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Analysis of quality-of-service in a wide-area interactive distance learning system

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Interactive distance learning (IDL) is an evolving paradigm of instruction and learning that attempts to overcome both distance and time constraints found in traditional classroom learning. The electronic classrooms at two sites of the University of Oslo and two further sites in Norway overcome separations in space by exchanging digital audio, video, and whiteboard information via the Norwegian academic ATM-based network "Supernett II". The electronic classrooms are used since 1993 for teaching graduate level courses. This paper presents measurements and analysis results of transport, application, and user level Quality-of-Service (QoS) of the electronic classrooms. We describe our general experiences with this system for synchronous IDL. The lessons learned represent the motivation for the ongoing extension to support asynchronous IDL by a multimedia database system (MMDBS) to manage all data used and generated in the electronic classrooms.

1. Introduction

Interactive distance learning (IDL) is an evolving paradigm of instruction and learning that attempts to overcome both distance and time constraints found in traditional classroom learning [12]. Basically, we can differentiate between *synchronous* IDL (also called real-time or live IDL) and *asynchronous* (or stored) IDL. Synchronous IDL facilitates data networks, computer applications, digital video and audio to merge physically distributed classrooms or sites to a single virtual classroom. To reach the atmosphere of a single classroom also in a distributed classroom is one of the main challenges and requires appropriate Quality-of-Service (QoS) and interactivity support. In asynchronous IDL, lecture notes, background material, digital audio, and video can be accessed independently of lecture hours via network and storage server (or database system).

In the MUNIN project [2] and the MultiTeam project [1], the Center for Information Technology Services at the University of Oslo (USIT), Telenor Research, and the Center for Technology at Kjeller (UniK) have developed the so-called *electronic classroom* for synchronous IDL. Since 1993, the two electronic classrooms at the University of Oslo are used for teaching regular courses to overcome separation in space by exchanging digital audio, video, and whiteboard information. Currently, four electronic classrooms are established in Norway: two at the University of Oslo, one at the University of Bergen, and one at the Engineering School of Hedmark. Since 1997, the electronic classroom system is commercially available from New Learning AS.

Several similar teleteaching systems are documented, including [5,7,10,13,19,21]. However, there are two aspects in which the distributed electronic classroom exceeds these systems: (1) the resemblance to an ordinary classroom; and (2) the experience of using the system for regular courses every semester since fall term 1993, and its incremental improvements over this time.

The main goal of this paper is to report the results of our QoS analysis in the electronic classroom. Furthermore, we describe ongoing work to extend the electronic classroom concept with multimedia database system (MMDBS) support for asynchronous IDL. The remainder of the paper is structured as follows: Section 2 describes the distributed electronic classroom and compares it with related systems. Section 3 analyzes QoS issues at transport and application level. User level QoS aspects are discussed in section 4. The MMDBS support for asynchronous IDL is outlined in section 5. Section 6 summarizes the lessons we have learned from this analysis and concludes the paper.

2. Electronic classroom system

The electronic classroom system is described in detail in [1,2]. The purpose of this section is to enable the reader to understand the subsequent sections without referring to the original descriptions. Thus, we roughly repeat the most important features of the electronic classroom system, i.e., the application and the platform related part of the system. To conclude this section, we compare the electronic classroom with related systems.

2.1. Application

The main goal of the distributed electronic classroom is to make the teaching situation in a distributed classroom as similar as possible to an ordinary classroom. Thus, the number of seats for students is limited to maximal 20 in each classroom. During a lecture, at least two electronic classrooms are connected. Teacher and students can freely interact with each other, this does not depend on whether they are in the same or in different classrooms. This interactivity is achieved through the three main parts of each electronic classroom: *electronic whiteboard*, *audio system*, and *video system*. All participants can see each other, can talk to each other, and may use the shared whiteboard to write, draw, and present prepared material from each site. The electronic whiteboard, audio, and video system in turn consist of several components. In table 1, these components are briefly described and denoted with a component identifier (CID). The following description of the electronic classroom refers to the components via their CID.

Table 1
Components of the electronic classroom.

CID	Name	Description
① ②	Whiteboards	100” large semi-transparent boards, they are used to display screen information from the back room workstation and the output of the H.261 codec.
③	Light-pen	Input device for the electronic whiteboard.
④	Student cameras	Two cameras pointing at two slightly overlapping parts of the student area.
⑤	Teacher camera	Camera that is automatically following and focusing on the teacher.
⑥	Control monitors	Two TV sets in the back of the classroom allow the teacher to control the incoming and outgoing video stream while facing the students.
⑦	Classroom workstation and scanner	Enables the teacher to control the application; the scanner can be used to scan material during a lecture and present it on the whiteboards.
⑧	Back room workstation	Running the application, i.e., handles all input from the electronic whiteboard and performs all interactions with the peer application in the connected classroom(s).
⑨	Mirrors	Reduce space requirements in the back room, because they double the distance between video canon and whiteboard.
⑩	Video canons	Connected to the monitor output of the workstation in the back room and to the H.261 Codec, respectively, and they project the input via a mirror onto the whiteboard

Figure 1 illustrates the basic layout of an electronic classroom and figure 2 shows two pictures from a local and remote classroom that are taken during a lecture. In addition to the ordinary classroom structure that is visible on these pictures, i.e., student and teacher area, a technical back room is located behind the classroom.

The *electronic whiteboard* is a synonym for a collection of software and hardware elements to display and edit lecture notes and transparencies that are written in Hypertext Markup Language (HTML). The whiteboard itself ① is a 100” semi-transparent shield that is used together with a video canon ⑩ and a mirror ⑨ as a second monitor of an HP 725/50 workstation ⑧ in the back room. A light-pen ③ is the input device for the whiteboard. A distributed application has been developed that can be characterized as World-Wide Web (WWW) browser with editing and scanning features. When a WWW page is displayed, lecturer and students in all connected classrooms can concurrently write, draw, and erase comments on it by using the light-pen. Thus, floor control is achieved through the social protocol – as in an ordinary classroom – and is not enforced by the system. Furthermore, a scanner ⑦ can be used to scan and

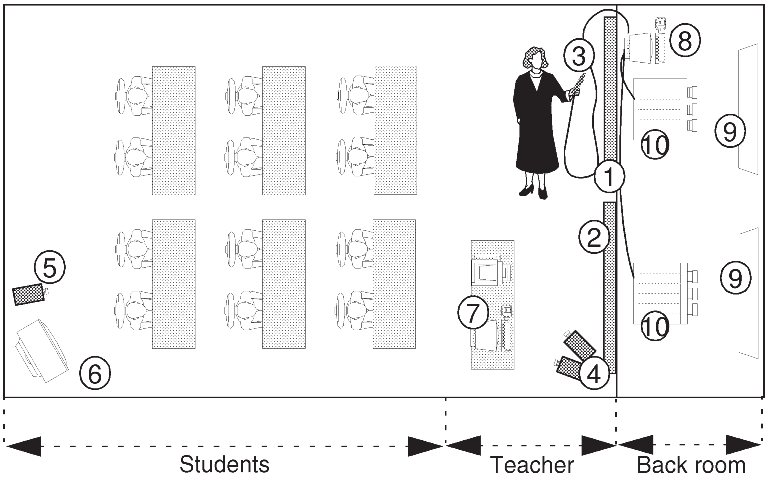
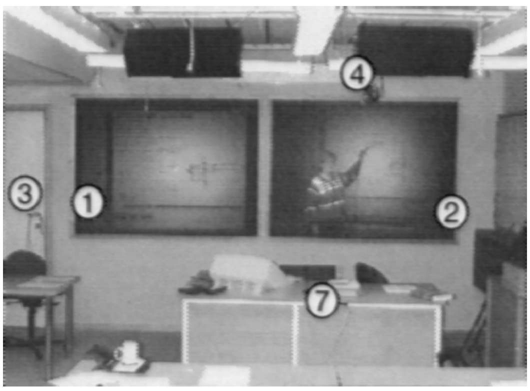


Figure 1. Structure of an electronic classroom.

(a) Student area



(b) Teacher area with teacher in remote classroom

Figure 2. Pictures from electronic classroom during a lecture.

display on the fly new material, like a page from a book, on the shared whiteboard. The entire application can be managed from the workstation in the classroom ⑦.

The *video system* comprises three cameras, a video switch, a set of monitors, and a H.261 coding/decoding device (codec) to generate a compressed digital video stream. One camera ⑤ is automatically following and focusing on the lecturer. The other two cameras ④ capture all events happening in the two slightly overlapping parts of the student area in the classroom. The audio system detects the location in the classroom with the loudest audio source, i.e., a student or the teacher that is talking. A video switch selects one of the three cameras that captures this location and person in order to produce the outgoing video signal. Two control monitors ⑥ are placed in the back of each classroom. The upper monitor displays the incoming video stream, i.e., pictures from the remote classroom, and the lower monitor displays the outgoing video stream, i.e., video information from the local classroom. Thus, the teacher can see the students in the remote classroom and can control the outgoing video information while facing the local students. The students in turn can see the remote classroom on a second large screen which is also assembled out of a whiteboard ②, a video canon ⑩ that is connected to the output of the H.261 codec, and a mirror ⑨ in the back room.

The *audio system* includes a set of microphones that are mounted on the ceiling. They are evenly distributed in order to capture the voice of all the participants and to identify the location of the loudest audio signal in the classroom. Furthermore, the teacher is equipped with a wireless microphone. To generate a digital audio stream, two codecs are available: the audio codec from the workstation ⑧ and the audio codec in the H.261 codec. Thus, one of the three coding schemes can be selected: 8 bit 8 kHz PCM coding (64 kbit/s), 8 bit 16 kHz PCM coding (128 kbit/s), and 16 bit 16 kHz linear coding (256 kbit/s). Speakers are mounted at the ceiling to reproduce the audio stream from the remote site.

2.2. *Platform*

The aim of the electronic classroom system is to be an open system. Therefore, standardized internet protocols have been used as far as possible (see figure 3). There are four streams, which are using IPv4 as network protocol: management, audio, video, and whiteboard stream.

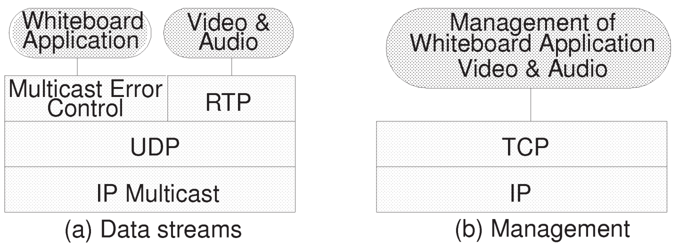


Figure 3. Protocol stacks used for audio, video, and whiteboard.

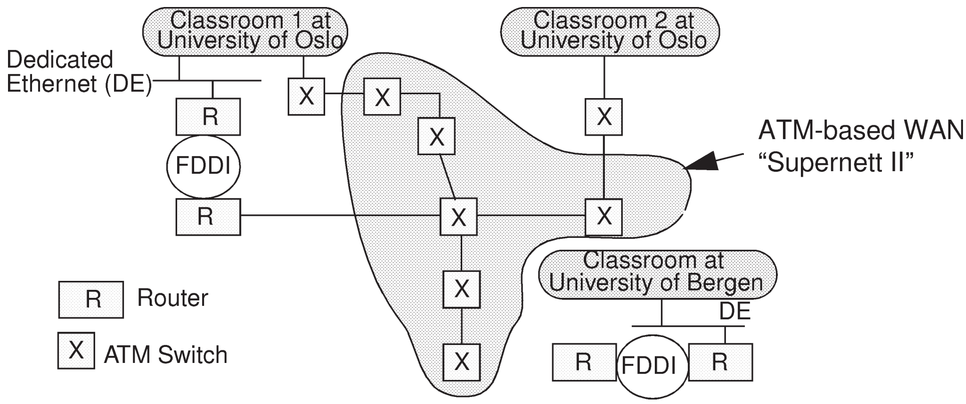


Figure 4. Network topology.

The management part of the classroom, e.g., setting-up a session, is performed in a point-to-point manner and utilizes the reliable TCP protocol. The data exchange (audio, video, and whiteboard stream) during a lecture requires multicast capable protocols, because more than two classrooms can be interconnected. Therefore, UDP is used on top of IP multicast. The audio and video streams have stringent timing requirements, and audio and video packets are time-stamped with the RTP protocol. For both streams, software modules are used in the application to adapt the streams from the codecs to the RTP protocol, i.e., fill a certain number of samples or parts of video frames into a protocol data unit (PDU). In contrast to audio and video, which tolerate errors, the whiteboard application cannot tolerate errors and is therefore placed on top of a proprietary multicast error control protocol (based on retransmissions) on top of UDP.

The network topology between the two classrooms at the University at Oslo, i.e., classroom 1 at USIT and classroom 2 at UniK, and the University of Bergen is illustrated in figure 4. Main part of this network is the Norwegian academic ATM-based network, called "Supernett II". Supernet II consists of 34 Mbit/s and 155 Mbit/s switches and uses only permanent virtual connections. The classrooms are connected either via a local ATM switch (ForeRunner 200) or via dedicated ethernet, routers and a FDDI ring to Supernett II. Addressing and routing of traffic on the IP layer is mainly performed from the workstations in the back rooms and the routers that are directly attached to Supernett II. As a backup solution, six ISDN lines can be used to interconnect two classrooms. The distance between both sites at the University of Oslo is approximately 30 km and the distance from Oslo to Bergen is approximately 600 km.

2.3. Comparison with related systems

In this section, we briefly review some systems that are similar to the electronic classroom and compare the different approaches. Video conferencing tools represent important building blocks of IDL systems, but these tools alone are not sufficient for the purpose of teleteaching [7]. Therefore, we concentrate our comparison on the following systems that additionally use an application to share teaching aids: Interactive Remote Instruction (IRI), Multimedia teleteaching (MMTT), Multimedia Whiteboard (MMwb), Telepoly, and Teleteaching. Table 2 summarizes the features of these systems and compares them with the electronic classroom, which is denoted Munin in table 2.

The IRI system [13] from the Old Dominion University provides a virtual classroom for geographically dispersed students. Students and teacher are sitting in front of workstations that are connected to an intranet with controlled resources (switched 10 Mbit/s ethernet and ATM). Video and audio information is sent from the teacher or current speaker to all students. Audio is “hands-free”, i.e., no buttons must be pressed to initiate or discontinue a conversation. An X Windows tool-sharing engine is used to share standard applications and IRI tools. The floor is controlled from a so-called *tool controller*, which is typically the teacher. TCP is used for session management and UDP/IP multicast to distribute video, audio, and application data. The system has been used in the fall terms 1995 and 1996 for one regular course.

The MMTT project [10] at the University of Erlangen-Nürnberg is concerned with three different types of learning environments: lecture theaters for several hundred learners, seminar rooms for groups up to 30 students, and teleteaching workstations. Lecture theaters and seminar rooms are equipped with cameras, microphones, speakers, beamers for large-scale displays, and teleteaching user terminals. A teleteaching user terminal is placed in the front of a seminar room or lecture theatre and is the most important part of the teachers workspace. The teacher can write on paper that lies under a document camera. A control monitor allows to easily control the size of the writing. Furthermore, the teleteaching user terminal provides a multimedia computer with a touch screen that allows the teacher to write or draw in an electronic document. Data from the document camera as well as from the multimedia computer are distributed to connected rooms and teleteaching workstations. Control centers are used to coordinate audio, video, and application, but it is still open whether all floor control tasks can be automated. Since 1995, two to three lectures use this teleteaching system.

Zheng et al. describe in [21] a Multimedia Whiteboard (MMwb) that is based on a commercial video conferencing engine. MMwb brings recorded audio and video to the virtual conference room and allows a synchronized movie to be played back and interacted on participants workstations simultaneously. Each conference member can play, stop, rewind or otherwise control a motion-JPEG movie with text captions. The transmission of the motion-JPEG movie with 20 frames per second (fps) requires a bandwidth of about 4 Mbit/s. The live video bandwidth with 1 fps requires 64 kbit/s bandwidth. Each MMwb client consumes approximately 50% of the CPU time of a Sun SparcStation 20.

In the Telepoly project [19], two lecture halls (one at ETH Zurich and one at EPFL Lausanne) are equipped with audio/video peripherals, a workstation and a document camera, and connected via an ATM network. These lecture halls are used since 1996 to transmit seminars and lectures. The workstation is used to exchange electronic teaching aids, which are based on standard applications like PowerPoint. The exchange is achieved through X Windows application sharing running on top of

Table 2
Comparison of synchronous IDL systems.

	IRI	MMTT	Munin	MMwb	Telepoly	Teleteching
Facility	Decentralized, per student a PC	Lecture theater, seminar room, work space	Classroom	Decentralized, per participant a PC	Large lecture hall	Lecture theater, seminar rooms, PC
Application	X windows tool-sharing engine to share X windows applications	Shared slides application and vic	Electronic white-board application	MMwb	Application sharing tool and standard applications	Digital lecture board (dld) and Mbone tools
Input	Microphones, camera, and keyboard	Microphones, camera, keyboard and document camera	Microphones, camera, keyboard, scanner, and light-pen	Microphones, camera, and keyboard	Microphones, camera, keyboard, and document camera	Microphones, camera, and keyboard
Network	UDP/IP multicast over intranet with controlled resources	TCP/UDP/IP over fast ethernet and ATM	TCP/UDP/IP multicast over ATM and Ethernet/FDDI	UDP/IP multicast over ATM	TCP/IP and native ATM	SMP and IP multicast over dedicated ethernet, FDDI, and ATM
Floor control	Tool controller, normally teacher	Still open whether system enforced or not	No system enforced control	No system enforced control	No system enforced control	Teacher uses dld to perform floor control
Experiences	Two courses (fall 1995, fall 1996)	Regular lectures since 1995	Regular lectures since 1993	Not reported	Since 1996 seminars and a course	First course summer 1996

the TCP/IP protocol stack. The screen information from the workstation is used for large scale projection with a beamer. The video stream from the remote classroom is displayed on two monitors, one for the teacher and one for the students. For transmission, video is compressed with motion-JPEG and directly assembled into ATM Adaptation Layer 5 protocol data units.

Since summer 1996, the TeleTeaching project [5,7] uses video conferencing tools to transmit courses and seminars between the University of Mannheim and the University of Heidelberg. A digital lecture board (dlb) has been developed to better satisfy the needs of teleteaching. On the application level, the dlb integrates a postscript module, a telepointer module, remote access to a multimedia database, a floor control and a session control module. Furthermore, dlb makes use of the Mbone tools vic and vat. Access to remote services is performed via the scalable multicast protocol (SMP) or IP-multicast directly, which in turn use an ATM network. Three instructional settings are supported in TeleTeaching: remote lecture room, remote interactive seminars, and interactive home learning.

All these systems use similar approaches, but the electronic classroom (Munin) is the system that creates a virtual classroom which resembles most a traditional classroom. There are two reasons for this: first, the usage of a video switch that is controlled by the loudest audio signal and not by system enforced floor control, and second, the usage of a light-pen as input device for the electronic whiteboard. These concepts have their limitations for larger lecture halls, e.g., the more students in a classroom the more noise that might interfere with the video switch. However, for courses with 20 students per room the system is most natural and achieves a high degree of interactivity, which is a primary goal of distance learning systems [13]. Furthermore, todays electronic classroom system is based on the experience of using the system for regular courses every semester since fall term 1993, and its incremental improvements over this time.

3. Transport and application level QoS

The Internet protocols that are used to transport the classroom data offer only best-effort QoS. We have instrumented these protocols and the application, and logged all important events at transport and application level. We used the SIMPLE tools (Source related and Integrated Multiprocessor and -computer Performance evaluation, modeLing and visualization Environment) [4] to analyze the large amount of resulting data (we logged roughly 520 events per second). The logging activities consumed less than 0.2% of CPU time. That means, their influence on the observed QoS parameters throughput, delay, and delay jitter is not significant [20]. In addition to these event based measurements, we recorded with an extra video camera the activities in the electronic classrooms, to relate the measurement results to the activities.

In the following sections, we present measurement results for the QoS parameters throughput, delay, and delay jitter for representative time slices of lectures. During these lectures, the teacher is the most active participant. This allows us to easily differentiate traffic patterns generated from the classroom with teacher, also called local classroom, and the remote classroom. For situations with high interactivity as they occur, for example, in distributed exercises, the traffic patterns from both classrooms show the same properties as the results from the local classroom.

3.1. Throughput

The results of our throughput measurements are performed during lectures between USIT and UniK. The distance of approximately 30 km between these sites is not of major importance for the throughput figures, because the network is no bottleneck and the amount of generated traffic directly depends on the applied coding schemes and activities in the classrooms.

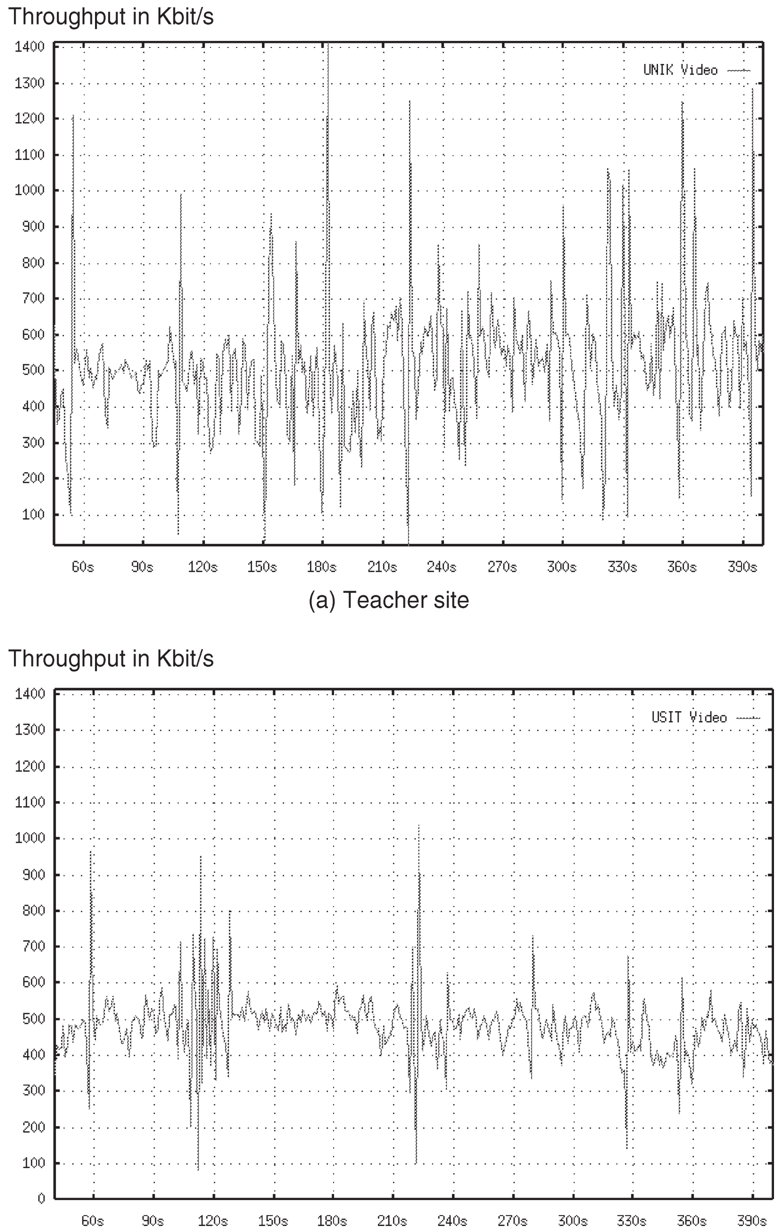
The observed traffic patterns at the UDP service interface of the audio stream do not surprise, because the audio codec generates constant bit rates according to sampling rate and sample length. Thus, 16 bit 16 kHz linear coding generates a bit stream of 256 kbit/s in average with small periodic variations that are caused by the software module that collects multiple samples for one protocol data unit (PDU).

The throughput of the video stream at the UDP service interface depends on the activities in the classrooms, because H.261 is a variable bit rate compression schema. In the classroom with the teacher, high variations occur that range from 13 kbit/s up to 1950 kbit/s. Figure 5(a) presents the throughput measurements of a video stream over a period of approximately 350 s (i.e., from 50 s to 400 s; 0 identifies the begin of the lecture).

In contrast to this, the throughput at the classroom without teacher is much lower, because there are less activities in the classroom, i.e., students sit quietly and follow the lecture. Thus, the average bit rate is approximately 522 kbit/s with less variation (see figure 5(b)). However, there are several unexpected large peaks in figure 5(b). These peaks are caused from shifts between transparencies on the whiteboard which are reflected from a glass door at the opposite side of the classroom and then captured from the student camera. The comparison of both scenarios shows the influence of user behavior, traffic patterns, and the corresponding resource requirements for a H.261 compressed video stream.

Obviously, the traffic of the whiteboard data between application and multicast error control is directly depending on user activities. The teacher uses either the light-pen to fetch and display transparencies, or to underline certain areas, to set a marker, and to write or draw on the transparencies. Figure 6 illustrates the whiteboard related patterns of incoming and outgoing traffic at the teacher site. The large peaks in figure 6(a) are generated by downloading transparencies from the application server and range between 30 kbit/s up to 125 kbit/s. Transparencies with a lot of graphics are in average 200 kbyte large.

The smaller peaks in figure 6(b) are generally below 10 kbit/s that are generated by light-pen activities, like editing, marking, etc., and are sent to the application server.



(a) Teacher site

(b) Remote site

Figure 5. Throughput of video streams between USIT and UniK.

At the remote site, transparencies and annotations from the teacher are displayed on the whiteboard. Consequently, the incoming whiteboard data traffic pattern at the remote site is a combination of incoming and outgoing data stream from the teacher site (see figure 7).

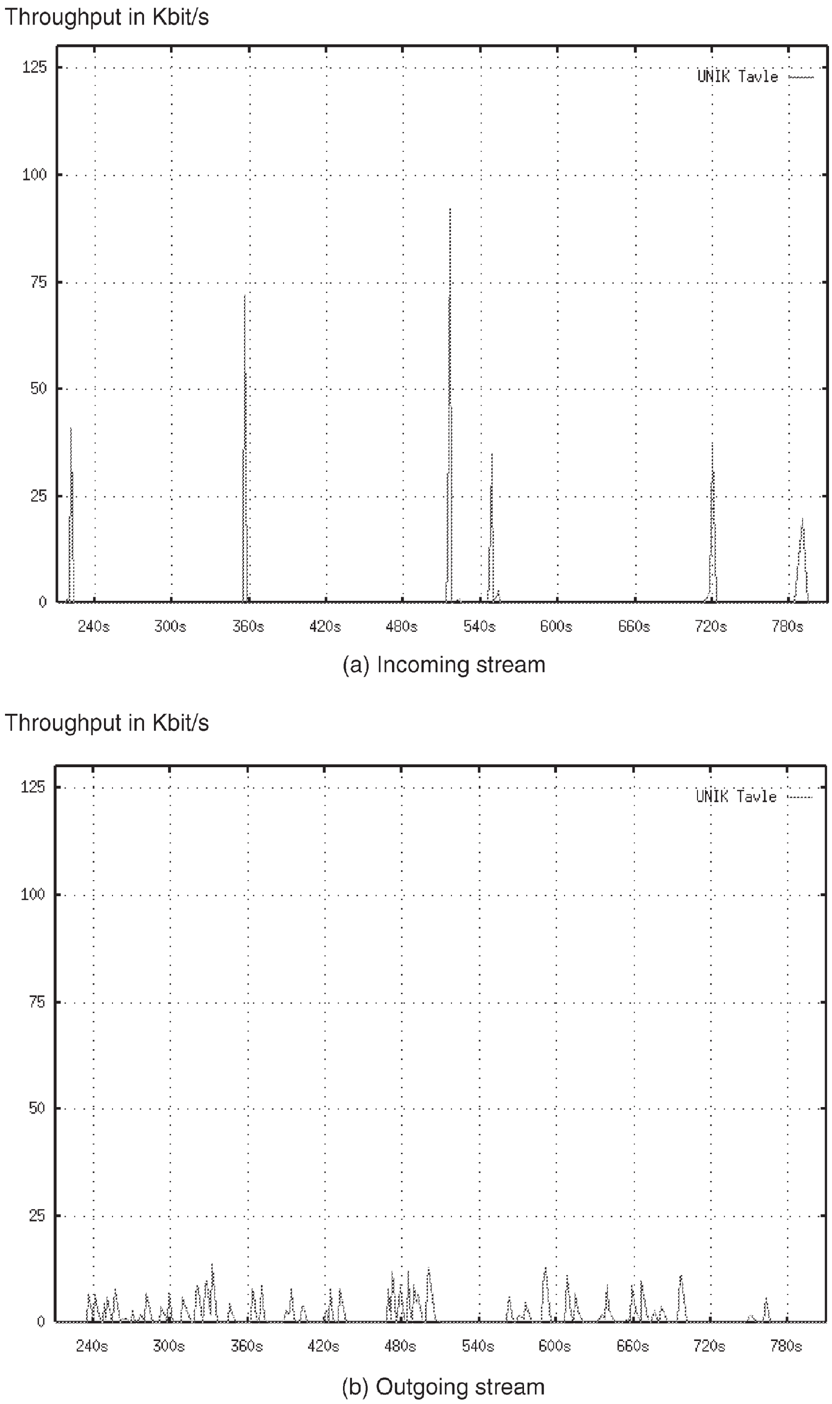


Figure 6. Throughput of whiteboard data streams at teacher site.

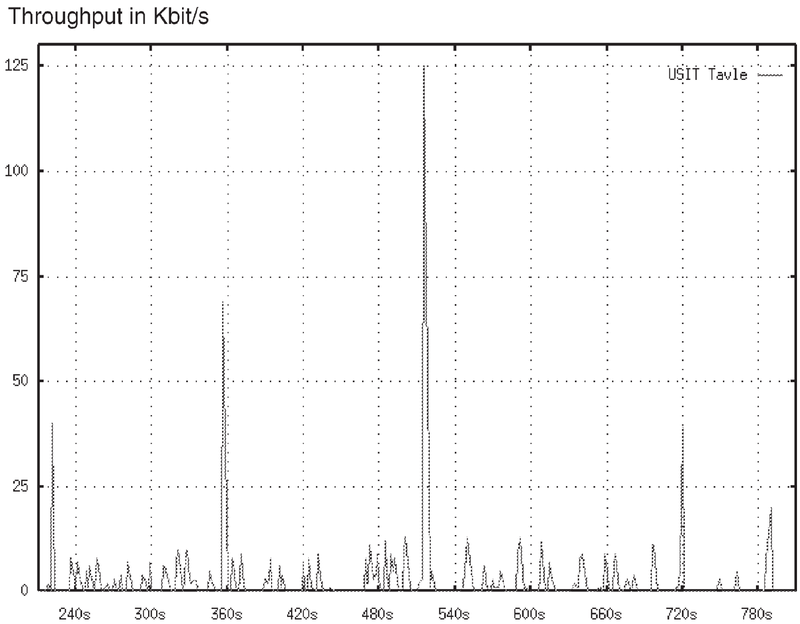


Figure 7. Throughput of incoming whiteboard data stream at remote site.

3.2. *Delay and delay jitter*

Due to problems with the synchronization of clocks the results of the delay measurements (between two UDP service users) exhibit high variations, but the average delay is 1.5–4.5 ms between both classrooms at the University of Oslo and 10.5–16.7 ms between USIT and the classroom at the University of Bergen.

The end-system internal delay from UDP to the application for audio depends on how many samples are stored in one PDU. The internal delay of an audio stream in which samples of 20 ms are stored in one PDU is in average 45 ms (min.: 30 ms, max.: 68 ms). For streams with PDUs that hold samples of 40 ms, the average internal delay is 117 ms (min.: 87 ms, max.: 168 ms). For both configurations, the resulting figures show a nearly periodic curve (see figure 8).

In contrast, the video codec generates packets of varying length which results in higher variation and non-periodic behavior of computation times, i.e., internal delay. Figure 9 illustrates the corresponding curve with an average value of 50 ms.

Delay jitter at the UDP service interface is minimized in the adaptation modules of the application. We have measured between USIT and UniK maximum delay variations at the UDP service interface of 424 ms between subsequent packets, but the average value is below 20 ms (between USIT and UniK as well as between USIT and University of Bergen). Generally, we have experienced a lower delay jitter in pure ATM networks, even if distances are much longer. Figure 10 gives an exemplary figure for a certain time window of the delay jitter in a video stream between USIT and University of Bergen. Furthermore, we observed that the delay jitter in the audio

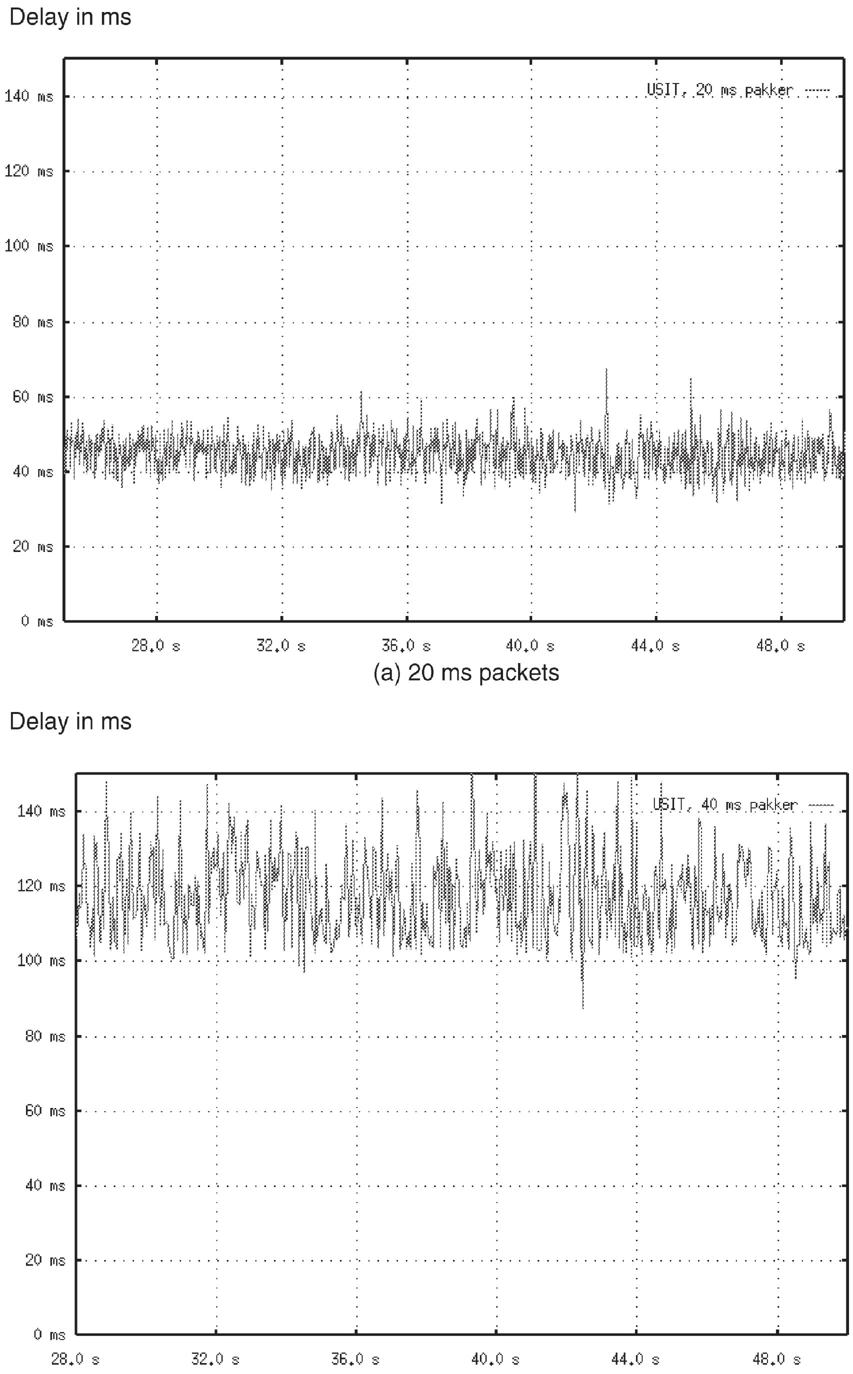


Figure 8. End-system internal audio delay for different packet sizes.

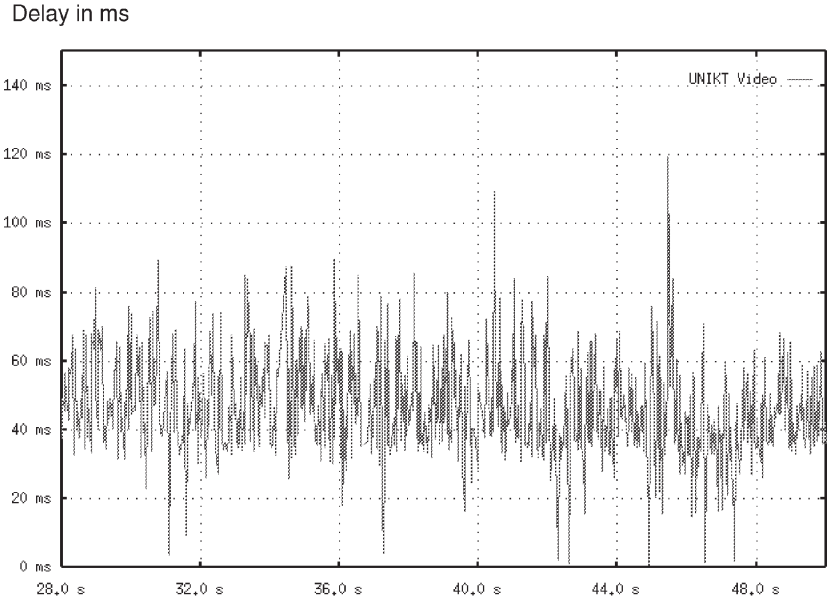


Figure 9. End-system internal delay of video stream.

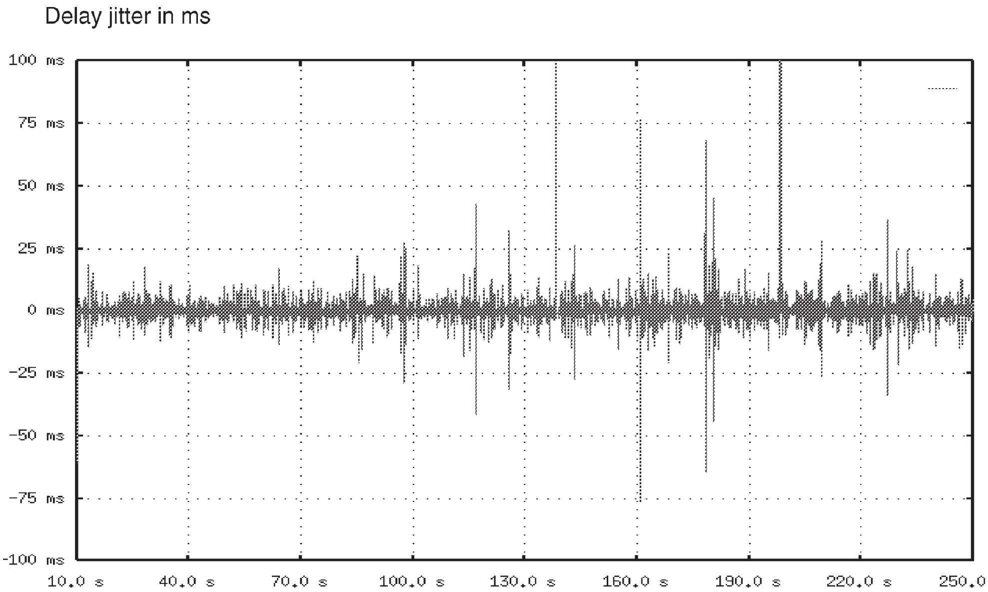


Figure 10. Delay jitter in video stream between USIT and the University of Bergen.

stream is generally much lower than in the video stream, because of the varying packet size in the video stream.

4. User level QoS

At the user level, subjective criteria have to be used to evaluate perceptional QoS in the electronic classroom. In the following subsections, we present an analysis of the relationship between packet loss and subjective quality, describe our personal experiences made by teaching graduate courses in the electronic classroom, and summarize the results of a student project [6] that analyzes the student-teacher relationship in the electronic classroom.

4.1. Packet loss and subjective quality

As a part of the course *Protocols for Multimedia Communication*, we have analyzed relationships between packet loss in audio and video streams and subjective quality. An artificial packet loss rate from 5% to 50% has been introduced and the students have rated the subjective quality with three levels: good, acceptable, and not acceptable. Figure 11 summarizes the results from these experiments with 15 students. Obviously, this number is too low to reach statistical confidence, but it is sufficient to get a good hint for the relationship between subjective quality and packet loss.

For both streams, a relative high packet loss rate is accepted, i.e., 5–10% and most of the students still judge it as good quality. Even with 20% packet loss the majority regards the quality as acceptable. On a first glance, it is surprising that the students react more critical against packet loss in the video stream than packet loss in the audio stream. However, the video stream is generated by a lossy compression scheme. Thus, no or only minimal redundant information is in the video stream, and therefore, loss of a video packet is more disastrous.

4.2. Personal experiences as teacher

Both authors have taught several graduate level courses in computer science in the electronic classroom. For all lectures, the electronic classrooms at UniK and USIT have been connected. Teachers and students are familiar with potential problems of such a complex system and quite tolerant.

Teachers that use the electronic classroom for the first time get an introduction before the course starts. The preparation of the course material, e.g., transparencies, has to be done in advance. Blank transparencies can be created on the fly during a lecture with the whiteboard application to write and draw on it. Furthermore, a scanner can be used during the lecture to present new material on the whiteboard. Nevertheless, it has been shown that a proper stock of prepared transparencies is of advantage. Teachers can use their favourite program to edit their transparencies, e.g., PowerPoint, MSWord, FrameMaker, etc. and convert the resulting document into HTML format; or they write directly in HTML. The whiteboard displays transparencies approximately in the same size than overhead projectors. Thus, no special guidelines for transparency

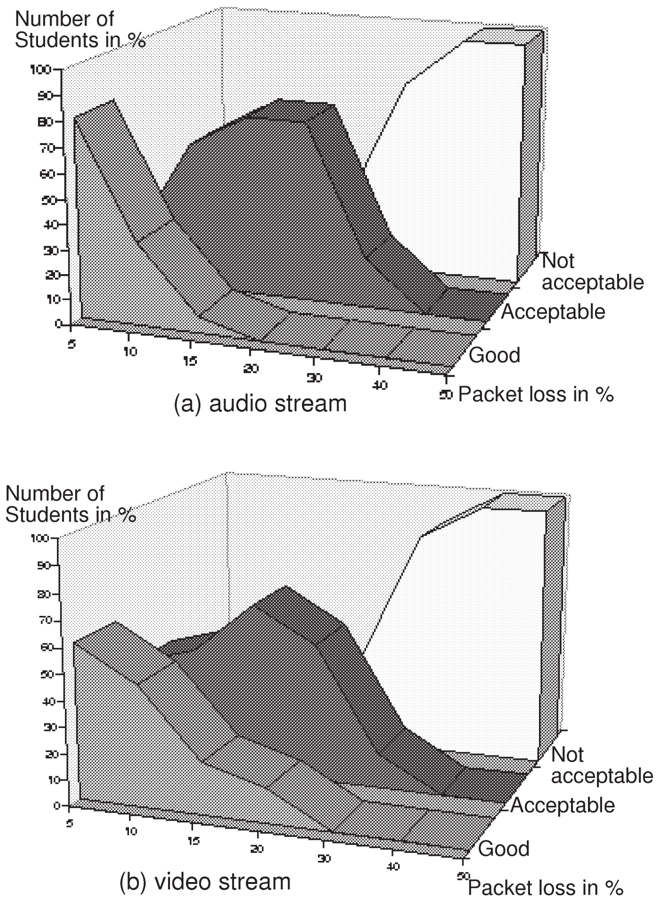


Figure 11. Relationship between packet loss and subjective quality.

design are necessary (as reported in [19]). The preparation of transparencies in HTML is worthwhile, because the material is also accessible after the lecture via WWW.

Another aspect teachers have to take care of, is the contact to students in the remote classroom. The relationship to students in the local classroom is the same than in traditional classrooms. However, for students in the remote classroom the teacher has to control the monitor how good she/he can be seen. Furthermore, gestures of the teacher, e.g., pointing at a particular point on a transparency, cannot be seen very good via the video. Therefore, the teacher has to use the light-pen to highlight the area she/he is pointing at. Furthermore, it is not possible to point at a student in a remote classroom, instead, the teacher has to know the names of the students or to identify the student by another characteristic, e.g., colour of the clothes, etc.

Our experience shows that it is advantageous to introduce the students during the first lecture in the electronic classroom. In particular, the video switch that selects a camera for the outgoing video stream according to the location with the loudest audio signal requires discipline from students and teacher. Only one person at a time should speak, otherwise the system switches permanently between both sources. This implicit floor control requires an appropriate social protocol. Each person has to wait until the former has finished speaking. This is complicated by the delay between the classrooms. The best way to enable students to adapt to this, is to practise discussions during the first lecture.

4.3. Student-teacher relationship

In this section, we briefly summarize the results of a student project that analyzed the relationship between teacher and students in a remote classroom [6]. Interviews with students and teachers led to answers for the following three questions:

- *How experienced students the contact with the teacher?* Generally, students felt that the contact with the teacher was not as good in the electronic classroom as in a traditional classroom. The style of teaching, i.e., motivating students for more interactivity, and whether students have already personally met the teacher positively influences this contact. On the other hand, technical problems during the lecture, e.g., broken network connections, negatively influence this contact.
- *How experienced teachers the contact with students?* All teachers experienced that the contact to students in the remote classroom is not as good as to students in the local classroom, because it is not easy to interpret the facial expressions of students on the monitor. The teachers emphasized on the positive influence of personal contact with students and that technical problems have a negative influence on the contact.
- *How can the contact be improved?* High reliability of the classroom system, lectures with a lot of interactivity, and a second teacher or assistant in the remote classroom are the best measures to improve the student–teacher relationship in the electronic classroom.

One important conclusion from these interviews is, that availability and reliability of the system (e.g., mean time between failure and the mean time to repair) are very important for the overall quality of the electronic classroom. One ongoing research activity is to increase in some sense the availability of lectures by using a MMDBS for asynchronous IDL.

5. MMDBS for asynchronous IDL

In general, MMDBSs are necessary for sophisticated data management in distributed multimedia systems [3], like asynchronous IDL. MMDBSs have to be capable to handle efficiently time-dependent and time-independent data, and to support QoS [8,17]. Currently, there are two projects at UniK that work with QoS issues in MMDBSs: OMODIS (Object-Oriented Modeling and Database Support in Distributed Multimedia Systems) and DEDICATION (Database Support for Distance Education). Main emphasis in OMODIS is on the conceptual aspects and the integration of MMDBSs offering QoS support into distributed multimedia systems [9]. In the DEDICATION project, we are aiming at MMDBS support for asynchronous IDL by exploiting the results achieved in OMODIS.

We face in DEDICATION the problem to support the concurrent playout of lectures that have been given in the electronic classroom and that are stored in a MMDBS. The goal is to develop a system that allows students to retrieve and playback lectures of the current term. Students should be able to select particular parts and particular media streams of interest, like video, audio, transparencies, or annotations for playout. The system should support for each media stream the QoS requirements of the student.

All transparencies and scanned images that are used in lectures, the interactions with the whiteboard in the classrooms, as well as video and audio streams from the different classrooms are separately stored in the MMDBS. This separate modeling and storing of different multimedia data allows to retrieve the data independent of each other, e.g., reading the transparencies of the first hour of a certain lecture. Furthermore, the entire lecture, i.e., all multimedia data, can be reproduced: audio and video streams from all classrooms are continuously retrieved and their presentation to the user is synchronized with retrieval and presentation of transparencies and interactions with the whiteboard.

Queries are defined by the user (i.e., student or teacher) to communicate to the system which data elements have to be retrieved and presented. The queries contain QoS specifications for the different multimedia data types and data elements. QoS specifications are used to reserve the necessary resources and to appropriately schedule the MMDBS tasks. Users that accept a lower QoS enable the system to save rare resources. Following, we describe three typical scenarios for reduced QoS and outline their consequences for the MMDBS [17,18]:

- *Reduced video quality*: can be achieved with mechanisms that are similar to those that are used for media scaling, e.g., [14]: drop frames or drop enhancement layers. Thus, less data has to be read from disk and transported to the user and more resources are available for other tasks.
- *Reduced reliability constraints*: if a student tolerates errors in transparencies, because the student has already a copy and wants only to recapitulate the lecture. Errors in I/O devices, e.g., caused by bad blocks on a disk or damaged disks in a disk array can be ignored. Thus, expensive recovery operations are not necessary and resources are saved for other tasks.
- *Relaxed synchronization requirements*: a student wants to get video, audio, and transparencies from a lecture. However, synchronization between the continuous media streams and transparencies is not important for the student. Synchronization implies that different tasks have to wait for each other and scheduling gets more complex. Relaxed synchronization reduces these constraints and decreases the timely tasks spend in the system and occupy resources, e.g., buffer space.

The examples show, that flexible data modeling, query processing, storage management, and transaction management controlled by QoS specifications in the MMDBS will lead to optimized resource utilization. Thus, user needs are better supported, services will get cheaper, and more users can be supported simultaneously with the same amount of resources.

Conventionally, any data loss is prohibited in database systems (transaction paradigm). In MMDBSs, however, losing a video frame or even dropping it explicitly will still provide a "correct" answer for a query only the quality is decreased. In MMDBSs we often have the trade-off between the quality of data, i.e., amount of data, and the timeliness of data, i.e., data has to be delivered before a certain deadline. Additionally, buffer capacity, network, and I/O bandwidth play a crucial role in this context [15]. For instance, we can ask for a video clip in highest quality, but might not have enough resources in order to deliver it in real-time, the consequences will be some kind of "hacked" or slow-motion presentation to the user/application. In MMDBSs, the user/application should decide what is more important, e.g., the resolution or the correct timing of the video clip.

6. Conclusions

The main goal of the distributed electronic classroom is to make the teaching situation in a distributed classroom as similar as possible to an ordinary classroom. Teacher and students see each other, can talk to each other and may use the whiteboard to write, draw, and present prepared material. Since 1993, the two electronic classrooms at the University of Oslo – and later on further electronic classrooms – have been used for synchronous IDL.

In this paper, we have presented analysis results of QoS aspects in the electronic classroom. These QoS aspects are classified into system related QoS issues, i.e., at transport and application level, and user related QoS aspects. The measurement results of transport and application level QoS have been used as input for several simulation studies, e.g., for a redesign of the flexible communication subsystem Da CaPo (Dynamic Configuration of Protocols) [16] on the realtime micro-kernel operating system Chorus, and MMDBS support studies. One important lesson we have learned from these measurements is, that only the audio stream represents a periodic task [11]. Neither H.261 compressed video traffic nor the whiteboard traffic show periodic behavior. Thus, more advanced models are necessary to schedule multimedia tasks with guaranteed QoS.

The most important lesson learned from the analysis of user level QoS is that users accept a relatively high error rate in video and audio streams. If this rate is below 5% to 10%, and the end-to-end delay is below 125 ms, than the availability and reliability of the system, e.g., mean time between failure and the mean time to repair, are much more important for the perceived quality.

In general, we regard the electronic classroom as a useful system with acceptable QoS for synchronous IDL. One important indicator for an acceptable QoS is the fact, that students prefer to follow a lecture from a remote classroom instead of travelling roughly 45 min to the other classroom with the teacher (both classrooms at the University of Oslo). Based on our experiences, we believe that synchronous IDL is a valuable complementary to traditional classroom teaching, especially if courses are taught by experts, i.e., there are no other persons that could teach the course, and travelling to the students is too expensive (with respect to time and/or money).

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