# An Interactive Multimedia Satellite Telemedicine Service

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**We present a telemedicine application that provides remote medical care services while taking advantage of the broadcast and multicast capabilities and the wide-band capacity of satellite systems. We developed the application in an open environment (Java) using a client-server architecture based on TCP/IP. We evaluated the performance of the application on satellite connections.**

Satellite communication systems have great advantages, such as wide-area coverage and the flexibility of providing broadcast and multicast connections. Even if the current capacity of satellite communications systems doesn't suffice for future multimedia applications, the satellite will be a fundamental element in the global information infrastructure (GII), which aims to carry information to anyone, anywhere, at any time, in any form, at an affordable price. The role of satellites must be integrated with the ground networks, rather than competing with them, because they can connect quickly to locations otherwise geographically or economically unreachable. Satellites provide a new opportunity by adapting the covered area to changes in demand for services. In particular, satellites offer a good facility for multimedia services where, up to now, it was difficult to forecast the different types of services and bit rates.

Commissioned by the European Commission EC-DGXIII within the frame of the Advanced Communications Technologies and Services (ACTS) 4th Framework Program, the Interactive Satellite Multimedia Information System (Isis) project developed a satellite communications system based on a dual-band concept and suitable for providing interactive multimedia services. The Isis system simultaneously uses a dual-band terminal, the Ku frequency band for a high-rate forward link, and the Ka frequency band for the return link to provide a small, low-cost transmitter/receiver that's easily transportable and installed.

The Isis project plans to offer interactive services for residential users in addition to the traditional TV distribution, porting applications typically developed for terrestrial networks (Internet) to the satellite Digital Video Broadcasting (DVB) environment. Using a PC and the same commands as most Internet applications, the connection by satellite will be transparent to users. Moreover, users' terminals can easily connect to terrestrial networks such as Integrated Services Digital Network (ISDN) and the Internet to obtain integrated multimedia services. The proposed approach aims to keep the basic Web solutions, allowing access to special data, large images, video sequences, and animations through special satellite links. This also provides access to services from sites not connected to the Internet or connected only with low-speed links, or from sites that must be connected in emergency cases.

The Isis project demonstrated the feasibility of satellite-based interactive multimedia services. The project selected and analyzed a number of applications for residential users and communities such as Internet services (file-transfer protocol or FTP, e-mail, and browsing services), distribution of electronic newspapers, teamworking, tele-education, and telemedicine.

These applications not only address commercial and business distribution, but applications such as tele-education and telemedicine have a fundamental impact on improving the quality of life. This article describes the telemedicine application Medical Environment for Diagnostic Images (MEDI).

MEDI has an open architecture with the following characteristics:

- developed in Java, it's machine independent;
- it uses the transmission-control protocol/Internet protocol (TCP/IP), so can run on different types of networks;
- it can be used on any commercial Web browser; and
- it supports broadcast connections for its client-server architecture.

*Table 1. Applications requirements*

| | Videoconference | Multimedia Mail | News on Demand | Telework | Telemedicine | Tele-education |
|---|---|---|---|---|---|---|
| Connection | Symmetrical | Asymmetrical | Asymmetrical | Symmetrical | Symmetrical | Asymmetrical |
| Capacity | BER $10^{-4}$ | BER $10^{-6}$ | BER $10^{-6}$ | BER $10^{-6}$ | BER $10^{-6}$ | BER $10^{-6}$ |
| Quality | 128 Kbps | 128 Kbps to 1.4 Mbps | 128 Kbps to 1.4 Mbps | 128 Kbps to 1.4 Mbps | 384 Kbps to 1.4 Mbps | 384 Kbps to 3 |
| Time Requirements | 200 ms | 1 s | 500 ms | 200 ms | 200 ms | 200 ms |
| Type of Connection | Real time | Scheduled | Scheduled | Real time | Real time/ scheduled | Real time/ scheduled |

## Service and terminal requirements

Dual-band (Ku/Ka) terminals permit tailoring the satellite system's characteristics to the actual users' needs.[1] In particular, the Ku band uses technology readily available for developing satellite terminals installed at the user premises (direct-to-home, or DTH). This reduces the required development costs and increases the growth of multimedia services because of the possibility of using the service during the start-up phases of commercial satellite segments.

On the other hand, the Ka band diffuses multimedia and interactive TV services because of the available wide-band capacity in the two directions (forward and return). It reduces the complexity of users' small terminals and improves the cost effectiveness because of the increase of system capacity throughput.

Depending on the type of information and connection, the Isis project offers a highly flexible platform for to provide a wide range of services:

- Internet service (FTP, Telnet, e-mail, Web navigation)
- bidirectional messaging (e-mail, paging)
- retrieval of documents, data, and high-resolution images
- interactive multimedia conversational applications (broadband multipoint videoconferencing, teleworking, teleconsulting, tele-education, and so on)
- user-controlled distribution (restricted digital information transmission, electronic newspapers, and so on)

Table 1 shows service requirements in terms of standards, required quality of service (QoS), bit-error rate (BER), acceptable time delay, and network connectivity for the major applications relevant to the Isis system.[1]

## System concept

Figure 1 shows the basic Isis architecture where the main blocks include[1]

- a service center, sometimes called the broadcasting center or hub;
- a small earth station (SES), also called a DTH terminal, which is placed at residential users' homes; and

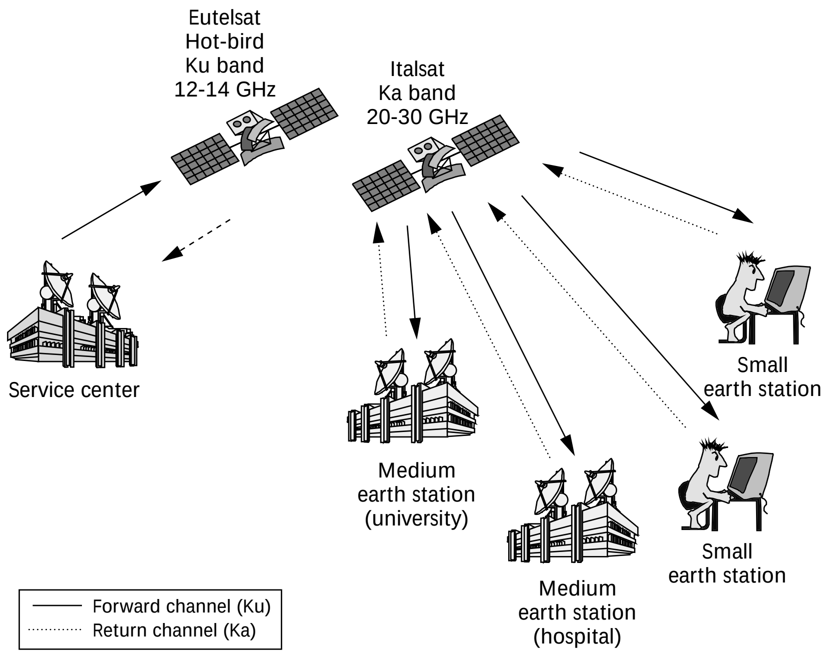



*Figure 1. Isis architecture scheme.*

> **Telemedicine aims to provide remote medical services to distant communities using current and emerging communications networks.**

- a medium earth station (MES), installed at community buildings such as hospitals or universities.

The service center has the following functionality:

1. System management and administration of the network. It manages all the user activities (service access, service delivery, service release) as a network control center.

2. Information data and signaling information use the same channel (in-band signaling).

3. Transmitting and receiving communication paths belong to different frequency bands. The Ku band antenna and radio frequency equipment manage the forward channel transmission toward the user DVB downstream (34 Mbps) that contains the information related to the selected application. The Ka band antenna and radio frequency equipment manage the return channel at a low bit rate (64 Kbps to 384 Kbps), carrying out signaling and interactive information from the user to the service center.

4. Storage of data, images, and videos of the Isis applications in the video server, which provides the digital MPEG-2 transport stream and can support

- *MPEG-2 video broadcasting.* The user selects and watches MPEG-2 videos (movies) among those the video server broadcasts. The movies are cyclically broadcast on the satellite high-speed link, then the user selects the channel, and real-time decoding starts at the client end.

- IP-based applications. The demonstration system gives the user full Internet access through an Internet server and the possibility to run any standard Internet application like FTP, a Web browser, and so on. Moreover, Isis partners developing their own IP-based client-server applications can run them using the IP over a DVB transport mechanism that the video server supports.

5. The DVB modulator (DVB-S standard ETS 300 421) receives the content information from the video server (that is, the MPEG-2 transport multiplexer) in a format suitable for the Ku radio frequency equipment to transmit to users through the satellite communication link.

6. The service center is connected to the Web by the Internet server. The Internet server provides connectivity for any server with IP-based applications, so it acts as a router for all the IP traffic and accesses data from either remote or local servers.

The MESs aren't service providing centers. These remote stations possess improved transmitting (up to 2 Mbps) and receiving capabilities only to satisfy specific service requirements such as bit rate and real-time interaction.

The SESs have asymmetric communication links to receive a great amount of data and to transmit low bit rates (64 Kbps) mainly for control message purposes.

The user terminals are mainly PCs with dedicated boards. Users run the required application from their PC, generating user traffic (such as requests or data) provided to the return channel. On the traffic channel, IP packets must be segmented for transmittal on the return channel slots, based on asynchronous transfer mode (ATM, ATM adaptation layer AAL5). The end-user terminal demodulates and demultiplexes the MPEG-2 DVB signal received from the forward channel (Ku band) containing the required information embedded on the MPEG-2 transportation stream.

## A telemedicine application

Telemedicine aims to provide remote medical services to distant communities using current and emerging communications networks. The telemedicine application MEDI provides the following two environments:[2]

- *Medical image database access*. Permits access to a medical diagnostic images database through the selection of search fields to retrieve the medical image, the image visualization and processing, and other image supports.

- *Remote expert consultation*. Provides interactive image transmission showing various medical diagnostic modalities with cooperative tools among physicians and specialists who exchange information and opinions about patient cases to obtain diagnoses in real time and to plan the treatment.

Based on Java,[3] the MEDI application runs on different platforms (such as Unix or Windows NT/95/98). We selected Java to develop MEDI because it provides interfaces and classes suitable for developing network applications. Java programs (applets) are architecture-independent, since they're written in a high-level language compiled in code (bytecodes), which any machine can interpret. Also, Java uses a virtual machine to run the applets, which can be embedded in other applications. For example, they can be enclosed in a Hypertext Markup Language (HTML) document to provide interactive, executable content on a Web page. Java also supports database development through Java Database Connectivity (JDBC), which offers a set of classes and interfaces to execute Structured Query Language (SQL) statements—using JDBC, the SQL statements can be sent easily to any commercial database (such as Oracle, Informix, Access, and so on).

MEDI is a Web application based on HTML pages with a Java client front end (applets) and Java servers connected via TCP/IP. All the images involved in the applications are in the Papyrus 3.0 format (see http://www.expasy.ch/UIN/html1/projects/papyrus/papyrus.html), which is in agreement with the Digital Imaging and Communications in Medicine (Dicom) 3.0 part 10 standard (see http://www.xray.hmc.psu.edu/dicom/).

Since MEDI is a Web-based application, it has a client-server architecture. A remote machine with server functionality controls concurrent processes from the clients. It hosts and runs the medical image database, the other MEDI databases, and the Java and HTTP servers. Many clients can start and see the MEDI application using any commercial browser such as Netscape, Internet Explorer, or HotJava. MEDI uses a broadcast model to send the same images and events to all the users sharing a medical session. In this model, each user has a separate copy of the application allowing cooperative diagnosis among multiple users by broadcasting the events required by each user to all the other users in the session. A synchronization system controls the use of a shared mouse and of cooperative tools among the different users to avoid collision problems in the multicast transmission. In this case only one user has the controls and can modify the image; the other users can see the results of the work on the image simultaneously. MEDI also lets participants exchange text messages with each other.

Here's an example of a typical client-server work session with MEDI:

- The client requests a service (database or remote consultation) through a homepage received from the HTTP server.

- After an authentication phase (login and password), the HTTP server sends the client an HTML page containing the Java front end (applet). Then, a socket between the Java server and the client is opened and a client-server application session can start.

- Messages (SQL commands, medical images, actions, and so on) are exchanged among the clients (remote consultation) or between the

## Acronyms

| | |
|---|---|
| BER | bit-error rate |
| Dicom | Digital Imaging and Communications in Medicine |
| DTH | direct-to-home, or |
| DVB | Digital Video Broadcasting |
| FTP | file-transfer protocol |
| HTML | Hypertext Markup Language |
| HTTP | hypertext transfer protocol |
| ISDN | Integrated Services Digital Network |
| Isis | Interactive Satellite Multimedia Information System |
| JDBC | Java Database Connectivity |
| MEDI | Medical Environment for Diagnostic Images |
| MES | medium earth station |
| QoS | quality of service |
| SES | small earth station |
| SQL | Structured Query Language |
| TCP/IP | transmission-control protocol/Internet protocol |

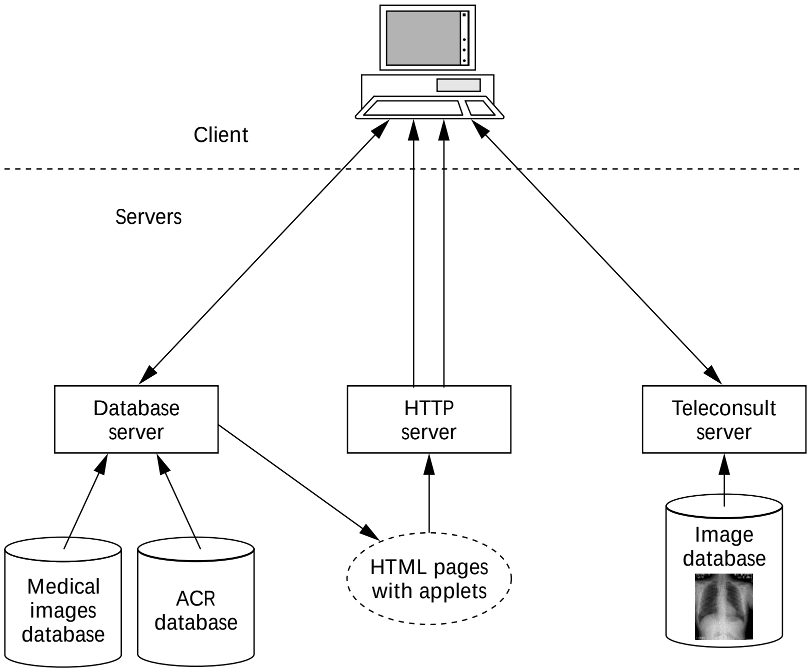



***Figure 2. Data and control flow in the MEDI client-server image database.***

client and the server (medical image database) directly over the socket connections the Java server(s) provide.

To coordinate the information exchange and collaboration with users, MEDI has three Java servers:[4]

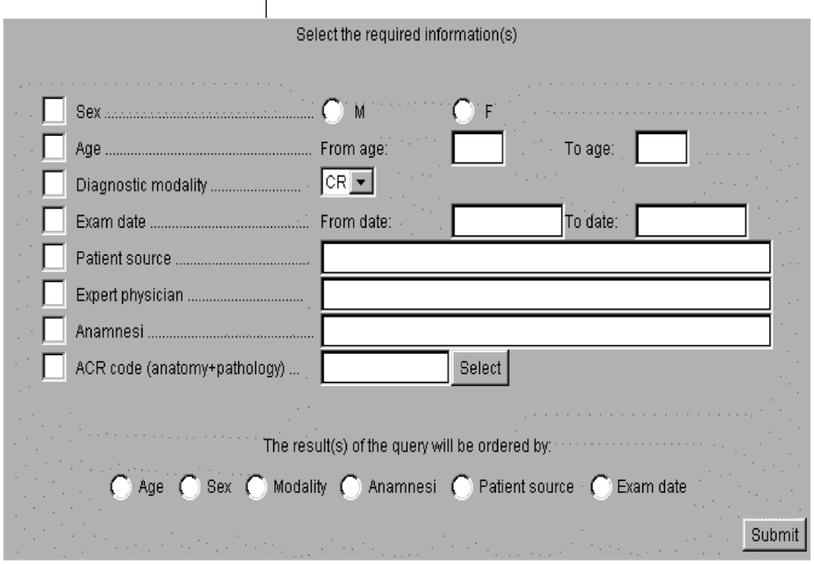
1. *Database server*. This server controls the user query for the access to the medical images database. The user fills out a consultation applet (in HTML) according to the following fields: sex, age, diagnostic modality, clinical history, American College of Radiology (ACR) diagnosis coding, hospital name, date and time of the medical report, number of images in the Papyrus 3 file, and so on. The server also interacts with the ACR standards database (http://www.acr.org/f-products.html), which contains all the necessary information for coding a diagnosis from the anatomical and pathological point of view. When users have selected a particular record, the database server creates a new HTML page embedding an applet for the visualization of the medical image(s) associated with the selected record. The visualization applet is based on the Java Abstract Window Toolkit and establishes a connection to the Java teleconsult server, which has direct access to the Papyrus 3.0 images.

2. *Queue server*. This server supports user requests for an expert service. In the queue database each record represents a request and contains all the necessary patient information—age and sex of the patient, hospital name, date and time of the request, and so on. The queue server manages the reception of the image(s) that must be analyzed, along with some information about the patient and the subscriber (the doctor). It controls the requests queue, the generation of the HTML page containing the information of the selected request, and the remote consultation applet configured for receiving the medical image(s) associated with the selected requests. It also manages the request deletion at the end of a remote consultation session.

▮ *Teleconsult server*. This server permits remote consultation sessions. It manages the transmission of the Papyrus 3.0 image(s) both to the user and to the expert consulted during the session. It provides a multicast transmission of each command (such as events, data messages, and images) received from a user to all the other participants in the remote consultation. It also manages the generation of the HTML page containing the medical report written by the expert at the end of the consultation and the HTML page containing the applet for the Medbase upgrade.

Figure 2 shows an example of the flow of data and control and the MEDI servers' functionality during access to the medical database. Figure 3 shows the applet for the MEDI medical image

***Figure 3. Applet of the medical database consultation.***



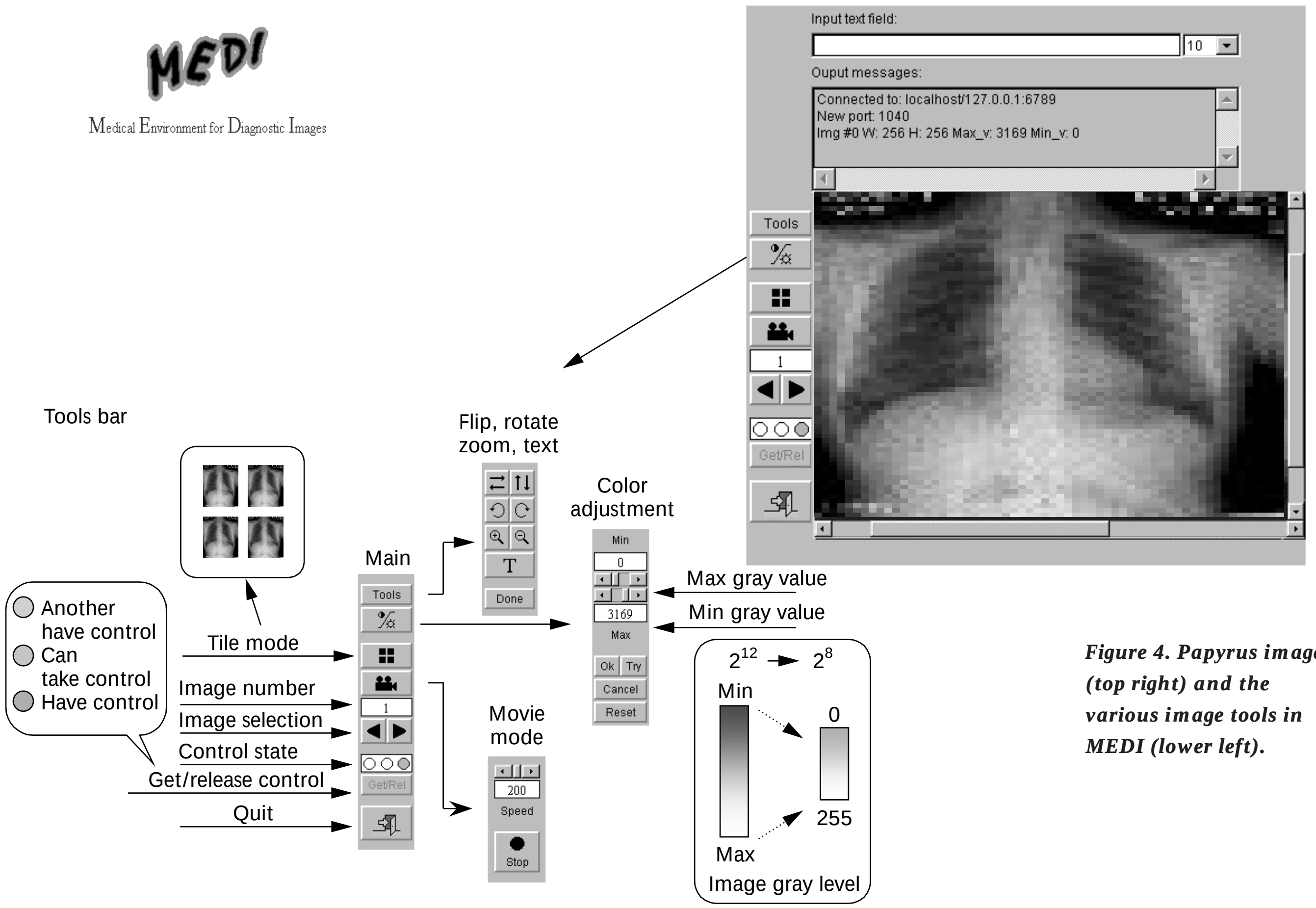



*Figure 4. Papyrus image (top right) and the various image tools in MEDI (lower left).*

database consultation, where it's possible to select the pathological case using the different search fields. After the form compilation, the applet informs the Java database server which records the user wants. Then the Java database server creates an HTML page containing the selected record information and the remote consultation applet configured for receiving the medical image(s) associated to the selected record. The user automatically receives the selected Papyrus image from the Java teleconsult server (see Figure 4).

As Figure 4 shows, various image tools are always available in MEDI, such as

- Tools for flipping, rotating, zooming, inserting text over the image, calculating distances between two points of the image, and gray adjustment of the current image.

- A movie mode, for showing all the received images in a loop. Some diagnostic modalities (such as magnetic resonance, or MR) can include more than one image related to different acquisition moments or points, or to different patient positions.

MEDI users may require the help of a remote specialist to have more information on the selected image. MEDI lets users exchange text messages according to a traffic-light control system (only one user at a time can transmit events and messages to avoid misunderstanding) that controls the shared mouse and processing tools on the same image. When the teleconsult session ends, the expert is invited to write a medical report, contained in an HTML page and automatically sent to users when they leave the session. The expert can also choose to save this new clinical case to the medical images database.

## Trial results

During the trials of the Isis project the MEDI servers were connected to the client via the Eutelsat satellite (forward channel) and the link from the client to the MEDI server via the Italsat satellite (return channel) using the Isis platform. The client,

*Table 2. Network tests.*

| Test | Results |
|---|---|
| Ping | Connectivity OK |
| | Round-trip times: 600 ms |
| | Packet loss: 0.014% |
| FTP | Connectivity OK |
| | 10K-100K-1000K file transfer OK |
| | Greater than 20 Kbps for one session |
| | No packet loss |
| HTTP | Acceptable performance |

*Table 3. Timing transfer on the forward link.*

| Images | Transfer | Evaluation |
|---|---|---|
| X ray (135 Kbytes) | 15 seconds | Tools OK |
| Cinecard (2 Mbytes) | 95 seconds | Movie/tools OK |
| MR (1Mbyte) | 60 seconds | Tools OK |

equipped with a dual-band terminal, received and transmitted multimedia signals and could start and see the MEDI application using a commercial browser. Table 2 shows a number of tests (ping, FTP, HTTP) that validate the Isis platform.

The ping time of 600 ms was the usual satellite delay, and the packet loss was nearly acceptable. For the HTTP tests, we evaluated two scenarios:

- retrieving data from the Web server and
- retrieving data from the Internet through a Web proxy.

The results showed that the MEDI application on the Isis platform performed well: all the connected clients received the images and used shared tools satisfactorily. Table 3 shows the transfer timing of images of different sizes from the server to the client.

Experts and doctors at the University of Florence Hospital—during the trials—quickly familiarized themselves with the MEDI tool and evaluated MEDI as a user-friendly application. During the trials of the Isis project, we carried out a teleconsult session on a clinical case of prostate cancer using medical images acquired from different medical equipment and used an audio tool available in MEDI. Visit http://lenst.die.unifi.it/isis/index.html for more information about MEDI.

## Conclusions

A satellite network can provide many more advantages than a terrestrial connection for MEDI, including

- a wide band in the forward and return links, compatible with a bit rate of 2 Mbps required by the application;
- a guaranteed bit rate, whereas Internet performance is highly dependent on traffic intensity;
- broadcast and multicast capabilities that suit the MEDI application based on a client-server architecture; and
- secure connections for routine and emergency cases.

In the future, we plan to conduct extensive trials to test the MEDI application among different European hospitals connected by satellite using the Isis infrastructure. MM

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