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ÉCOLE POLYTECHNIQUE
FÉDÉRALE DE LAUSANNE

Communication Systems Division (SSC)
EPFL CH-1015 Lausanne, Switzerland
http://sscwww.epfl.ch

Remote Inspection of Medical Images through High-speed Networks

Raffaele Noro and Jean-Pierre Hubaux, EPFL-DE-TCOM

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Contents

Abstract

In health care practice, diagnosis and therapy tasks are founded on the analysis of medical images. Traditionally, such analysis was performed using optical devices like light boxes or microscopes installed in clinical rooms or laboratories. In the last decade, personal computers have revolutioned this practice and today medical imaging is based on soft-copies of image material rather than films or specimens. Acquisition, storage and display of medical images are performed through digital computers and/or workstations. More recently, the introduction of networked computers has lead to the concept of telemedicine, that is making available remote medical facilities through the use of personal computers and digital networks.

In this document we analyse the problem of real-time performance in telemedicine applications and we propose a new architecture that allows the interactive and real-time exchange of medical images. This architecture is based on a hierarchical database to store images, an high-speed network to transmit images and a navigation module allowing the user to dynamically select the portion and resolution of the images under inspection.

In the second part of the document we describe, in particular, the prototype developed according to the described architecture and we discuss performance and optimization aspects.

Keywords: Telemedicine, Client-server architecture, Hierarchical database.

A Multimedia Architecture for Medical Tele-Imaging over ATM

A.Basso, O.Verscheure, J.P.Hubaux, R.Noro
Telecommunications Services Group TCOM Ecole Polytechnique Fédérale de Lausanne,

R.Meuli, R.Laurini, R.Patthey
Centre Hospitalier Universitarie Canton Vaud, Institut de Radiologie

Abstract

The goal of this paper is to present a multi-media telecommunication architecture based on ATM technology, which provides reliable and effective transmission of still and motion high resolution (1024x1024 up to 4096x4096, 16 or 32 bits/pixel) radiological and pathological images or part of them.

The peculiarities of such architecture are the following.

- Provide Quality of Service (QoS) awareness by means of inter and intra flow synchronization mechanisms.
- Provide mechanisms of reliable transmission of data.
- Provide the capability of remote manipulation of a Region of Interest (RoI), defined as a portion of a still or motion picture which is represented and coded with a higher quality than the remaining part of the picture.

1 Introduction

In the last decade the communication networks have had an enormous development both in local area networks (LAN) and in wide area networks (WAN). Recently a new mode of data transfer called *asynchronous transfer mode* (ATM) [1], suitable for very fast packet switching and with Quality of Service (QoS) guarantee has been developed. Such technique relies on large bandwidths (of the order of tenths and hundredth of Mbits/s) and allows a reliable transmission of real-time streams such as video and audio data, typical of multimedia applications. From an application point of view the navigation and the consultation of information stored in remote sites is made possible by means of well known and largely employed browsers such as the World Wide Web. Furthermore important progress has been done in the domain of the cooperative work.

The medical community is showing great interest for this evolution in the area of multimedia communications: a significative number of hospitals are already equipped with local ATM networks. At the same time a large number of servers make available important medical databases, in particular medical still and motion pictures. Finally the evolution of the production of electronic chips such as microprocessors makes the price of a quite powerful computer accessible to a large number of people.

The real-time transmission and processing of medical image data becomes today possible, opening interesting possibilities in particular in the area of the tele-diagnosis.

In this paper we propose a telecommunication multi-media architecture based on ATM technology, which provides reliable transmission of still high resolution (1024x1024 up to 4096x4096, 16 or 32 bits/pixel) radiological and pathological images or part of them. The peculiarities of such architecture are the following:

- provide Quality of Service (QoS) awareness. Inter and intra flow synchronization mechanisms assure a natural event synchronization
- provide mechanisms of reliable transmission of data. Proper packetization mechanisms assure system robustness against network errors, such as cell losses and cell delay variations.
- provide the capability of remote manipulation of a Region of Interest (RoI) called also detail image, defined as a portion of a still or motion picture which is represented and coded with a higher visual quality than the remaining part of the picture.

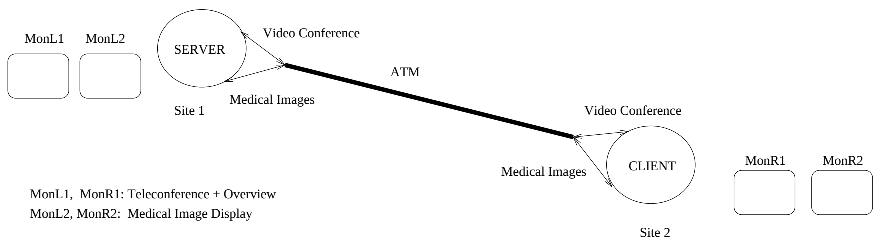

Fig. 1: A typical application scenario: MonRi, MonLi represent the monitors available at each site

A typical scenario is shown in Fig. 1. Two remote sites are interconnected by an ATM network. Each site has the following functionalities:

- Teleconferencing: the teleconferencing tool is based on a commercial product and is able to assure a reliable teleconferencing session between the two operators. It is capable of MPEG-1 video and audio coding as well as white board sharing.

- Access and inspection of medical images. Images are stored in an image database in which radiological and pathological high definition images (around 4000 dpi) are stored. Images can be accessed and inspected in real time without previous image file transmission.

The image inspection is performed by means of two windows. A first window, called *overview*, displays the image under inspection at low resolution. On such overview it is possible to dynamically displace a resizable rectangle to select a part of the image for detailed inspection. This sub-image is called *detail* image or *Region of Interest* (RoI). The detail image is displayed in a second window which is updated in real time (max speed 25 frames per second) according to the displacement of the selection rectangle on the overview. Image inspection is assisted by a teleconferencing tool which allows the two operators to interact and to cooperatively perform the analysis of the medical image.

2 Dynamic medical image inspection

The system architecture is presented in more detail in Fig. 2. A server provides the flows associated with the detail image. The client gets this flow and supplies the user with the position of the mouse and the dimensions of the detail image. The network support is based on ATM technology, with bandwidth of 34 Mbits/sec. The system sub-blocks are described in detail in the following sections.

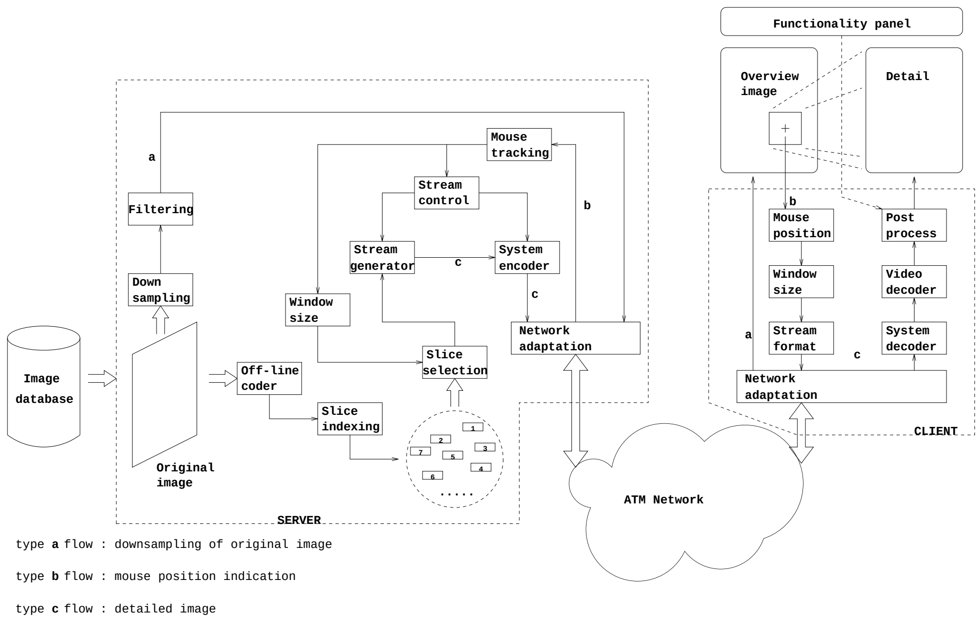

Fig. 2: Block diagram of the architecture

3 Image Data organization and storage

Each image is stored in the database in two different formats:

- subsampled: typically a subsampling factor of 4 in each spatial dimension is used. Less than 32 bits per pixels are used. The exact subsampling factor and number of bits per pixel depend on the image type. This is the format of the overview image.
- JPEG-like off-line encoded and organized in slices of fixed size (80x16 pixels).

An off-line indexing process labels each slice according to its position on the original image as shown in Fig. 2. The advantages of such data representation are the following.

- It allows a fast access to different parts of the image by different users.
- The coding is performed only once allowing a full software architecture without the need of a hardware encoder.
- The visual quality of the sequence of images generated by dynamic displacement of the reseizable rectangle on the overview is constant because the encoding process is performed only once. The operator has full control of the visual quality of the sequence at encoding stage. The JPEG coding method has been employed because it is the only compression method validated by the radiologic community [2].

4 Real-time Dynamic Image Inspection

4.1 Slice selection

The mouse position and the rectangle dimensions on the overview image are updated for each mouse displacement and are taken as input for the slice selection on the server side.

4.2 Stream generator

The selected slices are then encapsulated in a video stream by the stream generator. Proper headers (sequence headers, GOP headers, picture headers) are added in order to form an MPEG-2 compliant stream. This MPEG-2 stream is composed by only I-frames, assuring a constant visual quality. As an example, for a detail window of 512x512 pixels, 16 bits/pixel at 25 frames per second, with a compression rate of 10, the bitrate is around $10Mb/s$. The stream generator is under the control of a stream controller which is discussed hereafter.

4.3 Stream control

The stream controller performs a regulation on the stream generator. It takes as input the mouse tracked position and determines whether or not to generate and send the video stream. If the mouse is not moving for a given interval of time, the detail image is still, thus transmission is not needed. In that case, the stream generation and packetization are suspended.

Finally the elementary video stream is mapped to ATM by the system encoder in a similar way as specified by the ATM Forum and ITU [3, 4, 5].

4.4 System encoder and decoder

The system encoder creates an MPEG-2 [6] compliant Transport Stream (TS) [7] taking as input the video stream. The output is a sequence of 188 bytes long TS packets. The system decoder performs the inverse operation at the receiving end.

4.5 Network adaptation

The Network adaptation block maps incoming TS packets (188 bytes) into outgoing AAL-5 PDU packets (376 bytes).The inverse operation is performed at the receiving end.

4.6 Video decoder

One of the advantages of formatting the image material on an MPEG-2 compliant video stream is that it can be decoded with a standard MPEG-2 video decoder. In the case of slow mouse movements software video decoder can give satisfactorily performances if sufficient computation power is available. Best performances may be obtained using a hardware MPEG-2 video decoder.

4.7 Mouse Stream generation, formatting and handling

The mouse position is sampled on the overview image and mapped in the corresponding position in the high definition image.

There are three components for each sample: 2 spatial coordinates and 1 temporal coordinate (time stamp). Time stamps have the role to keep this flow synchronized with the video.

An error concealment method at the receiver end is used to recover from mouse position losses, which can be very annoying. It is based on mouse speed and acceleration estimation.

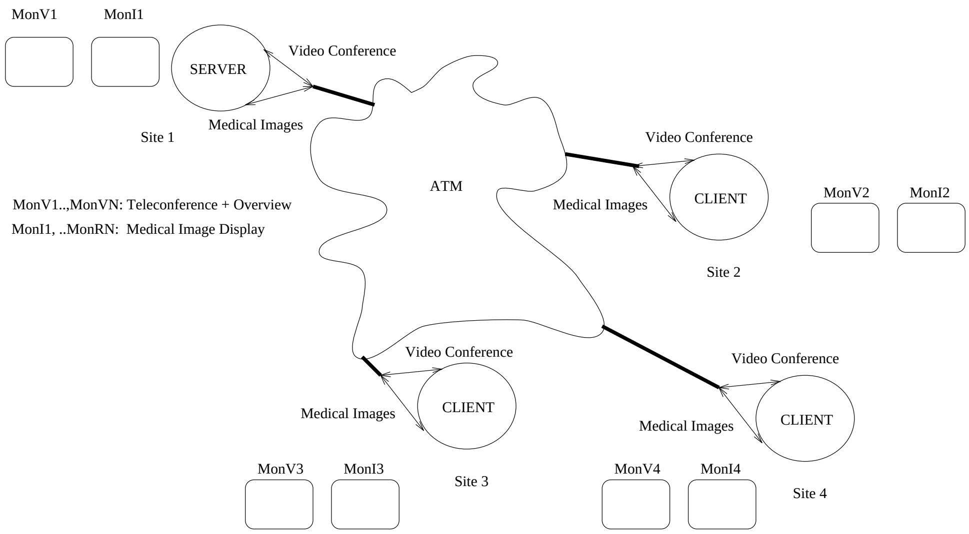

Fig. 3: Advanced Scenario: MonVi,MonIi indicate the monitors available at each site

5 Future Developments

Future developments of this architecture will go in the following directions:

- Extension to multi client architecture: to allow more that two users to interact as indicated in Fig. 3.
- Synchronization between different clients. In the current architecture interaction between two users is possible only by means of the teleconferencing tool. A possible extension is to allow to share also the detail image window.
- Real time acquisition and coding of the input image. In the current architecture the acquisition of the images and their storage in a proper format is performed off-line.
- Telemanipulation of the acquisition device (typically a remotely controlled microscope).
- MPEG-2 based video conferencing.

6 Conclusion

We have presented a real-time multimedia architecture for medical teleimaging over ATM. The work has been focused on two main aspects: the quality of service awarness, from a joint video and network point of view and the confidentiality aspect, from a medical point of view. A multimedia architecture allowing teleconferencing as well as the real-time inspection of high resolution medical images has been discussed. Future development of such architecture are foreseen, which will allow an extension to more users and improved handling of the Region of Interest.

Real Time Telediagnosis of Radiological Images through ATM network: the ARTeMeD Project.

R.Noro, J.P.Hubaux
Telecommunications Services Group TCOM Ecole Polytechnique Fédérale de Lausanne,

R.Meuli, R.Laurini, R.Patthey
Centre Hospitalier Universitarie Canton Vaud, Institut de Radiologie

Abstract

The ARTeMeD project aims to solve problems of interactivity and real-time in teleradiology. It integrates personal multimedia facilities and patient data access in a common platform that allow radiologists to collaborate from remote sites through a suitable communication support. ARTeMeD is based on ATM network technology and an optimized manipulation of medical image material. The ARTeMeD system opens interesting perspectives in the area of collaborative teleradiology.

1 Introduction

In this article we describe the *ATM Real-Time Medical Diagnosis* (ARTeMeD) project under way in Lausanne at the Telecommunications Laboratory of the EPFL and the University Hospital. In this project we are exploring solutions in telemedicine [8] that allow interactive, real-time remote diagnosis both in pathology and in radiology. To contribute effectively in this area, we analysed existing systems and identified ways of improving their performance. The project involves studying how medical image processing maps onto a network technology; the fast transmission of high resolution images, the capability of remote manipulation of *Region of Interest* (RoI), that is a user selected portion of an image with high perceptual quality and/or resolution and the live audio and video communication are addressed in ARTeMeD, as well as the synchronization requirements and the multi-party support for collaborative work.

The results of the project include an architecture, the ARTeMeD system, which englobes the aforementioned aspects. The key issues of ARTeMeD are the optimization of storage, access and retrieval of medical images, the use of high-speed networking technology and the deployment of suitable image compression algorithms.

The paper is organized as follows. In sections 2 and 3 we describe the architecture. In section 4 the organization and manipulation of medical image material is detailed. In sections 5 and 6 we present our prototype implementation, performance measures and a comparison to a pre-existing standard solution for teleradiology. Some conclusions and suggestions for further work are discussed at the end of the paper.

2 System architecture

The ARTeMeD project has evolved by taking into account the needs for real-time and interactivity in teleradiology: these needs have been analyzed in terms of system requirements and system design. The resulting architecture is an integration of desktop conferencing facilities and a new method for storage/retrieval of medical images over a suitable communication support, as indicated in Fig. 1. The communication support considered here is based on *Asynchronous Transfer Mode* (ATM) network technology [9]. This particular subsystem provides two access points to the application level: one for the exchange of medical data and one for the multimedia personal communication.

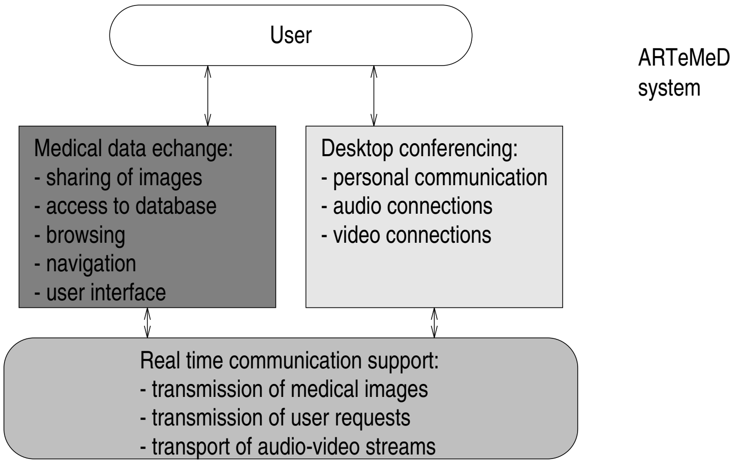

Fig. 1: Integration of desktop conferencing and medical data exchange over communication support for ARTeMeD.

A typical scenario in which our system can be used is composed as follows: images are stored in a server and one or more radiologists want to access and browse the images on their screen. Collaboration of radiologist over the same subject is allowed: in this case, the same images are distributed by the server to the participants of the session. The conferencing subsystem interconnects all the participants. At a given time, only one radiologist has control over the images: his interactions with the server produce the images that are distributed. Such a situation is sketched in Fig. 2 for the case of two radiologists.

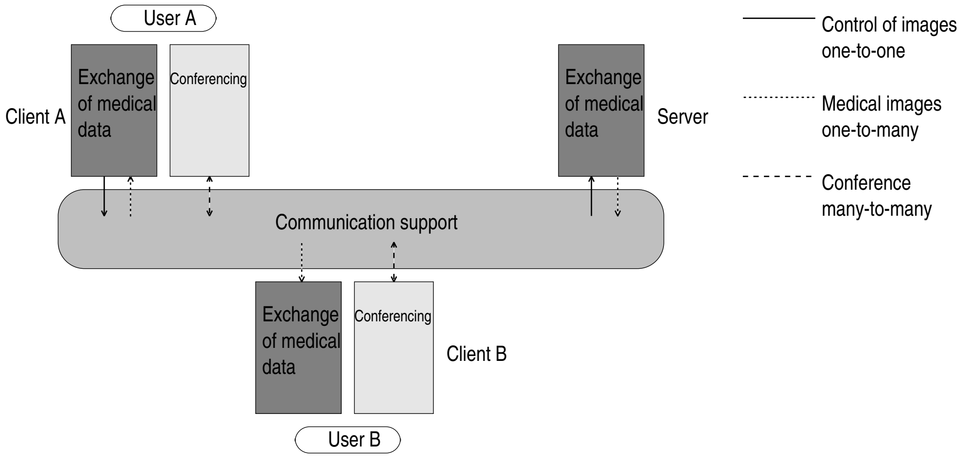

Fig. 2: Two users cooperating on the same medical subject.

It is worth noticing that the control of images flows from one client to the server (one-to-one connection), images flow from server to all the clients (one-to-many) and conferencing interconnects each client with each client (many-to-many).

The contribution of the ARTeMeD project is mainly in the medical part: we propose an innovative client-server approach for optimizing the retrieval and display operation times of medical high-resolution, still images. ARTeMeD allows interactivity and real-time thanks to the following design features:

- reduced amount of data to be processed, thanks to the compression and hierarchical organization of images,
- increased transfer rate for the communication support, thanks to the ATM network technology,
- a simple graphical interface for the navigation of the medical images, thanks to the concept of user-defined RoI.

Some additional requirements must also be satisfied for the efficient cooperation among specialists: the latency of the system must be kept under control (that is, the time between the generation of a request by the user and the display of the requested image on the users' screens) as well as the coordinated presentation of the same images in spatially separated sites. These two aspects are often referred to as *temporal* and *spatial synchronization* [10, 11] and are fundamental to allow interactivity in distributed environments; they are taken into account for the ARTeMeD project.

3 The architecture components

Any ARTeMeD session is opened with one ARTeMeD server and one or more ARTeMeD clients. The client is expected to offer an interface to the radiologist, while the server is designed to inteface with the medical data stored in an attached database and also to perform some centralized activities (among others, monitoring of the participants and spatial synchronization tasks).

The basic components used to build both the server and the client of the ARTeMeD system are represented in Fig. 3. The blocks labelled with 1, 2, 3 and 4 belong to the medical data exchange subsystem; the blocks 5, 6, 7 and 8 to the conferencing subsystem and the blocks 9 and 10 constitute the communication subsystem.

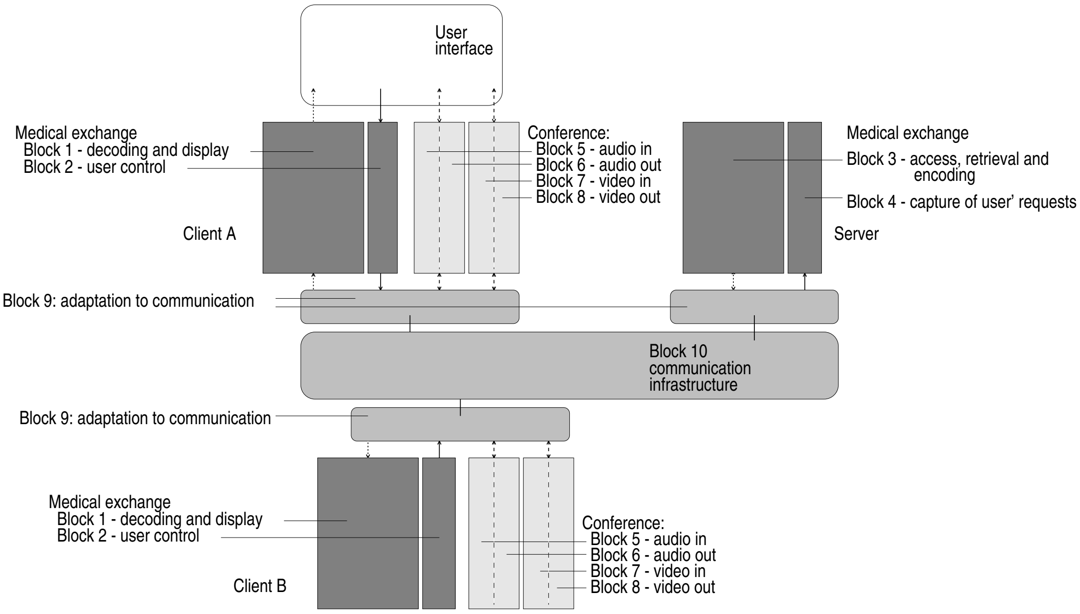

Fig. 3: ARTeMeD system components.

Block 1: decoding and display. Each ARTeMeD client is equipped with this block: it is designed to get compressed image data from the network, to process this information and to display the target image on the user's screen.

Block 2: user control and graphical interface. In the ARTEMeD client, this functional block provides the capability to the user to perform some remote actions on the server. The user actions (e.g., the definition of a RoI, the selection of a low resolution image to be magnified, the modification of grey windows) are captured by this block and mapped onto messages to be carried over the communication support.

Block 3: user commands interpretation and database request. This block is situated in the ARTeMeD server: it transforms the incoming user message from the network (generated by the Block 2) into a filter for the selection of images and/or portion of them to be retrieved in the database.

Block 4: access, retrieval and encoding. The selection required by the Block 3 is performed by the current block and the image data is generated in the format required by the Block 1. Block 4 operates on the compressed images: it must supply output data that correspond to the specified compressed format, but implementation can be done in several, independent manners.

Blocks 5, 6, 7 and 8: compression and rendering of audio-video streams. Audio-visual interconnections between participants are obtained by means of these blocks: they perform the two way mapping between audio and video frames and network packets. Their functionalities are out of the scope of the ARTeMeD project, which simply integrates them beside the medical imaging part. It is worth to notice that video communication can be optionally dropped from the setup with a reduced impact on the degree of interactivity of the system (if, for instance, a camera is not available or the audio quality is good enough or we can save bandwith/CPU for the medical exchange and so on).

Block 9: communication interface and adaptation. This block interfaces each user terminal with the communication support. It has two main tasks: first, it deals with etherogenity in the communication support (for instance, the host running the server can run at the same time a client and interconnection happens on the internal bus and not on network) and second handles the paths along which data are sent (all the client-to-client, client-to-server and server-to-client connections).

Block 10: communication infrastructure. This is one of the crucial components of the system. It must have a powerful and flexible communication infrastucture to support the information flow generated by such a system: high amount of data to be moved with strong temporal constraints. For this specific reason, ATM is at the moment the more suitable technology to do so. Nevertheless, in a LAN environment (for instance an hospital network), other technologies (e.g. Ethernet or Fast-Ethernet) can be appropriated, but as soon as we consider a more spread system it becomes prohibitive to obtain the same results with classical network technologies.

4 Medical image storage, access and retrieval in ARTeMeD systems

Our approach for the manipulation of radiological images in ARTeMeD is organized into steps: the storage in the server's disk or database is performed off-line, directly from the acquisition device. The access and retrieval of the stored material is done on user request and is performed in real-time during the operative session. It is important to notice that the ARTeMeD system is based on a completely file transfer-free paradigm: the requested images do not need to be stored in the client's disk. Instead, they are processed by the decoding block and directly browsed on the user's screen. They cost memory, but no extra disk space. The images do not leave the server's disk, they are just displayed, through a compression/decompression middlelayer, onto the client's screen giving the impression of manipulating a local copy. The remainder of this section describes the storage, access and retrieval phases of our system, that is, the most original part of ARTeMeD.

4.1 Storage in the database

The images coming from the acquisition device (CT, MRI) are pre-processed: they are organized in a hierarchy of resolution levels for the following access and retrieval phases. Two (or possibly three) subsampling operations of the high resolution images are performed and the different levels of resolution are obtained (Fig. 4). Then, for each level, all images are disposed in a *gallery* . The so obtained galleries are logically splitted in elementary regions which are the quanta of information for the access and retrieval phases. A compression algorithm is applied to the images in the hierarchy, reducing the amount of information to be transferred. In our implementation, the MPEG-2 standard have been choosen: the elementary regions just mentioned are the *slices* of the MPEG algorithm [12]. Compressed slices are indexed, in order to allow the fast access to specified portions of the images in the following phases.

4.2 Access of target images in the database

The user can specify which image(s) and resolution he wants (e.g., the coarsest gallery or *overview gallery* , a part of the semi-full resolution gallery, a single image at the highest resolution). Through his graphical interface, he sends a request to the server in the form of a geometrical area of an image and the corresponding resolution level. This request acts like a filter over the slice index and the selected slices are exctracted and aligned in an

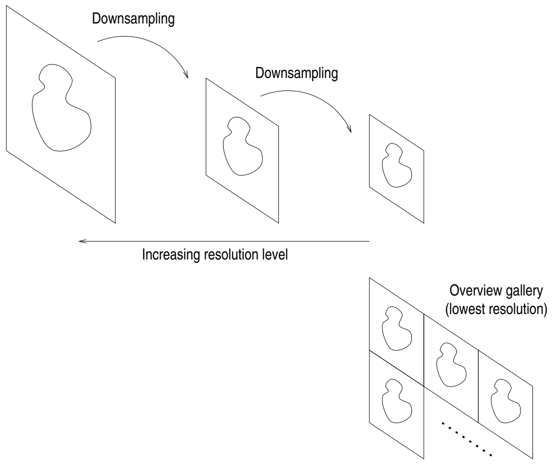

Fig. 4: Image hierarchy.

MPEG-2 compliant stream for the transmission and decompression in the client's host.

4.3 Retrieval of images: the user interface

The decision of which images or parts of image to analyze is left to the specialist(s). The system itself offers a minimal amount of initial information for starting inspection (the overview gallery) and a graphical interface for navigating images and increase by predifined steps the resolution of images. The radiologist selects the images(s) needed to do the inspection and/or diagnosis. By using the screen's pointer, he defines the portion of the gallery he wants to magnify (the RoI). The request is then sent to the server (a simple click on one button of the mouse). It is noticeable that, as the pointer can be moved around in the gallery, the user can generate a stream of requests with a well defined temporal behavior: in this case the server response is a sequence of images with the corresponding temporal characteristics.

In this way, the retrieval is interactive, because the user(s) can easily control which part of the radiological folder is more or less important, also communicating with the other participants of the session, and real-time, because only a little amount of information flows from server to clients and no intermediate storage operation are performed, only decompression and display.

The RoI is the one of the key aspects of the ARTeMeD system. It is taken into account for the organization of the database and the graphical user interface. At the same time, it is suitable to improve the interactive performances of the remote diagnosis: the amount of information and the processing time are consistently reduced for each operation.

5 Prototyping of an ARTeMeD system: implementation and performances

The prototype currently implementeted at the Telecommunications Laboratory includes most of the features discussed above (see a snapshot in Fig. 5).

Fig. 5: ARTeMeD system in use.

The hardware-software platform is composed of:

- a communication subsystem: ATM boards and one ATM switch connect the clients and the server and simulate a WAN.
- A conferencing subsystem: one comercial videoconferencing tool is integrated in the prototype on top of an ATM access point. The perceived quality is pretty good.
- A radiological browser: in the server, the image are compressed in MPEG-2 format [12, 13], stored with the corresponding index files. The client is provided with an MPEG-2 software decoder to process the data sent by the server. The system works both on HP and SUN workstations: the graphical interface is programmed in X-Windows. Three resolution levels can be browsed.

The current implementation is point-to-point: it does not allow multiple clients to connect to the server. This is an aspect on which we are still working. Instead, an additional feature added to the prototype is a synchronization module in the client to guarantee that the response of the server is closed enough (in time) to the request generated by the user [14].

Table 1: Main characteristics of ARTeMeD systems.

Allocated ATM link capacity:	1 to 1.5 Mbit/s.
Image compression tecnique:	MPEG-2.
Levels of hierarchy:	3, that is full resolution (512 $\times$ 512 pixels), 4 and 16 times downsampled.
Frame rate for interactive navigation:	5 to 10 frames/s. Transmission errors are cancelled by such refresh rate, without bothering the user.
Latency of the system:	less than 0,5 s, from the request to the display of the image.
Bandwidth occupation for conference subsystem:	$\leq$ 0.5 Mbit/s.
Bandwidth occupation for medical exchange subsystem:	$\leq$ 1 Mbit/s.

Table 1 summarizes the characteristics and performances of the current prototype (HP version).

6 Comparison with other systems

The implemented prototype shows several advantages when compared to the existing systems for teleradiology. In table 2 the comparison between the behavior of a traditional system (based on file transfer over N-ISDN links) and ARTeMeD is presented.

Even if the prototype still needs some refinements, the achievable performance encourages the deployment of such approach: we estimate, in particular, that a high degree of interactivity as well as the capability to collaborate among different users are the fundamental issues to be considered for any solution in teleradiology.

7 Conclusion and further work

Current systems for teleradiology do not fullfill the requirements for a completely distributed approach to remote diagnosis. In particular, they are lacking in an acceptable perceived level of interactivity and collaborative capability (because of the bottlenecks in the communication support and in the manipulation of images compared to the amount of information that need to be processed). The ARTeMeD project has revealed a possibility to improve such aspects. In this project we have analysed the existing systems

Table 2: Comparison between traditional systems and ARTeMeD.

feature	traditional system	ARTeMeD
Link capacity:	128 Kbit/s	1-1.5 Mbit/s (flexible, user specified)
Disk capacity:	required, very high	optional, reduced
Host resources:	required, consistent	reduced (software decoder and ATM board)
User friendliness:	good	good
Execution time of an inspection:	long (minutes)	very short, in two or three navigations of the overview gallery we obtain the target image (a few seconds)
Degree of interactivity:	poor	high
Collaborative capabilities:	possible but due to link saturation, perceived quality is poor	supported and reliable
Openess of the system:	not allowed	taken in account

and we proposed a new system which, basically, results from the balancing of three different subsystems in an unique, integrated architecture.

The ARTeMeD system is designed to have high speed link supports (ATM) that provide service guarantees, an efficient and optimized storage, access and retrieval of images and the openess to conferencing facilities in the same platform.

We have produced a point-to-point protoype of such system. Future work will explore, among other, the reliability of communication (transmission error resilience), fidelity of image material (MPEG-2 algorithms or other compression techniques have to be taylored to take in account the specificity of medical data, see [15]), security aspects (closed communication sessions), centralization vs. distribution of the server database.

References

[1] "Broadband Aspects of ISDN", CCITT Recommendation I.121, CCITT Blue Book, 1988.

[2] S. Wong, L. Zaremba, D Gooden, and H.K. Huang, "Radiologic Image Compression: A review", *in Proc. IEEE vol 83 n. 2*, pp. 194–219, Feb. 1995.

[3] "B-ISDN ATM Layer Specification", ITU-T Recommendation I.361, March 1993.

[4] "B-ISDN ATM Adaptation Layer (AAL) Functional Description", ITU-T Recommendation I.362, March 1993.

[5] "B-ISDN ATM Adaptation Layer (AAL) Specification", ITU-T Recommendation I.363, March 1993.

[6] "MPEG: Coding of Moving Pictures and Associated Audio for Digital Storage Media at up to about 1.5 mbits/s", International Organization for Standardization (ISO), Nov. 1991.

[7] Draft ISO-IEC/JTC1/SC29/WG11, Motion Picture Expert Group, "MPEG–II: Test model 4", January 1993.

[8] A. Basso, O. Verscheure, and R. Noro et al., "A Multimedia Architecture for Medical Tele-Imaging over ATM", *in CAR '96*, Paris, France, June 1996.

[9] M. De Prycker, *Asynchronous transfer mode: Solution for broadband ISDN*, Ellis Horwood, Bodmin, Cornwall, GB, 3rd edition, 1995.

[10] G. Blakowski and R. Steinmetz, "A Media Synchronization Survey: Reference Model, Specification, and Case Studies", *IEEE JSAC*, vol. 14, pp. 5–35, January 1996.

[11] P. Sénac, M. Diaz, and A. Léger et al., "Modeling Logical and Temporal Synchronization in Hypermedia Systems", *IEEE JSAC*, vol. 14, pp. 84–103, January 1996.

[12] ISO/IEC, *Information technology - Generic coding of moving pictures and associated audio information - Part 3: Video*, Oct. 1994, DIS 13818-3.

[13] ISO/IEC, *Information technology - Generic coding of moving pictures and associated audio information - Part 1: Systems*, Oct. 1994, DIS 13818-1.

[14] R. Noro, "Un mécanisme distribué de synchronisation appliqué à un cas de téléconsultation", *in JDIR '96*, Paris, France, September 1996.

[15] O. Verscheure, A. Basso, and M. El-Maliki et al., "Perceptual Bit Allocation for MPEG-2 CBR Video Coding", *in ICIP '96*, Lausanne, Switzerland, September 1996.