ATM Network Experimentation in the State of Oregon

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Abstract

An extensive technical trial of ATM technology and related applications was conducted in the state of Oregon during the months of April 1994 through March 1995. In a joint effort between U S WEST, the Oregon Joint Graduate Schools of Engineering, and the NERO Project, five widely dispersed graduate level engineering schools in western Oregon were interconnected via a network of five ATM switches and associated OC3c and DS3 lines. A diverse set of applications was tested as part of this trial. This paper documents the results of the experimentation in the areas of desktop video teleconferencing and collaboration, delivery of educational video to the desktop, and desktop access to multi-media servers.

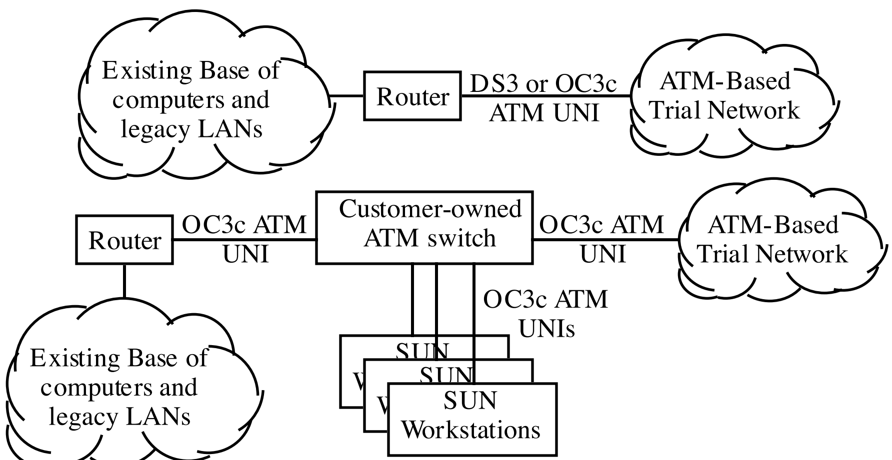

Figure 1 - Typical User Configurations

Introduction

A high level of interest among network users and providers alike has surrounded Asynchronous Transfer Mode (ATM) over the past several years. Major public network providers began announcing ATM plans and strategies as early as 1992, and the pace of activity and announcements accelerated as we moved through 1993 and into 1994. MCI [1-3], AT&T [12-19], Sprint [20-26], MFS [9-11] and WilTel [4-8] were all in the trade press with various announcements and articles during this period.

U S WEST announced its 3-phase ATM strategy in October of 1993 [27]. Key elements of this strategy included small, scalable ATM switches which could be flexibly deployed in a distributed architecture, along with plans for several technical trials of associated equipment and customer applications. These technical trials provided an opportunity to experiment with the ATM hardware, the proposed distributed architecture, and the associated customer applications. One of these technical trials was conducted in the state of Oregon during the months of April 1994 through March 1995. It was conducted in conjunction with the Oregon Joint Graduate Schools of Engineering as part of "Project NERO" (Network for Education and Research in Oregon). [28, 29] Project NERO provided a unique collaborative opportunity to link five widely dispersed graduate level engineering schools (Oregon State University, Oregon Graduate Institute, University of Oregon, Portland State University and Oregon Health Sciences University) via a high speed ATM network. These engineering schools, along with several State of Oregon office buildings and the Oregon Center for Advanced Technology Education were linked together via a network of ATM switches and associated OC3c and DS3 lines in several major cities along the I-5 corridor in Western Oregon.

One of the primary objectives of this ATM trial in Oregon was to determine the types of user applications which would drive the widespread acceptance and utilization of ATM wide area networks. ATM offers user network interfaces (UNIs) which function at speeds of 45 to 155 Mbps, well beyond the DS0 (64 kbps) and T1 (1.5 Mbps) capabilities which have been traditionally used by customers for the creation of their wide area networks. What would a customer do with a 100-fold jump in bandwidth from 1.5 Mbps to 155 Mbps? The Oregon ATM trial provided the opportunity to get real-life, hands-on answers from a leading-edge group of universities.

An Emphasis on Routers and Switches

The Oregon trial participants already had an extensive imbedded base of local area networks (LANs), along with the associated computers and workstations which were connected to them. These "legacy LANs" gained access to the outside world via high speed routers. Typical user trial configurations are illustrated in Figure 1. The first configuration used a router to access the public ATM network via either a DS3-based (45 Mbps) or an OC3c-based (155 Mbps) ATM user network interface (UNI). The second configuration included a customer-owned ATM switch which provided local high speed switching for a building or campus. The combination of this customer-owned ATM switch and the attached router provided access to the public ATM network, again at either 45 or 155 Mbps.

An Emphasis on IP-Based Networking

As you may have guessed, the presence of routers in these configurations implies that the dominant applications utilized IP-based (internet protocol) routing. A clear emphasis emerged on IP-based networking between a combination of legacy LANs, associated computers and workstations, and a new set of high performance desktop workstations. The emphasis was on ATM-based connectivity which provided both high speeds and high aggregate throughput. The use of customer owned ATM switches addressed this need at the local level. U S WEST addressed the need at the wide area level.

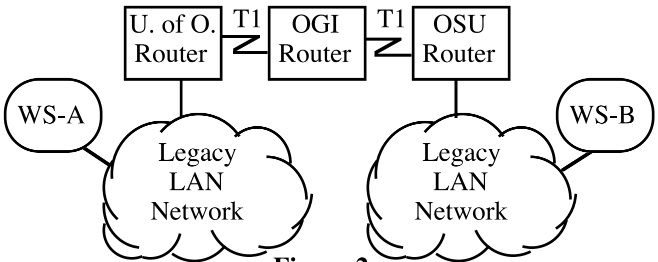

Figure 2
Typical Internet Configuration Using T1 Lines

As illustrated in Figure 2, today's internets are usually based upon routers which are interconnected by either DS0 (56 Kbps) or T1 (1.544 Mbps) leased lines. As shown in Figure 2, workstations located at the University of Oregon and at Oregon State University which wish to communicate do so today via three routers, one at each end and an intermediate router located at the Oregon Graduate Institute (OGI) in Portland. These routers are interconnected by 1.544 Mbps T1 lines. Applications in Oregon are therefore restricted to a maximum speed of 1.544 Mbps across the local internet, and these applications share that bandwidth with everyone else on the local internet.

As illustrated by Figure 3, the ATM trial configuration opened up an alternate internet path between these two locations. This path utilized 155 Mbps (OC3c) ATM UNIs and eliminated the intermediate router at OGI. The ATM-based internet therefore offered 100 times the speed and throughput of the old T1-based internet while eliminating the need for intermediate routers to switch the data. This provided a tremendous jump in both speed and in aggregate throughput capacity.

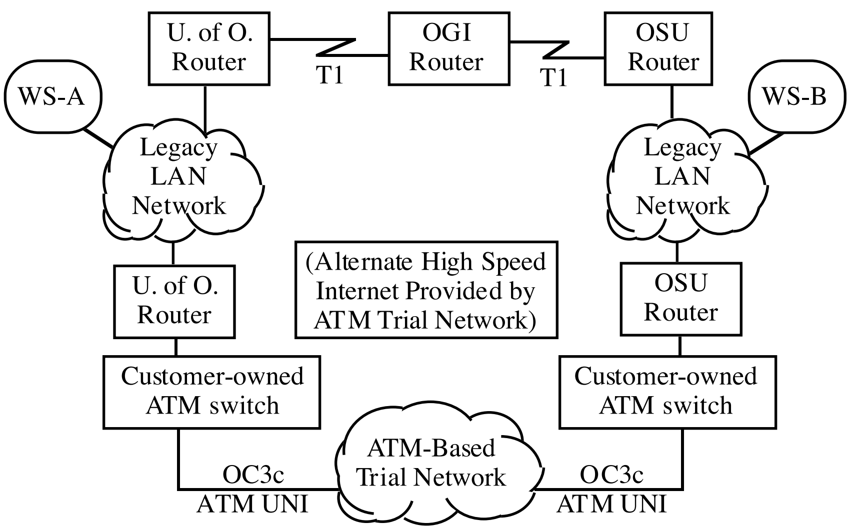

Figure 3
ATM Trial Network Provides Alternate High Speed Internet Paths

To control utilization of the alternate paths, each network connection was given a "dual identity" as far as IP was concerned. A separate IP address space was created, along with a special set of names which ended with "nero.net".

Models for running IP over ATM, and their characteristics, continue to be the subject of extensive research, engineering, and implementation. [30, 31] Two major camps have emerged. The IETF fielded the Classical IP over ATM model [31], which represented the first native protocol for ATM. The LAN Emulation group engaged in an effort to retain as much of the existing data networking as possible by transmitting 802.3 or 802.5 MAC level frames over ATM. A third possibility, implementation of transport protocols such as TCP directly on ATM (i.e., with no network layer such as IP), required much greater changes to the existing networking models, and hence was much less mature.

While the trial discussed here exclusively utilized Classical IP over ATM, LAN Emulation remained an interesting and attractive possibility.

An Emphasis on Desktop Video

Given this 100-fold increase in bandwidth and aggregate throughput for their IP-based networks, the primary applications which emerged for this user community were focused upon desktop video applications. These applications came in three basic variations:

1) Collaboration via desktop teleconferencing,
2) Delivery of educational video to the desktop, and
3) Desktop access to multi-media servers.

Perhaps it should not be surprising that a university community's applications would be oriented around collaborative work and the delivery of educational materials. All three of these application categories can and do exist in the absence of ATM. However, ATM-based networks contributed to the success of these applications through the raw speed and high aggregate throughput which ATM offers.

An Emphasis on MBONE

Desktop teleconferencing and the delivery of educational video to the desktop were both being accomplished via the use of MBONE (Multicast Backbone) capabilities. [32-34] MBONE originated from an effort to multicast audio and video from the Internet Engineering Task Force (IETF) meetings [35]. By late in 1993 MBONE was in use by several hundred researchers located at approximately 400 member sites worldwide. The MBONE is a virtual multicast [36-38] network which is layered on top of portions of the physical Internet. The network is composed of islands that can directly support IP multicast (such as ethernet LANs), linked by virtual point-to-point links called "tunnels". More recently, several vendors have supplied native IP multicast routing protocols. The NERO trial distributed multicast routing information using PIM (Protocol Independent Multicast). [45,46]

Desktop Video Teleconferencing and Collaboration

MBONE has proven itself to be extremely useful and versatile for desktop teleconferencing and collaboration. Desktop video delivery for the trial was initially accomplished almost exclusively using the MBONE tool "nv". A newer video tool "vic" was used in later phases of the testing. Vic supported not only nv but also various other video encodings and standards such as H.261 and JPEG. Nv uses a time-domain compression technique that transmits only the differences in the image in each update. This results in good bandwidth utilization properties, as compared for example to JPEG encoding. However, on lossy or congested lines, these difference-encoded frames can either be lost or arrive past their "playback point". Note that the desktop audio/video application being discussed here is a member of a class of applications called "playback" applications. Within this context the "playback point" refers to the point in time which is offset from the original departure time by some fixed delay (possibly fixed a priori). By definition, data that arrives before its associated playback point can be used to reconstruct the signal, while data arriving after the playback point is essentially useless in reconstructing the real-time signal.

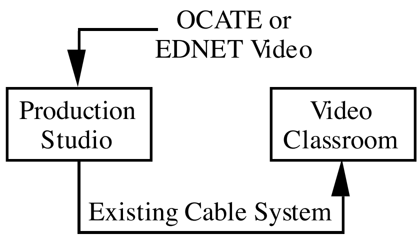

Figure 4 - Video Distribution to Specially Equipped Classrooms

The performance of the playback application can be measured by its sensitivity to latency and the fidelity of the reconstructed signal. The desktop conferencing application (and other playback applications which involve interaction between the ends of the connection) are particularly sensitive to latency and its variation known as jitter. If you know the upper bound on the variation in latency (i.e., jitter), then you can always delay playback at least this long and insure the ability to replay faithfully. We found that for high frame-rate video conferencing (frame rates higher than 20 fps), congestion on the existing T1-based infrastructure injected delays and loss which made N-way video conferencing virtually unusable, even with N < 5.

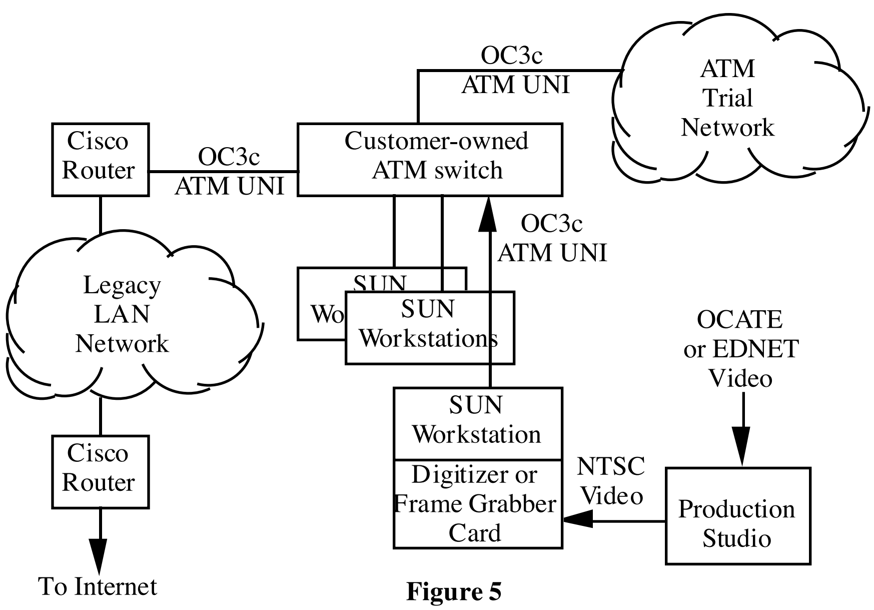

Figure 5
Originating Configuration for Delivery of Educational Video to Desktop Workstations via TCP/IP and MBONE

In contrast, the ATM OC-3c infrastructure did not have this limitation. We found that low congestion and latency made N-way video conferencing very usable. The average loss as reported by nv at 20 frames per second is shown in Table 1. It should be noted that the T1-loss statistics were taken from an unused T1 circuit. Note also that using a Sparc Station 10 class machine, nv generated video streams that used up to approximately 2 Mbps, which for N=1 would saturate a T1 circuit.

N	T1-Loss	ATM-Loss
2	17%	0%
4	26%	1%
8	72%	3%

Table 1
Average Loss as Reported by nv at 20 FPS

Delivery of Educational Video to the Desktop

MBONE is routinely used to broadcast various events to participants' desktops. Examples include "NASA Select", the NASA in-house cable channel broadcast during space shuttle missions; and "Radio Free VAT", a community radio station. "Internet Talk Radio" is a variation on this technique which conserves network bandwidth by making pre-recorded programs available as data files which can be retrieved via ftp and then played back on the local workstation as desired. Programming as varied as talks by Larry King and the "Geek of the Week" are made available via this technique. [39] These broadcast services have been significantly expanded recently via the Internet Multicasting Service (IMS) which broadcasts live multicast channels on the internet such as satellite-based programming like Monitor Radio and World Radio Network, network-based programming such as CBC News and SoundBytes, and live links into the National Press Club, the U. S. Congress, and the Kennedy Center for the Performing Arts. [47] Could MBONE capabilities be utilized to deliver educational video to the desktop? The capabilities are certainly there. NTSC video (or PAL or SECAM) can be fed into a workstation via the video input on a frame grabber card. Once digitized by the frame grabber card, the MBONE capabilities can be used to broadcast the video out to desktop workstations dispersed around the network.

Figure 4 illustrates how educational video is currently delivered at universities in Oregon. Video programming enters an individual campus via a satellite feed into a production studio. The video programming is then distributed to specially-equipped video classrooms via the existing campus cable TV network.

As shown in Figure 5, the MBONE solution feeds the NTSC video directly from the production studio into the back of a SUN workstation which then distributes the video programming directly to desktop workstations via MBONE capabilities. Specially equipped video classrooms are no longer needed.

The key to the success of this approach lies with the ability of the network to handle the load introduced by this application. Will ATM networks provide the raw and the aggregate bandwidth needed to support this application? Our results have shown that, as was the case for the "Desktop Video Teleconferencing and Collaboration" experimentation, the low latency/loss characteristics of the ATM infrastructure made distribution of high fidelity Educational Video to desktops possible.

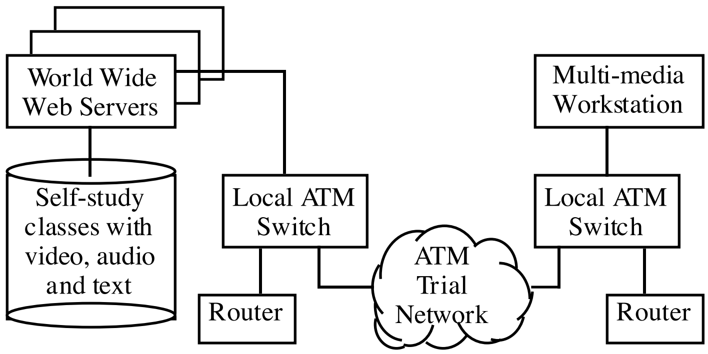

Figure 6 - Basic Configuration for Multi-media Desktop Self-Study

Desktop Access to Multi-Media Servers

The third area which emerged as extremely important in the Oregon ATM trial was desktop access to multimedia servers. The National Center for Supercomputing Applications (NCSA) at the University of Illinois has developed an environment called "NCSA Mosaic" [40,41] which enables wide-area network-based information discovery and retrieval using a blend of distributed hypermedia, hierarchical organization, and search functionality. NCSA has developed Mosaic client software for X Window Systems, Macintosh, and Microsoft Windows. NCSA Mosaic's communications support is provided courtesy of the CERN World Wide Web project's common client library. [42] World Wide Web has emerged as one of the Internet's most popular technologies, accounting for about 3% of the Internet traffic and growing rapidly. [43] It is one of a growing number of resource discovery tools which are available on the Internet. [44]

In addition to the ability to efficiently utilize their desktop workstations for both telecollaboration with their colleagues and for receipt of educational video programming, the Oregon ATM trial users were provided with desktop access to multimedia servers. A typical configuration is shown in Figure 6.

As shown in Figure 6, the World Wide Web (WWW) servers controlled a set of self-paced courses which contained a mixture of video, audio and text. A student would take a particular course via a multimedia workstation such as a Sun. The course consists of multiple windows on the screen, including full motion film clips with audio, along with associated interactive text. The multimedia courseware is delivered over the WWW and is received and viewed using a WWW reader such as NetScape or Mosaic. The success or failure of this type of desktop self-study is directly dependent upon the performance of the network. If the multimedia course is delivered too slowly, then the student's concentration and momentum will be interrupted and the self study course will not be successful. Would an ATM-based internet provide the raw speed and aggregate bandwidth necessary to successfully support this type of application? Our test results showed that the answer is yes. When students accessed the self-study server using the existing T1-based infrastructure, the time required to access a 3.2 Mb video clip is shown in Table 2. Note that these figures are for a Sparc Station 10/30 server running SunOS 4.1.3.

Students	Time (s)
1	41.45
2	67.90
4	82.77
8	93.69

Table 2
Access Time for 3.2 Mb Video Clip Using T1-based Infrastructure

The large delays experienced by students in this case were due to a combination of congestion on the T1 link and load on the server. Table 3 shows the results for the same experiments using the ATM-based infrastructure. This table shows that almost all of the delay previously experienced by the students was injected by the T1-based network. With the ATM-based network, the server is able to service multiple students with minimal delay.

Students	Time (s)
1	1.45
2	2.80
4	3.25
8	3.25

Table 3
Access Time for 3.2 Mb Video Clip Using ATM-based Infrastructure

Summary Comments

Trial users placed a strong emphasis on the combination of ATM and TCP/IP networking, utilizing ATM to boost their T1-based internet infrastructure to OC3c speeds. This increase in both raw speed and in aggregate capacity enabled a number of important applications. Significant improvements in performance were measured for desktop video teleconferencing and collaboration applications via MBONE, as well as for delivery of educational video to the desktop via MBONE. Significant improvements in performance were also measured for applications accessing multi-media servers. In all cases, the blend of TCP/IP and ATM enabled the efficient use of desktop applications which would be marginally useful at best if run across a T1-based internet. Other than for the dramatic increases in performance, the switch from T1-based networking to ATM-based networking was transparent to the applications, with the routers handling the introduction of ATM networking routinely as just one more form of network connectivity.

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