Storage and Network Requirements of a Low-Cost Computer-Based Virtual Classroom

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In this paper we investigate the network and storage requirements of an virtual classroom. The virtual classroom replaces traditional class methodologies by using the computer as the sole instrument for all class activity. The instructor and the students each have a networked workstation in an X cluster that provides for the creation, modification, and distribution of presentations, note-taking, capturing of presentation material, out-of-class reviewing of presentation material, and viewing of supplemental materials provided by the instructor (including selected readings, exams, and assignments).

We have designed and implemented a virtual classroom as a means of enhancing the teaching/learning process. The creation of this virtual classroom was accomplished by using only existing computing resources: SUN workstations, X tools, an Ethernet network, and UNIX operating system support. Network statistics were collected to determine how well existing networks can be utilized within this environment. We also observed the performance of the system in a realistic setting by using it to teach an Office Information Systems class at North Dakota State University.

1. Introduction

We have designed and implemented a low-cost virtual classroom. The virtual classroom replaces traditional class methodologies by using the computer as the sole instrument for all class activity. The instructor and the students each have a networked workstation in an X cluster that provides for the creation, modification, and distribution of presentations, note-taking, capturing of presented material, out-of-class reviewing of presentation material, and viewing of supplemental materials provided by the instructor (including selected readings, exams, and assignments). It is generally agreed that such aids improve the effectiveness of the instruction and achieve better learning results [5].

Previous work in this area [3, 4, 7, 8, 9] has been based on one basic underlying principle: *a virtual classroom can be realized by utilizing special-purpose audio-visual equipment to carry out of the classroom presentations.* This results in an effective, but high-cost, classroom. Our work differs from previous work in that our system is designed to be used in a generic workstation lab requiring no specialized equipment or support. This is accomplished by using existing (and widely available) computing resources: SUN workstations, X tools, an Ethernet network, and UNIX operating system support. Since only existing resources are used, our system results in a low-cost virtual classroom, portable to most workstation labs running X Windows and interconnected with a network. It should be noted that we do bring additional equipment into the generic workstation lab in order to provide an instructor image on each workstation screen during presentations. The equipment consists of a video camera, a PC on a cart, and an Ethernet connection to the file system. This equipment was already available to us.

Several delivery methods for education over a network are possible (each with differing costs and capabilities):

1. The use of simple correspondence (e.g., electronic mail),
2. the use of an information retrieval system (e.g., gopher or xmosaic),

3. the use of computer-based presentation systems with slow-scan video and 2-way audio capabilities, and

4. expensive interactive television systems.

In this paper we determine the network and storage requirements for an virtual classroom system based on a set of networked X workstations that have been equipped with 2-way audio and slow-scan video capabilities (option 3 above). The objective for this work was to investigate the use of widely available (and cost effective) graphical workstations running X window applications with the added support of audio and slow-scan video to enhance the instruction process and thereby improve the productivity and effectiveness of learning. We wanted to look at the limitations imposed on an virtual classroom environment by network bandwidth and storage. These limitations can be important in using a network of workstations in a classroom. When limitations exist, they may limit or completely inhibit various uses of the technology in the classroom. In addition, these limits are very important in evaluating the suitability of using this technology in support of remote education.

The remainder of this paper is organized as follows. In section 2, we outline the features of the virtual classroom. Section 3 discusses the computing environment and section 4 describes the design and implementation of the virtual classroom. We also review the software components (X applications) used to realize the system. In section 5, we determine the storage requirements of the virtual classroom and provide results of our analysis of the network behavior during actual system use. Section 6 provides conclusions to the paper.

2. Features of the Virtual Classroom

There are a wide range of features available for use in the virtual classroom. The most important feature is the distribution of presentation material to the individual workstations. In addition, a slow-scan image of the instructor, updated every eight seconds, is displayed on all workstation screens to provide a *human* element to the presentation. The slow-scan image of the instructor is included to provide a focal point on the display screen for students taking the course locally and for students taking the course remotely.

Other features vary with the needs and desires of the users. The following is a list of the features currently used in our virtual classroom. Other features can easily be added by using other X tools.

- presentation creation and distribution
- windowed display of presentation material
- windowed display of the instructor image
- online note-taking during the presentation
- student ability to display presentation material
- shared whiteboard space for creating material during presentation
- review of the presentation material offline after class
- personal communication between participants
- capturing all or part of presentation material
- distribution of assignments online
- availability of supplemental material and selected readings online
- student class evaluations online

The quality of the presentation can easily be changed by simply using different X tools. For example, displaying the presentation material can be accomplished by several different methods (**xv, xloadimage**, etc), each with differing characteristics and degrees of success. Thus, our system is portable and can easily support new capabilities (X tools) as they become available.

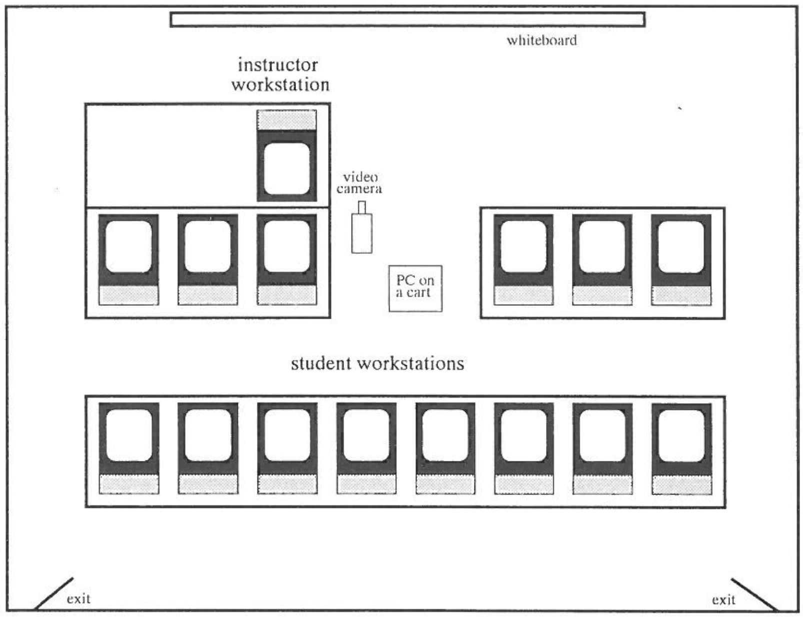

Fig. 1. X Cluster Configuration

3. Environment

3.1. Hardware

The classroom consists of fifteen SUN SPARC CLASSIC workstations in the configuration shown in figure 1. In addition, a video camera connected to a PC on a cart was used to provide the instructor image to the picture capture machine which then sent the image to each of the workstations in the classroom. The picture capture machine was a DEC 500/133 workstation with 16 MB of memory and 800 MB of secondary storage with an 8-bit color monitor. The instructor and student workstations each had 8 MB of main memory, a 400 MB disk, and an 8-bit color monitor. The file server was a SUN SPARC CLASSIC workstation with 32 MB of main memory, a 1.2 GB disk drive and an 8-bit color monitor.

3.2. X Support

X was developed at MIT as a windowing environment for UNIX workstations. The use of X for the virtual classroom system was selected because of its portability, flexibility, and the wide variety of quality software packages available (via ftp). X is intended to solve intercommunication problems between different platforms and allow X applications to move to/from workstations of different vendors. X requires no specialized hardware, so it can be run on most systems running UNIX. Because of the popularity of X, much software can be acquired at no cost.

4. Design and Implementation

The virtual classroom was designed and implemented using only existing available X tools and UNIX operating system utilities. This allows for flexibility in adding additional tools to the system. The instructor and each student occupy a workstation in the X cluster. If necessary, students can share workstations.

4.1. Information Flow

The flow of information in the virtual classroom is shown in figure 2. This flow can be divided into the following parts:

- presentation preparation
- presentation delivery
- note-taking and capture of presentation material

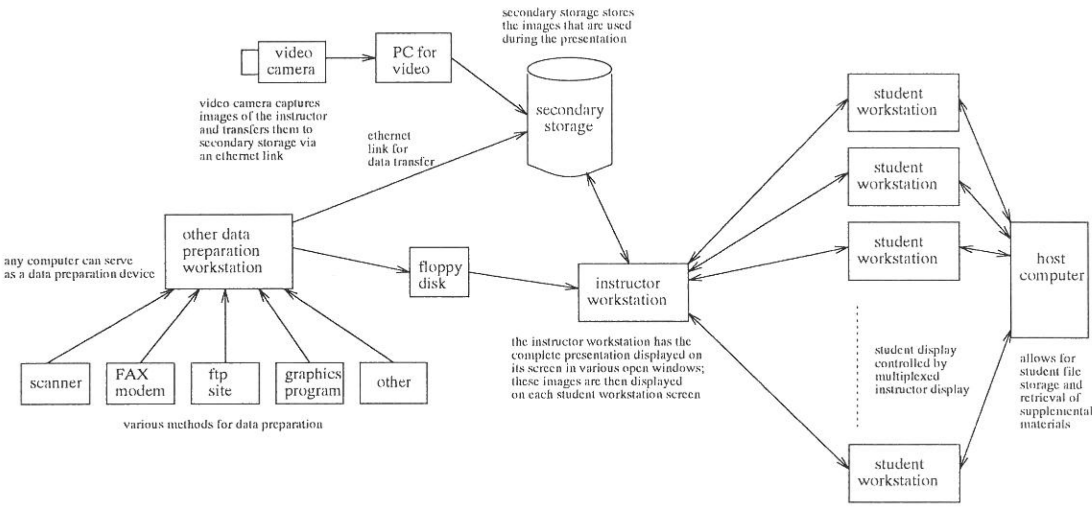

Fig. 2. Dataflow in the Virtual Classroom

- out-of-class retrieval of class materials
- communication

4.1.1. Presentation Preparation

There are many different ways that data can be collected and prepared for use during presentations. The only requirement is that the data be in a file format recognizable by the available X tools used in the presentation. Common file formats include: GIF, JPEG, and POSTSCRIPT, which can be displayed by a wide variety of X display programs. Example methods of data preparation include scanning, FAX, graphics programs, text editors, and downloaded images from ftp sites. Once the data is prepared, it is stored on secondary storage for use during the presentation.

4.1.2. Presentation Delivery

Presentation delivery requires that the same image be displayed on all workstation screens. This can be accomplished in two ways. The simplest way is for each student to individually run an X display program on their workstation and display images stored in a common directory according to instructor requests. The second way is to use a collaborative software tool. Using this method, the images selected by the instructor (or even a student), are multiplexed out to each workstation screen and automatically displayed. This method offers the advantage of convenience for the students since material is presented *to* the students, rather then accessed *by* the students. Another important advantage of using collaborative software is the ability to create material during the presentation. Paint programs or other graphic software can be used much the same way as a chalkboard/markerboard is used in a traditional presentation.

Another image shared among all workstations is that of the instructor. Full-motion video cannot be supported in our virtual classroom because of the high bandwidth requirements. As a compromise, a still image of the instructor is captured and updated on all workstation screens approximately every eight seconds. We refer to this as a slow-scan image. To implement this, a video camera captures the instructor image. The image is then digitized and stored in a file. When the file becomes complete, each workstation, running a display program, will display the updated image.

4.1.3. Note-Taking and Capture of Presentation Material

During the presentation, students can create their own material. This includes note-taking and capturing all or part of the material being presented. To take notes, students use their favorite editor. To capture presentation material, a screen-grab utility is used.

4.1.4. Out-of-Class Retrieval of Class Materials

A wide variety of material can be made available to the students on secondary storage. This includes tests, assignments, selected readings, course syllabus, handouts, or any other supplemental material. These can be stored as read-only files in a directory accessible to the students and displayed using image display software.

While teaching the Office Information Systems class, the instructor found it useful to include MS-DOS application software on-line so that students could evaluate them. Students download these packages to a PC and run them. All of these packages must be either shareware or have an explicit license to copy.

4.1.5. Communication

UNIX utilities such as *mail* and *talk* can be used to provide a communication link between the instructor and the students, and between the students themselves. These can be used both during and after class. In addition, *mail* can be used to hand in completed tests and assignments. In our case, the instructor opted for paper tests in case of computer failure.

Because of the experimental nature of our virtual classroom, we had weekly evaluations distributed and collected via electronic mail to a special account. A "trusted individual" then striped off the mailing addresses and prepared a summary report[1].

4.2. User Interface

The user interface can vary widely depending on the situation and the X tools that have been selected for use. For example, if a student is out of class and reading a scanned journal article or some other image, the user interface may simply consist of the interface provided with the display program. Figure 3 shows an example view of a workstation screen during a presentation.

The windowed display includes the presentation area, slow-scan instructor image, and the note-taking area. The display program interface for selecting images to be displayed may or may not be present depending on the display program being used.

4.3. Software Tools

In addition to UNIX operating system support (which provides file storage, text editors, etc.) there are four main software components used in the design of the virtual classroom.

1. Collaborative Software - allows sharing of applications among several workstations. Examples include: **xtv**, **xmx**, and **Collage**.
2. Display Software - allows presentation material and the slow-scan image of the instructor to be displayed on the screens. Examples include: **xv**, **xloadimage**, **XLI**, and **Ghostview/Ghostscript**.
3. Utility Software - used to make presentations more effective. Examples include: **xfig** - graphic drawing utility, **import** - screen grabbing utility, **vote** - distributed group voting.
4. Video Capture Software - used to capture still images of the instructor from the video camera and save them as a file for

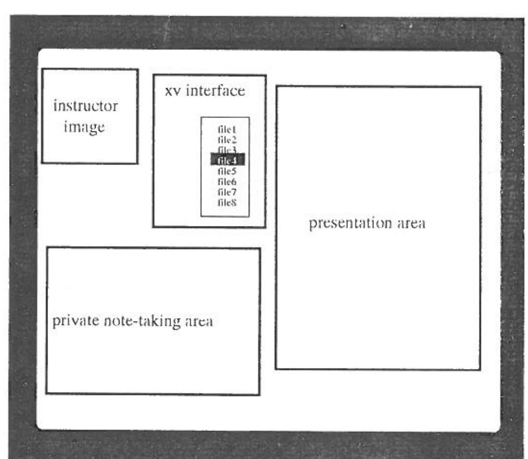

Fig. 3. Example View of Workstation Screen

[1] A report is currently being prepared that will summarize our findings in this area.

display. Example: **ComputerEyes/RT** from Digital Vision.

See [6], for a discussion of the software packages that have been investigated for suitability in our virtual classroom. In a recent survey article [2], a survey of X protocol multiplexors (i.e., collaborative software tools) was given. We also evaluated the suitability of these collaborative X tools for use in our virtual classroom.

5. Storage and Network Requirements

In order to understand the performance characteristics of a virtual classroom, we monitored the network and storage requirements of our system during the teaching of an Office Information Systems class at North Dakota State University. This analysis and measurement included personal observations and experimentation as well as the determination of the actual system usage via UNIX network monitoring tools.

5.1. Storage Requirements

The number of files and the amount of storage required for class material was as follows:

- scanned presentation material - 270 files, 4.5 megabytes
- eight scanned articles - 230 files, 7 megabytes
- slide presentation - 30 files, 1.6 megabytes
- MS-DOS applications - 80 files, 1.1 megabytes
- old tests, handouts, assignments, etc. - 25 files, 50 kilobytes

In total, there are approximately 635 files requiring about 14.3 megabytes of storage. In addition, supporting software (X applications) requires about 8 megabytes storage. We do not count this in the storage requirements for the virtual classroom (we assume they are available from system space).

5.2. Network Requirements

The network configuration consists of a segmented Ethernet network that interconnects 15 SUN SPARC CLASSIC workstations all co-located within a single classroom[2]. The system uses a segmented network so that all traffic is confined to the local segment and does not traverse the campus backbone network which is bridged to it. The network speed is 10 Mbps.

Network traffic consists of the slow-scan video image containing the instructor image, the presentation material, and any data traffic generated by students in the private note-taking area (e.g., traffic generated by the vi text editor). The average size of a single piece of presentation material (i.e., a digitized graphic and text image stored in a single file) was approximately 13,000 bytes. The material stored in the presentation area is transmitted from the file server and displayed on each of the 15 workstations every 60 seconds (on average). This is controlled by the instructor.

Every 8 seconds the instructors image is automatically captured and sent to the file server for storage. Then each of the 15 workstations (the instructor/presentation machine and the 14 student workstations), pull the instructors image (a file) from the file server to their local disks and display the captured image on their screens. That is, there are 15 separate Ethernet transmissions of the same image file. This is due to the fact that the xv display software does not take advantage of the multicast feature inherent in the Ethernet protocol and thus point-to-point connections are utilized. The average size of a single image of the instructor that was captured with a video camera and then displayed on all workstations was roughly 35,000 bytes.

Thus, we expect that the average network traffic sent to each workstation is[3]:

- 4375 bytes/sec for the instructor image
- 217 bytes/sec for the digitized image in the presentation area

[2] In our system, there is one master (instructor/presentation) workstation that can control the displaying of images on all other 14 (student) workstations.

[3] This does not take into account the student traffic generated in the private note-taking area.

Since the mean length of an Ethernet packet is typically around 122 bytes (of which 26 bytes is header information) [11], the system will send approximately 48 packets or 5856 bytes (46,848 bits) across the network each second to each of the 15 workstations, for a total bandwidth requirement of 702,720 bits/sec. Although the maximum bandwidth of an Ethernet network is 10 megabits/sec (Mbps), this capacity is never realized in actual systems. Under heavy load conditions, packet collisions cause the actual channel utilization to fall to around 80 to 90 percent of the ideal case [11]. We must also take into account overhead associated with the operating system and other supporting software. This software overhead typically reduces the usable end-to-end application bandwidth further.

We collected network statistics for a typical 90 minute classroom presentation on several different machines (enumerated below). For each machine we monitored the number of packets received by the machine, the number of packets sent by the machine and the number of packet collisions that occurred on the Ethernet network. The following graphs were produced from this data[4].

1. The video capture machine had less than one percent of its packets involved in collisions. The average number of packets received by this machine was 25.42 packets/second (see figure 4) and the average number of packets sent by this machine was 21.07 packets/second (see figure 5). Note that the network bandwidth requirements are steady throughout the classroom presentation period.

2. The instructor/presentation machine (running **xmx** and sending GIF files) had five

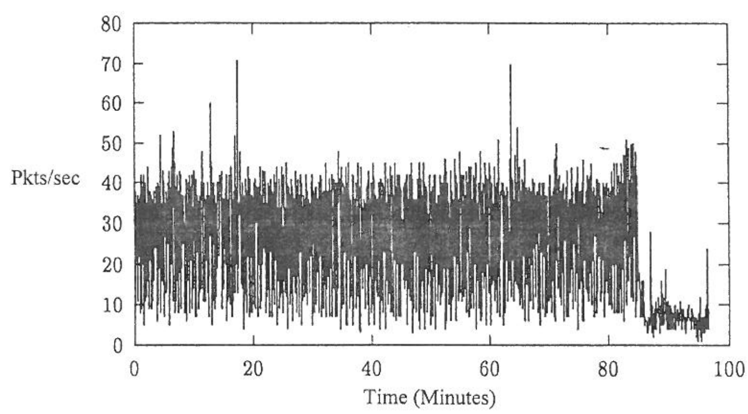

Fig. 4. Number of Packets Received By The Video Capture Machine

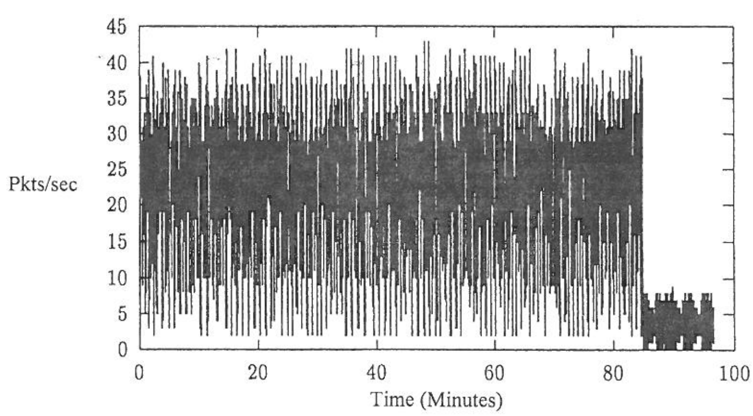

Fig. 5. Number of Packets Sent By The Video Capture Machine

[4] The magnitude of the vertical axis varies from graph to graph as automatic scaling was used.

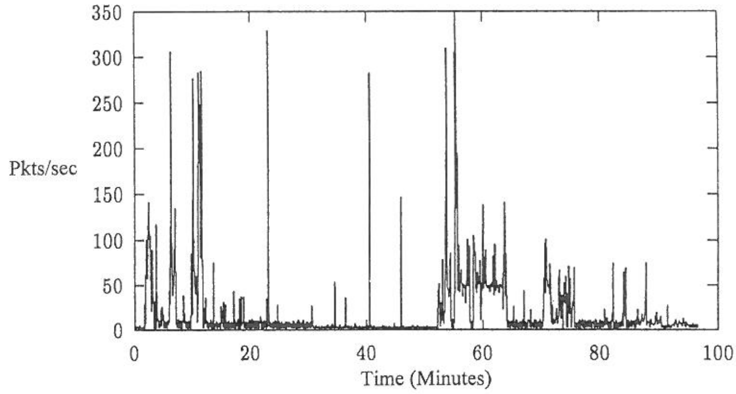

Fig. 6. Number of Packets Received By The Instructor/Presentation Machine

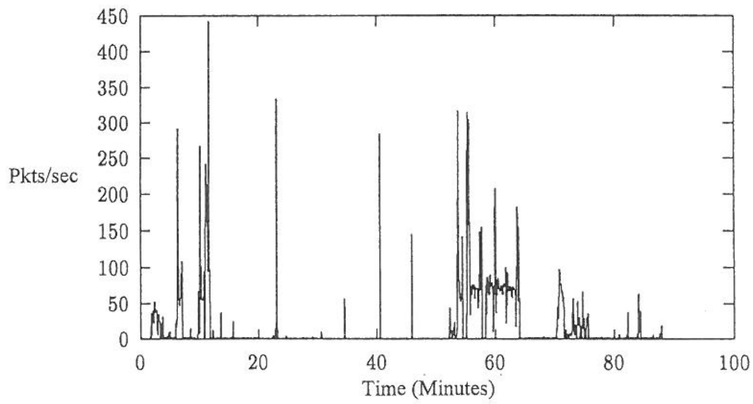

Fig. 7. Number of Packets Sent By The Instructor/Presentation Machine

percent of its packets involved in collisions. The average number of packes received by this machine was 20.36 packets/second (see figure 6) and the average number of packets sent by this machine was 16.02 packets/second (see figure 7). As shown in the figures below, the network traffic is very bursty (whenever the instructor requests a GIF file for display in the common presentation area).

3. The instructor/presentation machine (running **xterm** and using **vi** as the presentation tool) had less than one percent of its packets involved in collisions. The average number of packets received by this machine was 7.26 packets/second (see figure 8) and the average number of packets sent by this machine was 1.95 packets/second (see figure 9). It is clear to see that the network bandwidth for these tools are considerably less than when **xmx** was used with GIF files (figures 6 and 7).

4. A typical student workstation (running **xv** to display the instructor's image) had less than 1% its packets involved in collisions. The average number of packets received by this machine was 7.58 packets/second (see figure 10) and the average number of packets sent by this machine was 1.46 packets/second (see figure 11). Note that the bandwidth requirements are fairly low. The "spike" in each of the figures was due to additional student activity that occurred approximately 20 minutes into the presentation (this was caused by each student beginning to use their workstation as requested by the instructor).

5. The file server workstation had 42% of its packets involved in collisions (due to the high number of network requests). The average number of packets received by this machine was 27.48 packets/second (see figure 12) and the average number of packets sent by this machine was 45.14

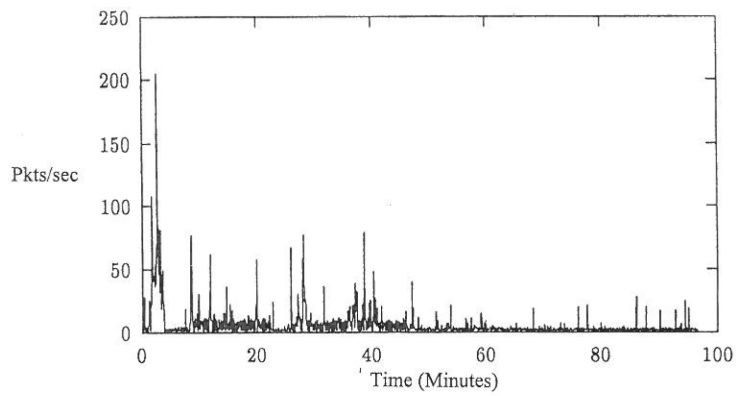

Fig. 8. Number of Packets Received By The Instructor/Presentation Machine

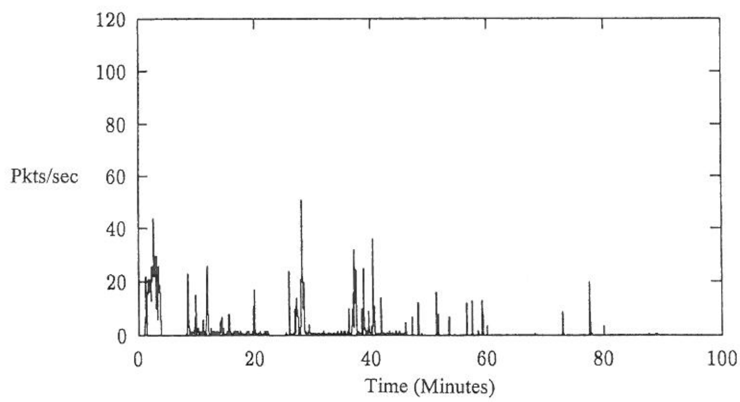

Fig. 9. Number of Packets Sent By The Instructor/Presentation Machine

packets/second (see figure 13). Here we see that the file server has somewhat bursty traffic. There are steady states (due to continuous image transfer) of traffic throughout the presentation.

Several observations can be made from this collected data:

- The video capture machine has a constant bit rate data flow (this is what you expect from a video source).
- The number of packets received by the instructor/presentation machine is essentially the number received by a typical student workstation. That is, the instructor/presentation machine has network requirements similar to a typical student workstation. This makes sense since a bulk of the traffic received is the common image of the instructor.
- The number of packets sent by the instructor/presentation machine is slightly more than the number sent by a typical student workstation. This makes sense since the instructor is presumably more active – sends more requests – than the student).
- The instructor/presentation machine using **xmx** and GIF files has a much larger number of packets sent and received than the same machine running **xterm** and using **vi**. In the first case (figures 6 & 7), network traffic was monitored when large GIF files of scanned foils/transparencies were used. The second case (figures 8 & 9), network traffic was monitored for the instructor/presentation machine using **xterm** with **vi** as the presentation tool. That is, the **xterm/vi** combination has a very minimal bandwidth requirement and allows interactive display whereas the **xmx/GIF** combination has a very high

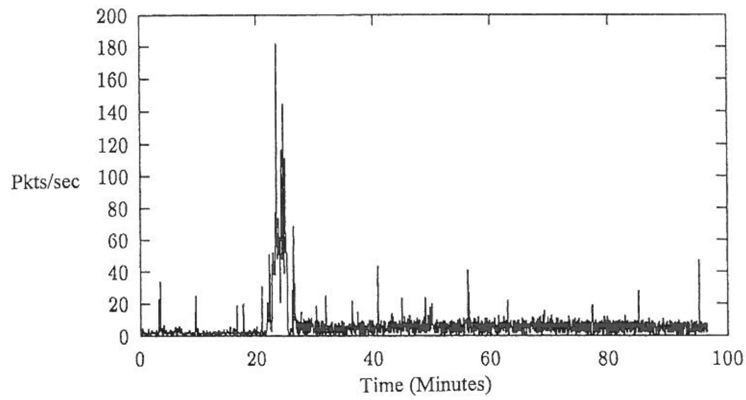

Fig. 10. Number of Packets Received By A Typical Student Machine

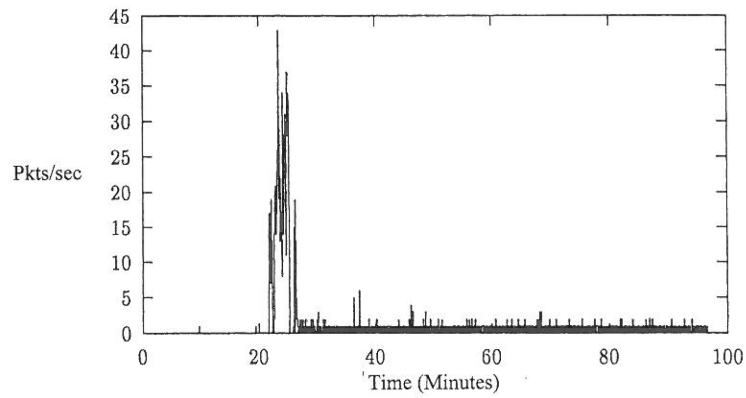

Fig. 11. Number of Packets Sent By A Typical Student Machine

bandwidth requirement and allows little interaction other than changing the presentation area display. The GIF files were about 20,000 bytes, but since **xmx** sends them out as bit mapped images, they are around 700x800 bytes.

- The number of collisions seen by the file server is roughly 42% whereas the student and instructor/presentation workstations typically had between 2 and 3% of their packets involved in collisions. Thus, the bottleneck of our system is the file server. The number of packets sent by the file server is large (45.14 packets/second). Thus, we conclude that virtual classrooms designed under this environment should have at least two file servers to ensure reasonable response times.

Thus, our computerized presentation system is easily supported by existing Ethernet speeds. The collection of network statistics confirmed this observation since very few packet collisions occurred on the instructor or students workstations (although, at times, many network collisions did occur on the file server machine). During a typical classroom presentation, personal observation of the performance of the system can be described as adequate. It was slow at times (with various combinations of X tools) but this did not hinder the instructor's ability to teach the course. Of course, if we increase the number of images sent per second (e.g., display an image in the presentation area every 30 seconds and display the instructor image every second), then the network load would become too heavy for good response times to be achieved. We plan to expand the virtual classroom so that remote presentations over the Internet are possible. Many Internet connections are now running at T1 speeds (1.544 Mbps). This should be sufficient to support several concurrent remote workstations (e.g., 15 network connections require approximately 0.7 Mbps – see analysis above).

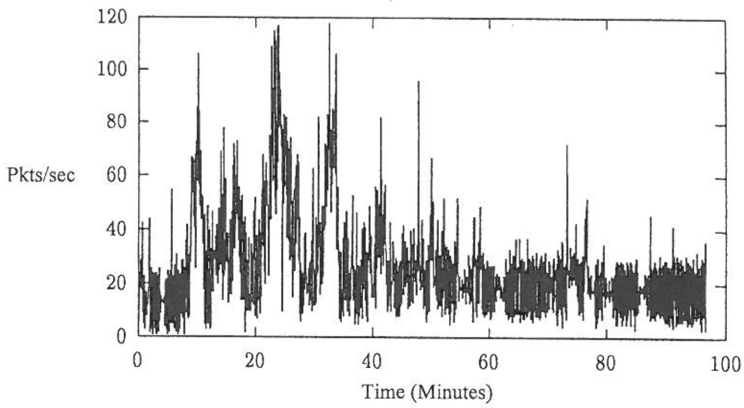

Fig. 12. Number of Packets Received By The File Server Machine

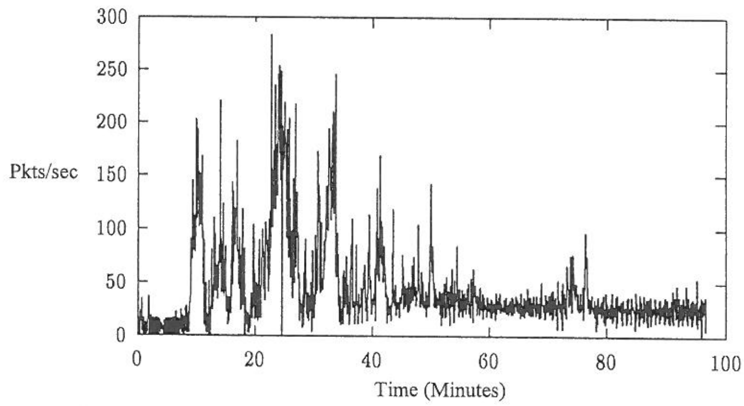

Fig. 13. Number of Packets Sent By The File Server Machine

6. Conclusions

At the time of this writing, the virtual classroom has been used successfully to teach a graduate course in Office Information Systems at North Dakota State University. During the 14 weeks that the virtual classroom was operational, much experimentation was done. Different methods for making presentations were the focus of this experimentation. We tried using **xmx** and **Collage** for the collaborative software. These two packages are quite different with respect to interaction. **xmx** is non-interactive while **Collage** is completely interactive with no instructor protection. Also, **Collage** limits the kinds of file formats that can be displayed (like GIF). With **xmx**, any display program can be run, hence any file format could be used. The choice of which to use depends on the type of presentation material, and whether the instructor wishes to allow interaction for the presentation of that material.

The student evaluations of the virtual classroom have been positive. However, there have been several problems with individual presentations. There have been occurrences of individual workstations and even the entire lab "locking-up." The cause of the "crashes" has yet to be determined. We have also had problems getting some X tools to work properly on the cluster, resulting in some "patchwork" presentations. We feel these problems may be due in part to the newness of the lab since it became fully operational only the night before classes were to begin. This left no time to get all the X tools fully operational. We hope that many of these problems will be eliminated once the platform becomes more stable.

We are expanding the virtual classroom so that remote presentations are possible over the Internet. All a student needs at a remote site is an X workstation connected to the Internet to make the platform for the class the same as if it were attended locally. The remote workstation could also be connected to the network via a high speed modem and a SLIP (serial line interface protocol) connection. We are investigating additional X applications at this time to improve our system (e.g., IVS - Interactive Television System, is a new X application that will permit 2-way audio capabilities and should improve the transmission of the slow-scan video as well). To date, we have had one presentation carried out over the Internet to a student workstation at another university.

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