOM devices used in the project and our DICOM tool. Good results have been reported.

A preliminary demonstration of the TENECI platform was carried out in June 2004 in the presence of French and Swiss doctors. This application runs on 2,5 GHz work stations equipped with 2 output video cards (GE Force FX 5200) in order to be able to use 2 screens to display the TENECI application (figure IX). Results were very good; the use of Java does not seem to interfere with the interactive aspect. Engineers involved in the TENECI project are still developing the platform; the aim is to obtain a stable release in order to perform large-scale experimentation in 2005.

Figure IX. *TENECI Platform*

4. Conclusion and further works

The aim of this paper was to outline an innovative computerized platform in the field of emergency neurology. This work is significant for it combines the expertise of a team of neurology researchers with those of a team of IT researchers. The multidisciplinary nature of this exchange ensures the high technological capacity and also the high level of reliability of this platform.

This project has received funding for 18 months at the end of which the first prototype will be presented in the test phase (non-emergency) at the end of 2005. A new project, which consists in a portable solution to and logical follow-on to TeNeCi, the PocketNeuro project, has already been examined by Besançon ISTI. Further work in this area will be oriented towards all adaptability techniques [Pha02] and of wireless networks. PocketNeuro will allow the neurologist to access relevant medical information for any given patient in the "patient file". It should allow patient-related medical information to be consulted and modified in a secure mode. PocketNeuro proposes an innovative solution based on wireless radio communication such as Wi-Fi.

Acknowledgments

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