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Evaluation of teleteaching services over ATM and IP networks ☆

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Abstract

This paper presents the components of a synchronous teleteaching application, their underlying technology and their interaction with network services. In addition, it presents the architecture and design of a synchronous teleteaching application used over the public ATM network in Greece. This paper presents various teleteaching scenarios over an ATM network infrastructure with the use of native ATM and IP over ATM. In each scenario we present the standards used, the logical components, the resource demands (network and equipment) and its special characteristics. For each scenario we give detailed information about the transmission and frame rates and the video delay. The main result of our experiments is that broadband networks offer many capabilities for high quality teleteaching, and generally speaking, high quality telematic services.
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Keywords: Teleteaching scenarios; ATM; Broadband networks; Teleteaching evaluation

1. Introduction

In the recent years, both computer and communication companies have made great efforts to include multimedia capabilities in workstation and desktop systems. Multimedia teleconferencing systems have thus become widely accepted, because

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they can support applications such as collaborative applications or teleteaching (Bouras et al., 2000a,b).

There is a growing public interest in the Internet, and at the same time, computer networks using new technologies are becoming faster. Furthermore, asynchronous transfer mode (ATM)-based networks, which offer speeds of up to 622 Mbps, are being installed and quality of service (QoS) for applications is being improved. These achievements can support the implementation of tools offering teleteaching capabilities over networks with QoS characteristics (Jorg and Steven, 2000).

In this paper, we present various Teleteaching scenarios over an ATM network infrastructure, used for evaluation of an ATM network infrastructure, implemented during the ATMnet project (see Section 2). Before the ATMnet project, in Greece many universities had implemented their campus networks based on ATM, but they were interconnected using private lines, not a public network. At the same time, the Hellenic Telecommunication Organisation was implementing its public ATM-based national network. The ATMnet project was the first attempt in Greece to test this large-scale public ATM network (Bouras et al., 2000c).

In each scenario we present the standards used, the logical components, the resource demands (network and equipment) and the special characteristics of the scenario. We mainly focus on three teleteaching scenarios: (a) point-to-point over native ATM, (b) point-to-point with the use of IP over ATM infrastructure, and (c) multipoint with the use of IP over ATM infrastructure.

The rest of this paper is organised as follows: In the following section, we describe the project that supported this work. Then we present some motivating factors for the use of teleteaching. In Section 4, we describe the functionality of a teleteaching application, along with the components of a teleteaching application. Section 6 presents the teleteaching scenarios used during our experiments, and in Section 7, we present some of the experiments that we made. Finally, some concluding remarks are given.

2. ATMnet project description

This work has been done in the context of the ATMnet project of the Greek Secretariat of Research and Technology. [1] The ATMnet project is the first large-scale attempt at the introduction of public ATM technology in Greece. The project aims to interconnect the local ATM networks of Greek universities with the public ATM network of the Hellenic Telecommunication Organisation. This interconnection creates a test-bed for study in the following research areas:

- Interconnection of private ATM networks with the public ATM network.
- Interoperability of alternative technologies (i.e. IP networks, Frame Relay).
- ATM standards for administration, control, and routing.

[1] Greek Secretariat of Research and Technology: http://www.gsrt.gr.

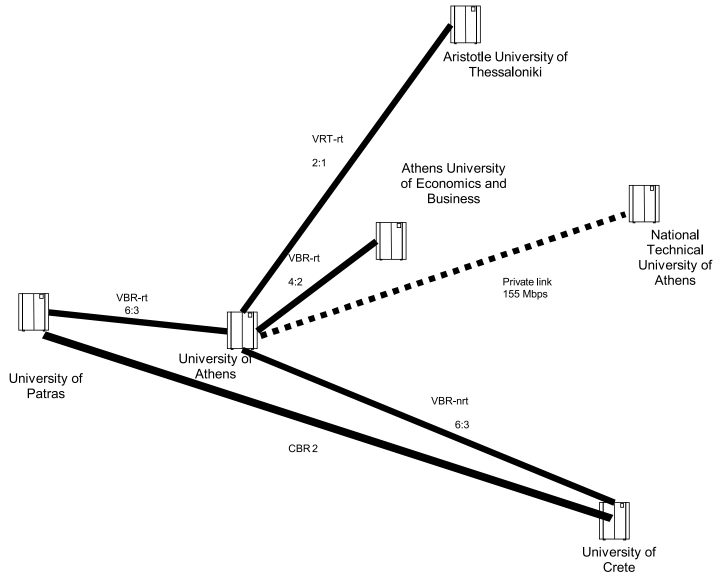

Fig. 1. Teleteaching test-bed.

- Quality of ATM services.
- Quality of advanced telematic services with multimedia characteristics.

The ATMnet project has installed telematic services (Videoconference, Computer Support Collaborative Work, Teleteaching and Telemedicine) in order to evaluate the quality of those services to the end user. The evaluation will be based on the design and implementation of various experiments on the implemented test-bed. Fig. 1 shows the teleteaching test-bed, which consists of six points, connected with ATM virtual paths/circuits. The main goal of the project was to evaluate these services in terms of feasibility, network infrastructure and bandwidth requirements. Apart from the technical requirements, we have concentrated on the functionality issues that result from the proposed services. Issues concerning end users are described below.

3. Motivation

Teleteaching could be regarded as the process of learning with the use of telematics, that is, the combination of telecommunication, information and multimedia technology and its services. In such a scenario:

- All the interactions among trainees, trainers and instructional material, which are essential for the instructional process, can be implemented.

- The information and knowledge, which are essential for the instructional process, are accessible and readable.
- The place, time and the pace of learning are flexible.

Teleteaching has as its target the development and promotion of special methods and techniques to increase the quality, effectiveness and flexibility of the learning. It has the following goals:

- Development of learning environments and methods suitable for using information technology in different learning environments.
- Improvement of the organization environment in which the new methods are applied, and the quality and manageability of the multimedia applications and real time services.
- Recognizing the quality characteristics obtained through teaching with the use of new Teleteaching technologies and services.

Teleteaching has two main results:

1. *Educational*: Improvement of existing learning methods and the development of new learning methods.
2. *Technological*: Provision of new distance learning methods with the use of information and communication technologies (ICT).

These reasons give rise to the need to implement tools that support teleteaching (asynchronous learning, synchronous learning and computer support collaborative work for learning – CSCW/L). In asynchronous distance learning, the student selects the time, duration and pace of the lesson. During a synchronous lesson there is live interaction between participants (the teacher and students). The CSCW/L functionality includes application sharing, bulleting boards, chat, e-mail and sharing workspace.

In this paper, we focus on teleteaching scenarios that offer synchronous distance learning services.

4. Teleteaching application functionality

Before conducting our experiments, we had to define the functionality of the teleteaching application based on the above-described motivation and the users' perspective. Further, we should offer users desirable functionalities in a simple and effective manner. The main requirements are:

- *Perception*: of the other participants is realized by distributing the users' input as well as the user's independent behaviour in order to achieve the impression of a group.

- *Various content and application support*: several widely used applications and forms of data should be supported.
- *Communication*: users in a teleteaching application should be able to communicate based on widely accepted conference standards (such as H.323 and T.120).
- *Simulation of tools in the traditional classroom*: it is useful to simulate some basic tools of the traditional classroom (e.g. blackboard) to introduce inexperienced users to the teleteaching application.

To accomplish the needs for user communication and perception, we offer audioconference, videoconference and chat functionalities. The functionality can be combined in such a way as to overcome problems in using the teleteaching application. For example, we use the chat functionality for questions to the teacher without interrupting him on the audio channel. Also, using a list of participants in the chat functionality gives the participants the feeling that they are participating in a group, since they know who the lesson participants are, who is talking, etc.

Using the whiteboard functionality, we try to simulate two basic tools of a traditional classroom: the blackboard and presenter. The whiteboard can be used as a shared blackboard among participants, where they can write, paint and highlight something. The teacher can also upload slides (as pictures) to present them to the students.

Another functionality we have integrated into the teleteaching application is data and application sharing, in order to satisfy the need for various content and application support. Using the data and application sharing functionality, a participant can share every application and file with the others. This functionality is also useful for perception and (indirect) communication among participants.

This functionality of the teleteaching application is described in detail below.

- *Videoconference*: This can be defined as real time audio/video communication among a group of geographically dispersed users. The videoconference combines the transmission of video screens with high quality audio to provide communication facilities to a group of users. Synchronous teleteaching applications use videoconferencing because it has many advantages, like visual communication and the capability of attending lesson from distant locations. The main disadvantage of a videoconference is the high cost of (high quality) videoconferencing equipment and the operating expenses (videoconferencing needs network connections with a high capacity). To support teleteaching services, we can use either a point-to-point videoconference (there are only two participating points in the teleteaching lesson), or a multipoint videoconference (more than two participating points). Multipoint videoconferencing uses special equipment, called a multipoint control unit (MCU).
- *Audioconference*: Similar to a videoconference, an audioconference can be defined as real time audio communication among a group of geographically dispersed users.
- *Whiteboard*: This simulates the blackboard of a traditional classroom. It gives the capability to a group of geographically dispersed users to communicate through

exchanging digital material. Each participant has the ability to draw different shapes, or write text on the whiteboard. It immediately displays the user's actions to the other participants. Therefore, all participants have the same view of the whiteboard, which consists of the actions of all the participants. The whiteboard gives the flexibility to its users to prepare digital material either before the lesson or during it. Whiteboard applications do not demand high capacity network connections, but the delay time during transmission of whiteboard data must be sufficiently low.

- *Application and document sharing*: This provides to two or more users the capability to share applications like document editors, spreadsheets or other applications. It offers users the ability to edit a document together. It is usual to use the application-sharing capability in cooperation with videoconferencing and chat capabilities. Application and document sharing does not demand high capacity network connections, but the delay time during the transmission of data must be sufficiently low.
- *Chat*: Offers users real time communication based on the exchange of text messages. Chat is useful in teleteaching applications because, through the chat, participants have the ability to communicate with each other without the need to interrupt the lesson. For example, through chat a student has the ability to submit a question to the teacher without interrupting his audio communication. Chat does not demand high capacity network connections, but the delay time during the transmission of data must be sufficiently low.

5. Teleteaching application description

To offer the above functionality to users, and to be able to experiment with different scenarios, we use the logical topology depicted in Fig. 2. First, a network infrastructure must be available for communication among participating end-points to the teleteaching session. The central point of a teleteaching application is the MCU, which is responsible for the transmission of audio, video and data to multiple end-points.

The end-points should be the appropriate equipment, such as a desktop multimedia personal computer with appropriate hardware and software (in the case of single user), or a teleteaching room (in the case of a class). To ensure interoperability among different manufacturers' equipment, we use international recommendations and/or standards to define the audio, video and data encoding. The role of an MCU is to collect the video and audio streams of all the participants and transmit it to all the participants only one video at a time, usually the video of the speaker.

With the use of gateways, users with different equipment (equipment which follows different standards) have the ability to participate in the same virtual classroom. For example, with a H.320–H.323 gateway, users with H.320 equipment have the capability to participate in a H.323-based teleteaching lesson.

Table 1 shows the major recommendations, which are used by teleteaching applications.

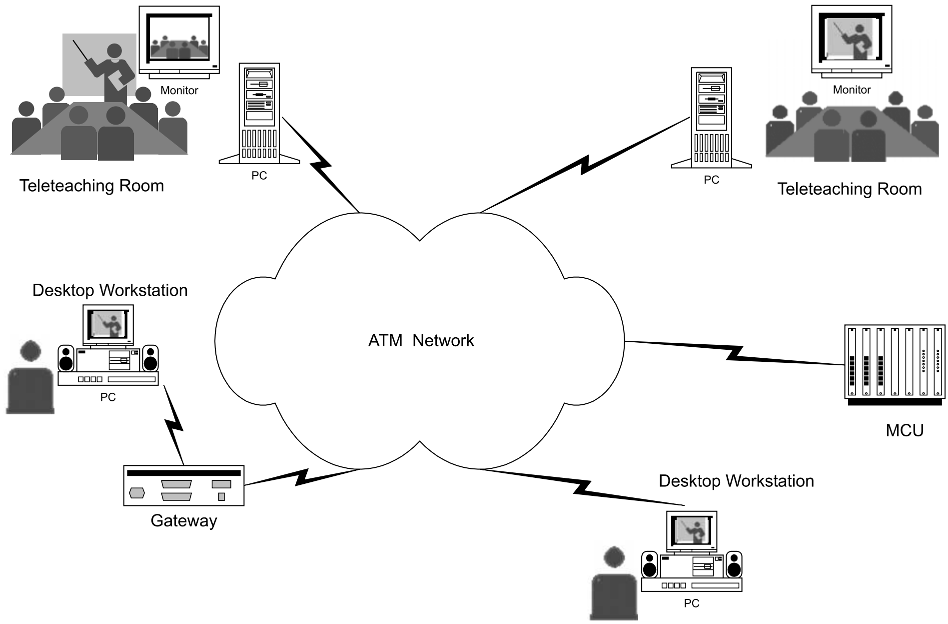

Fig. 2. Logical topology of the application.

Table 1
Major recommendations used by teleteaching applications

Recommendation	Network	Date	Title
H.310	ATM	11/99	Broadband and audio-visual communication systems and terminals
H.320	ISDN	03/96	Narrow-band visual telephone systems and terminals equipment
H.321	ATM	03/96	Adaptation of H.320 visual telephone terminals to B-ISDN environments
H.322	LAN	03/96	Visual telephone systems and terminal equipment for local area networks which provide a guaranteed QoS
H.323	LAN	11/96	Visual telephone systems and terminal equipment for local area networks which provide a non-guaranteed QoS
H.323 version 2	LAN/ATM	02/98	Packet-based multimedia communication systems
H.324	Telephone	03/96	Terminal for low bit rate multimedia communication
T.120	–	07/96	Data protocols for multimedia conferencing

In each teleteaching experiment, two types of users are participating: Users in a specially equipped room (teleteaching room) and users using a multimedia PC equipped with videoconferencing software and hardware.

Table 2
Bandwidth requirements for transmission of different media

Application requirements	Comment
Image transmission	
64 Kbps	Low quality – high transmission time
384 Kbps	High quality – low transmission time
Compressed video	
128 Kbps	Low quality video (no important educational material)
1.15 Mbps	Important Education Material
9 Mbps	Many channel with education material
Document imaging	
Low quality (256 bps)	Black and white digital document – low transmission rates
High quality (2 bps)	High document quality – high transmission rates
Document sharing	
Low quality (64 Kbps)	Transmission of static text
High quality (384 bps)	Transmission of text and graphics
High quality (1.5 Mbps)	Transmission of high quality document

A teleteaching room is a specially equipped room for the distance education of a group of users. The equipment of a typical teleteaching room is:

- Video camera with the capability to focus in specific coordinates.
- Overhead camera.
- Video board.
- PC with videoconferencing software and hardware or a videoconference set box.
- Overhead projector.
- Video multiplexer.

Teleteaching applications are based on the transmission of different types of media over a network. The different types of media used during a teleteaching lesson include text, images, audio and video. The quality of a teleteaching application is heavily dependent on the network infrastructure used for the transmission of the media. Table 2 shows indicative bandwidth requirements for the transmission of different media.

6. Teleteaching scenarios

In this section, we present the following teleteaching scenarios over ATM networks:

- Point-to-point over native ATM.
- Point-to-point with the use of IP over ATM infrastructure.
- Multipoint with the use of IP over ATM infrastructure.

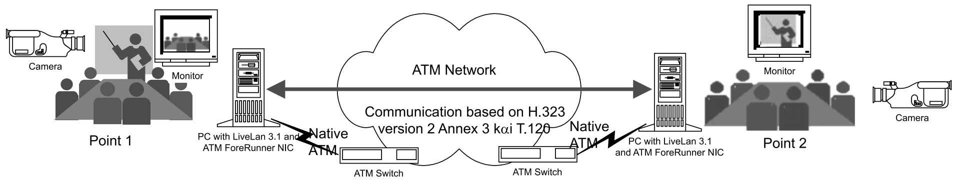

Fig. 3. Point-to-point over native ATM.

6.1. Point-to-point teleteaching scenarios

This is the simplest teleteaching scenario, in which one group of users communicates with another group of users. The workstations or teleteaching rooms at each point use the appropriate software and communicate through the ATM network. In addition, these scenarios are easily implemented, because there is no need for special servers such as MCU.

6.1.1. Point-to-point over native ATM

In this scenario we use the ATM infrastructure and protocols to transmit data (video, audio and application sharing data). In this scenario, the transmission of video and audio is based on the ITU H.323 version 2 standard (ITU-T Study Group 16, 1998), and more particularly on Annex C of this standard (ATM Forum, 1999). The application sharing capability in this scenario is based on the ITU T.120 standard (ITU-T Study Group 8, 1996). ITU recommendation H.323 version 2 upgrades the recommendation H.323 version 1 (Visual Telephone Systems for LAN with a Non-guaranteed QoS). Annex C of the H.323 version 2 defines videoconferencing over native ATM. With the use of H.323 version 2, we ensure interoperability between ATM and IP networks without the use of gateways. In this scenario we investigate the new capabilities that native ATM protocols offer to teleteaching. Fig. 3 shows the architecture of the point-to-point teleteaching scenario over native ATM. During this scenario, the video encoding is based on the H.261 and H.263 standards and the audio encoding is based on the G.711, G.722 and G.728 standards. The quality of the transmitted video is FCIF/QCIF, with a frame rate up to 30 (frames per second) fps. The typical bandwidth required for the implementation of this scenario is 768 Kbps.

For the implementation of this scenario, each point has the following equipment:

- Access to ATM network with ForeRunner [2] ATM adapter.
- PC with the PictureTel [3] LiveLan 3.1 videoconference tool installed.

[2] Fore Systems Corporation, http://www.fore.com.
[3] PictureTel Corporation, http://www.picturetel.com.

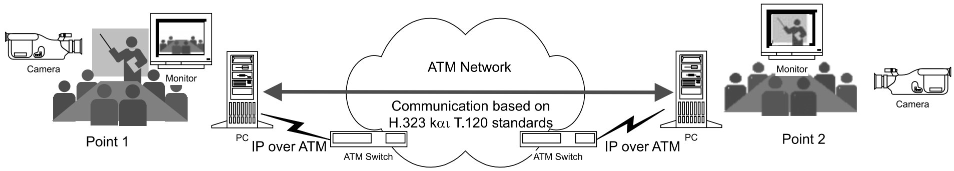

Fig. 4. Point-to-point with the use of IP over ATM infrastructure.

During this scenario we investigated the capabilities of native ATM in supporting teleteaching. The use of native ATM has the advantages that it gives the capability to reserve the appropriate network resources and provide specific QoS characteristics to applications during the teleteaching lesson.

6.1.2. Point-to-point with the use of IP over ATM infrastructure

In this scenario, we use tools and technologies that are the same as those for typical teleteaching over TCP/IP networks. In particular, we use the ITU H.323 standard for the transmission of audio and video, and the ITU T.120 standard for application and data sharing. We investigate both the capabilities and benefits of using the ATM network infrastructure for the implementing teleteaching scenarios, which are applied for a long time over IP networks. In addition, this scenario is easily implemented because of the availability of software for IP-based network services. Fig. 4 shows the point-to-point teleteaching scenario using the IP over ATM infrastructure. Here the video encoding is based on the H.261 and H.263 standards and the audio encoding is based on the G.711, G.722 and G.728 standards. The quality of the transmitted video is FCIF/QCIF, with a frame rate up to 30 fps. Typical required bandwidth for the implementation of this scenario is 768 Kbps in each point.

For implementation of this scenario, each point has the following equipment:

- Access to ATM network with an ATM adapter.
- PC with the H.323 compatible videoconference system installed.

During this scenario we investigate the capabilities that the ATM infrastructure offers to the already implemented solution of teleteaching over IP networks.

6.2. Multipoint with the Use of IP over ATM Infrastructure

In the case of multipoint teleteaching, an MCU acts as the central point where all participants are connected using multipoint teleteaching. The participants communicate with video, audio and data.

Fig. 5 shows the architecture of the multipoint teleteaching scenario with the use of an IP over ATM infrastructure. This scenario uses the same standards as the previously described scenario (ITU H.323 and ITU T.120), but is different from the point-to-point scenario as it needs special equipment – the MCU, which acts as a

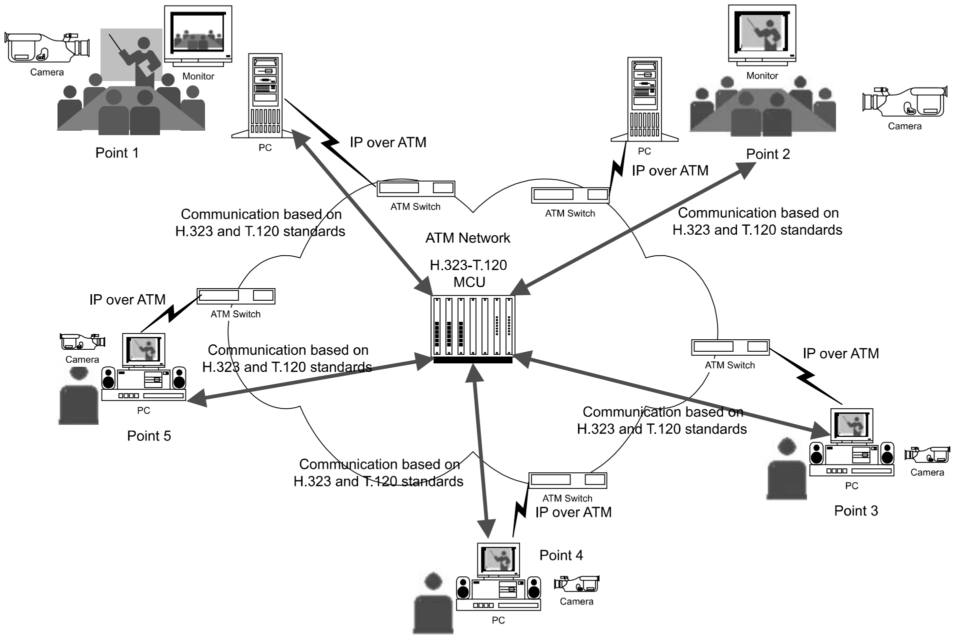

Fig. 5. Multipoint with the use of IP over ATM infrastructure.

reflector. The MCU collects the video and audio streams of all the participants and transmits back only one video at a time (usually the teacher's video during teleteaching). Video encoding is based on H.261 and H.263, and audio encoding is based on G.711, G.722 and G.728. The quality of the transmitted video is FCIF/QCIF, with a frame rate up to 30 fps. Typical required bandwidth for the implementation of this scenario is 400 Kbps in each point. In this case, we have to pay special attention to bandwidth requirements into the MCU connection, as the required bandwidth is $n * 400$ Kbps, where n is the number of participants at the multipoint lecture. In this scenario, we investigate the advantages of using an ATM infrastructure for multipoint teleteaching, where the demand for high bandwidth is crucial (especially to the MCU network connection).

For the implementation of this scenario, each point has the following equipment:

- Access to ATM network with an ATM adapter.
- PC with the H.323 compatible videoconference tool installed.

In addition, during this scenario, we use an H.323 compatible MCU to provide the multipoint capabilities.

We investigate the capabilities that the ATM infrastructure offers to the already implemented solution of multipoint teleteaching over IP networks. The use of an ATM virtual circuit for the implementation of network connections between participants and the MCU offers the appropriate bandwidth for the implementation of this teleteaching scenario.

7. Teleteaching experiments

In this section, we present the experiments conducted to evaluate the performance of teleteaching applications over ATM networks. Many experiments have been conducted, but we present results for the two more interesting cases:

- *Experiment 1*: Point-to-point teleteaching with the use of IP over ATM between the University of Patras and University of Crete.
- *Experiment 2*: Multipoint teleteaching with the use of IP over ATM among the University of Patras, University of Athens and University of Crete.

The experiments we describe were done on the topology of Fig. 1.

7.1. Experiment 1

During this experiment we used a point-to-point connection between the University of Patras (UoP) and the University of Crete (UoC). This point-to-point connection is a virtual channel (VC) with constant bit rate (CBR) characteristics and 768 Kbps capacity implemented in the virtual path between UoP and UoC.

During this experiment we investigated the quality of a teleteaching application when the application has enough bandwidth available through the CBR VC. Both participants (UoP and UoC) were using the same equipment, a PictureTel LiveLan 3.1 videoconferencing system, both using the parameters of Table 3. The two stations communicated with the use of the ITU-H.323 standard, and they used the ITU-H.261 standard for video encoding and ITU-G.722 ADPCM standard for audio encoding.

Table 3
Station parameters during the first experiment

Characteristic/station	Station at UoP	Station at UoC
Video conference protocol	ITU-H.323	ITU-H.323
Data conference Protocol	ITU-T.120	ITU-T.120
Video channel	Active	Active
Audio channel	Active	Active
Data channel	Active	Active
Video encoding	ITU-H.261	ITU-H.261
Audio encoding	ITU-G.722 ADPCM	ITU-G.722 ADPCM
Video format	FCIF	FCIF
Maximum transmission rate	768 Kbps	768 Kbps
Audio encoding rate	64 Kbps	64 Kbps

Fig. 6 shows the transmission rate of the UoP (Local Transmission Rate) and UoC stations (Remote Transmission Rate). This figure shows only the transmission rate for the video information: the audio information is transmitted with a constant transmission rate of 64 Kbps in both directions. In Fig. 6 the station in UoP transmits video with a transmission rate of approximately 700 Kbps, and receives video with a transmission rate near to 630 Kbps from the station in UoC. Local video has a greater transmission rate from the remote station because the local video is displayed directly from the local camera and the remote video is coming from the network. The total transmission rate (video and audio information) is near to the expected transmission rate of 768 Kbps.

Fig. 7 shows the frame rate of a station at the UoP (Local Frame Rate) and the station at the UoC (Remote Frame Rate). The station at the UoP had a frame rate near 15 fps, and the station at the UoC has a frame rate which fluctuates from 10 to 16 fps. Local video has a greater frame rate from the MCU because the local video is displayed direct from the local camera, and the remote video is coming from the network.

Fig. 8 shows the mean values of transmission delay (measured in milliseconds) during the first experiment. As can be seen, the mean value of transmission delay fluctuates from 25 to 70 ms. Concerning delay jitter, more than 99.9% of the measurements had value less than 150 ms.

During this experiment, both video and audio had high quality, and no problems appeared during the video, audio and data (T.120) communication between the two stations. As the values of the diagrams described earlier suggests (high bandwidth, high frame rate, small network latency, small frame losses), the ATM infrastructure allows the realization of high quality teleteaching sessions. The frame rate (15 fps) and the low transmission delay (50–60 ms) during our experiments allow high quality without problems.

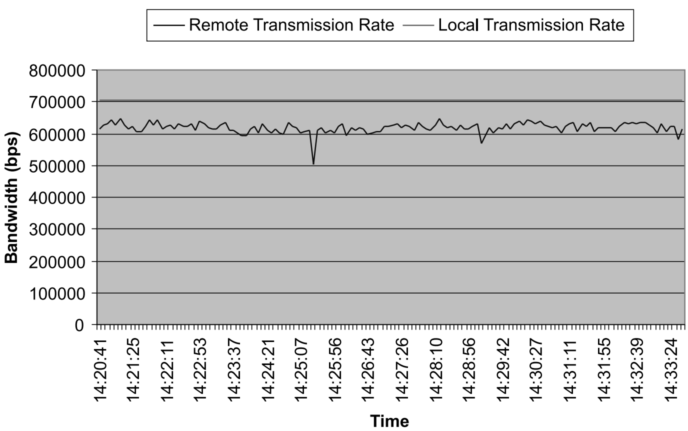

Fig. 6. Transmission rate in the UoP during the first experiment.

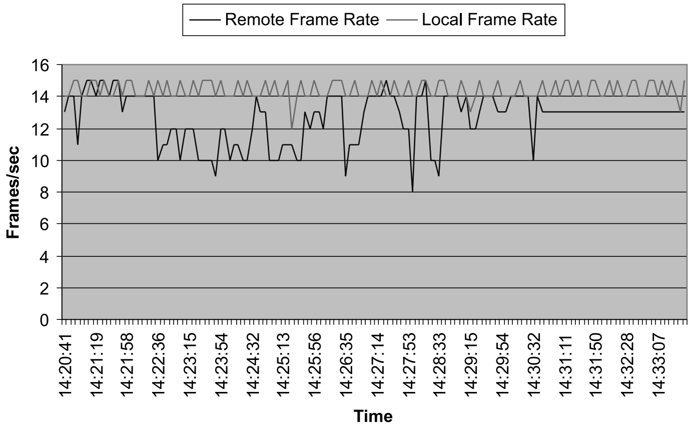

Fig. 7. Frame rate in the UoP during the first experiment.

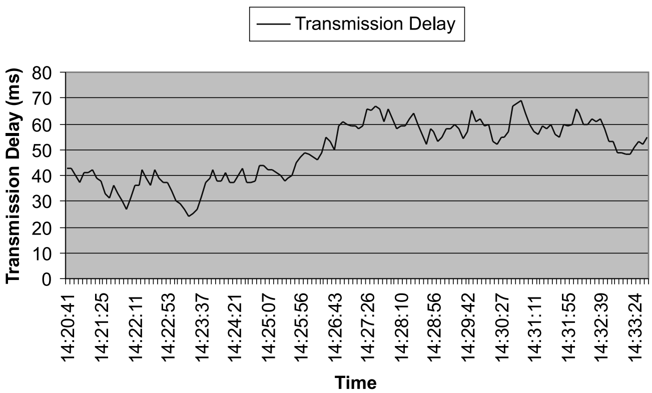

Fig. 8. Transmission delay in the UoP during the first experiment.

From the users' point of view the main requirements of teleteaching were fulfilled by the system. The high quality video and audio allows interaction of the teacher with the audience, and unproblematic communication between the two points. In addition, the unproblematic data communication allows users to communicate and exchange ideas using the whiteboard and application sharing capabilities that the system offers.

7.2. Experiment 2

During this experiment we evaluated a multipoint teleteaching scenario using three stations: one at the University of Patras (UoP), one at the University of Crete (UoC) and one at the University of Athens (UoA). To realize the scenario, we used

Table 4
Station parameters during the second experiment

Characteristic/station	Station at UoP and UoC	Station at UoA
Video conference protocol	ITU-H.323	ITU-H.323
Data conference protocol	ITU-T.120	ITU-T.120
Video channel	Active	Active
Audio channel	Active	Active
Data channel	Active	Active
Video encoding	ITU-H.261	ITU-H.261
Audio encoding	ITU-G.711 MULAW	ITU-G.711 MULAW
Video format	FCIF	FCIF
Maximum transmission rate	384 Kbps	384 Kbps
Audio encoding rate	64 Kbps	64 Kbps

an MCU located at the UoA. During this experiment we used the topology of Fig. 1. The administrator of MCU had defined a conference in the MCU which describes the topology and characteristics of the stations. Each station was connected to the MCU just before the teleteaching session started. During the session, we collect the appropriate statistical information. During this experiment, we evaluated how one must configure an MCU in order to provide multipoint teleteaching services. The MCU we used during this experiment was a Cisco [4] IP/VC MCU, and the stations at the UoP and UoC used the PictureTel LiveLan 3.1 videoconferencing system; the station at the UoA used a VCON videoconferencing system. The videoconferencing systems used the parameters in Table 4. Stations communicated with the MCU using the ITU-H.323 standard, the ITU-H.261 standard for video encoding and the ITU-G.711 MULAW standard for audio encoding. During this experiment, we reduced the transmission rates of the videoconferencing systems to 384 Kbps, because during multipoint sessions we have to pay special attention to bandwidth requirements into the MCU connection because the required bandwidth to the MCU connection is $n * 384$ Kbps, where n is the number of participants to the multipoint lecture (in this experiment $n = 3$).

Fig. 9 shows the transmission rate of the UoP station (Local Transmission Rate) and MCU (Remote Transmission Rate). This figure shows only the transmission rate concerned with the video information. The audio information is transmitted with a transmission rate of 64 Kbps in both directions. In Fig. 9 the station at the UoP transmits video with a transmission rate of approximately 320 Kbps, and receives video with a transmission rate near to 300 Kbps from the MCU. Local video has a greater transmission rate from the remote station, it is displayed direct from the local camera, and the remote video comes from the network. The total transmission rate (video and audio information) is near to the expected transmission rate of 384 Kbps.

Fig. 10 shows the frame rate of a station at the UoP (Local Frame Rate) and the MCU (Remote Frame Rate). The station at the UoP had a frame rate near 22 fps, and the station at the UoC has a frame rate near to 15 fps. Local video has a greater

[4] CISCO systems, http://www.cisco.com.

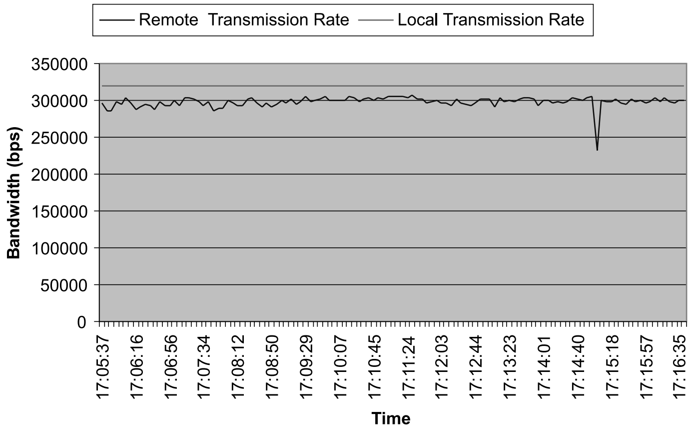

Fig. 9. Transmission rate in the UoP during the first experiment.

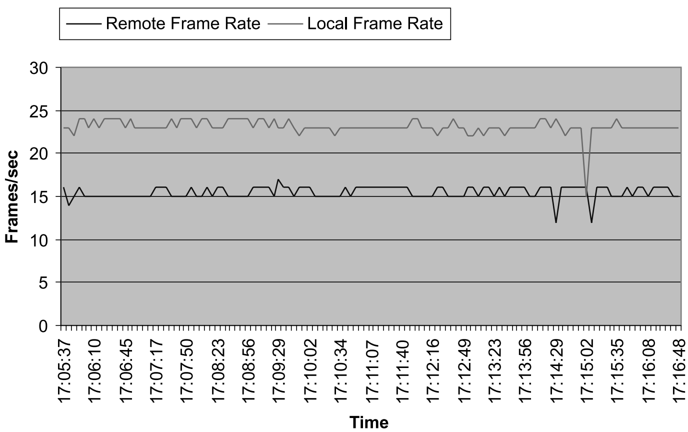

Fig. 10. Frame rate in the UoP during the second experiment.

frame rate from the MCU because it is displayed direct from the local camera, and the remote video comes from the network. In this experiment, the local frame rate had greater values than in Section 7.1 due to the negotiation between the PictureTel LiveLan videoconferencing system and the MCU, which results in the PictureTel LiveLan videoconferencing system transmitting with the highest frame rate that it can support.

We record transmission delay values (fluctuating from 25–70 ms) similar to Section 7.1, and concerning delay jitter, more than 99.8% of the measurements had values less than 150 ms.

During this experiment, both video and audio had high quality, and no problems appeared during the video and audio communication between the two stations. In addition, no problems appeared for the data communication (T.120) between the two stations. Moreover, there were no problems with the interoperability among different videoconferencing systems and the MCU. As the values in Figs. 9 and 10 suggest (high bandwidth, high frame rate, small network latency, small frame losses), the quality of the communication allows the realization of high quality teleteaching sessions. The high frame rate (15 fps) and low transmission delay (50–60 ms) in our experiments allowed high quality with no problems during teleteaching.

From the users' viewpoint, the main requirements of teleteaching were fulfilled by the system. The high quality video and audio allows a high level of interaction between teacher and participants, and problem-free communication between the three points. In addition, the unproblematic data communication, whiteboard, application sharing and MCU voice activation simulates an effective virtual classroom.

8. Conclusion

In this paper, we have presented our evaluation work of the teleteaching services in the context of the ATMnet project of the Greek Secretariat for Research and Technology. The goal of this project is the internetworking of local ATM networks at Greek universities with the public ATM network, and the demonstration of advanced telematic services over this network.

We have defined different teleteaching scenarios (point-to-point with native ATM, point-to-point with IP over ATM, and multipoint with IP over ATM), and have conducted some experiments based on these scenarios. In each scenario, the appropriate network resources were allocated as ATM Virtual Path/Virtual Circuits. During the experiments we took various performance measurements, and we drew conclusions about the use of ATM for teleteaching applications. The main conclusions are that broadband networks offer many capabilities for high quality teleteaching, and generally speaking, high quality telematic services and broadband networks like ATM must be widely used for the realization of teleteaching services by the educational community. In the experiments, both video and audio had high quality, and no problems appeared during the video and audio communication.

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