A METHOD FOR COST-EFFECTIVE INTEGRATION OF HIGH-SPEED WAN TRANSMISSION TECHNOLOGIES INTO A COLLEGE COMPUTER NETWORKING CURRICULUM

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ABSTRACT

The physical structure of the Internet has entered a transition recently due to the demand for higher bandwidth worldwide. Technologies such as T1 and frame relay have been superseded by asynchronous transfer mode (ATM) and digital/asymmetrical subscriber loops (DSL/ASL). Along with the new hardware technology there are improvements in software/network protocols as well. The concepts of quality of service and reservation bandwidth further enhance the efficiency of these new technologies by optimizing the use of the increased bandwidth provided.

While networking is extremely important, representing this physical structure in labs for educational purposes can be expensive, with even simple setups costing a quarter of a million

dollars or more. The purpose of this paper is to illustrate how this new technology can be integrated into the information systems/computer networking curriculum in a less costly manner, thereby allowing universities to enhance students' learning experience by using industry current technology**.**

INTRODUCTION

The rapid growth of networks in the U.S. and around the world has made networking and data communications classes a critically important component of Computer Information Systems/Management Information Systems (CIS/MIS) educational programs. In fact, Shah and Martin (1997) report that data analysts rate data communications as the most important IS class taught. Even at the graduate level, the importance of data communication and networking classes is evident. For example, Ramakrishna and Vijayaraman (2000-1) found that data communication classes are among the top four required topics in IS master's degrees.

The seeming ubiquitous presence of the client-server architecture only fuels the need for a supply of trained networking support personnel (Misic & Hill, 1998), and the support for the client-server architecture comes from graduates of CIS/MIS programs. In a study of the importance of IS job skills, Richards, Yellen, Kappelman and Guynes (1998) found that managers rated maintaining local area networks as the single most important of these skills. In reflection of these realities, MIS programs are changing to cover important data communication topics (Gill & Hu, 1999). But while the IS curriculum is changing, educators are still seeing significant gaps between the perceived importance of local area network (LAN) tools and student achievement in these areas (Tang, Lee & Koh, 2000-1). Tang, Lee and Koh (2000-1) suggest that one solution to the problem is adding yet more networking classes into the curriculum. They recognize, however, that IS curriculum in colleges of business accredited by the AACSB are limited by the 50% rule in how many classes can be required. If more classes cannot be added, perhaps the content of current classes can be altered to reflect the most important and current networking topics.

Industry studies emphasize the need for more networking personnel trained in the latest technology. A recent employment study shows that nationwide the greatest need for technology staff is in the area of networking (Pace, 2001). But while data communications and networking are important academic topics, an important aspect of networking classes should be inclusion of a hands-on component to these classes (Lee & Maier, 2001). The hands-on aspect of the class provides students with experience they can immediately put to use on the job. Some suggest that one barrier to the inclusion of hands-on experience is the price of outfitting a LAN lab (Lee & Maier, 2001).

But it is easy to overlook, in our concentration on developing skills for local area networking, that LANS are typically connected to wide area networks (WANS). At the same time, technology traditionally associated with WANS is being incorporated into LANS. WANS themselves, fueled by an increasingly mobile workforce (Pace, 2001), are growing in popularity. This provides a dilemma for teaching networking. Teaching WAN technology is becoming more important than ever because of the increased use of this technology in both WANS and LANS. But WAN technology is even more expensive than the technology for LANS, making hands-on teaching of WAN technology less likely rather than more.

More specifically, computer networking courses need to expose students to transmission technologies beyond traditional serial and Ethernet. This need is supported by recent trends in

WAN technologies that feature ATM backbones and DSL to the workstation of the end user. Both of these technologies are radical departures from the technologies they replace. Hence, students will need direct investigation and hands-on activities in the curriculum if they are to fully understand their impact.

Because ATM is an integrated technology, it features numerous architectures designed to optimize data, voice or video traffic. These services are supported by several adaptation layers that allow the physical cell-based transfer methodology of ATM to be linked to a variety of network interfaces Handel, Huber & Schroder, 1994). For example, AAL1 (adaptation layer one) is designed for circuit emulation with a constant bit rate for audio/video applications (Guizani & Rayes, 1999). In all, there are five different adaptation layer services. Some, such as AAL5, are similar in function to backbone Ethernet traffic (LANE and IP/ATM), but others are designed to ensure real time delivery of video or voice traffic. It is these quality of service and optimization features, coupled with its virtual path/virtual circuit structure, that necessitate this technology's inclusion in the computer network curriculum.

Furthermore, DSL technology has provided end users with a much higher speed alternative to standard dial-in phone lines. Although still dependent on the existing phone wire scheme, this technology is designed to provide the end user access back to a high-speed ATM backbone. This scheme, while not quite approaching the bandwidth now being allocated in LAN designs to workstations, is a big step forward for the WAN end user and certainly merits inclusion in the computer network curriculum.

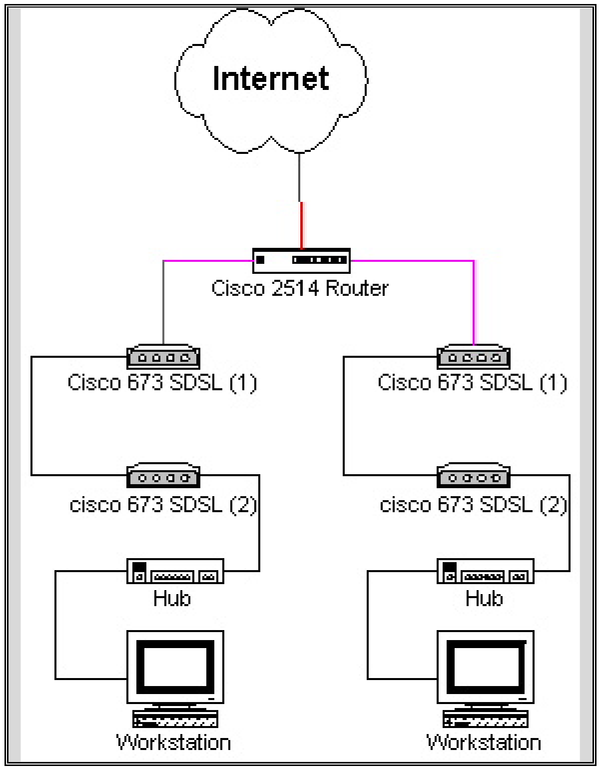
But, as mentioned above, implementation of ATM and DSL into networking courses can be an expensive undertaking. The DSLAM switch (a 24-port model, for example) most often used for ATM and DSL switching in industry, costs in the vicinity of $200,000 by itself when populated. Constructing a lab using this technology is beyond the means of many institutions of higher education that have trouble financing the construction of simple communications labs (Lee & Maier, 2001). This paper illustrates a method for introduction of ATM and DSL technology into a 30-position lab without using the relatively expensive DSLAM switch and its accompanying hardware. Using the method outlined in this paper, the costs of introducing the advanced networking technologies described here can be as little as a third of the cost of using a DSLAM**.** The reduced cost should make installation of this technology possible to more colleges and universities struggling with the costs of maintaining an current lab setup.

EQUIPMENT AND CONFIGURATION OVERVIEW

The basic approach in this configuration is to mimic the operation of the DSLAM switch using a combination of Cisco 1010 Lightstream and Cisco 2900 Catalyst switches, and Cisco 2514 routers. The savings (see Appendix A) come from consolidating and routing all traffic through the Lightstream switch instead of providing separate ports in a DSLAM. The increased overhead and decreased performance is viewed as acceptable in a teaching environment because of the dramatic cost savings.

The basic configuration is illustrated in Figure 1 and a more complex configuration is depicted in Figure 2. Figure 3 depicts a configuration for a cascaded WAN link. Figure 1 is representative of a real-world setup for a smaller organizational unit such as a workgroup or a department. Figure 2 might be a more realistic representation of a divisional or enterprise setup. Figure 3 shows how an organization spread over three sites might configure their private WAN to save line costs when compared to leasing two dedicated lines (one to each site).

Figure 1.
Single Router Setup.



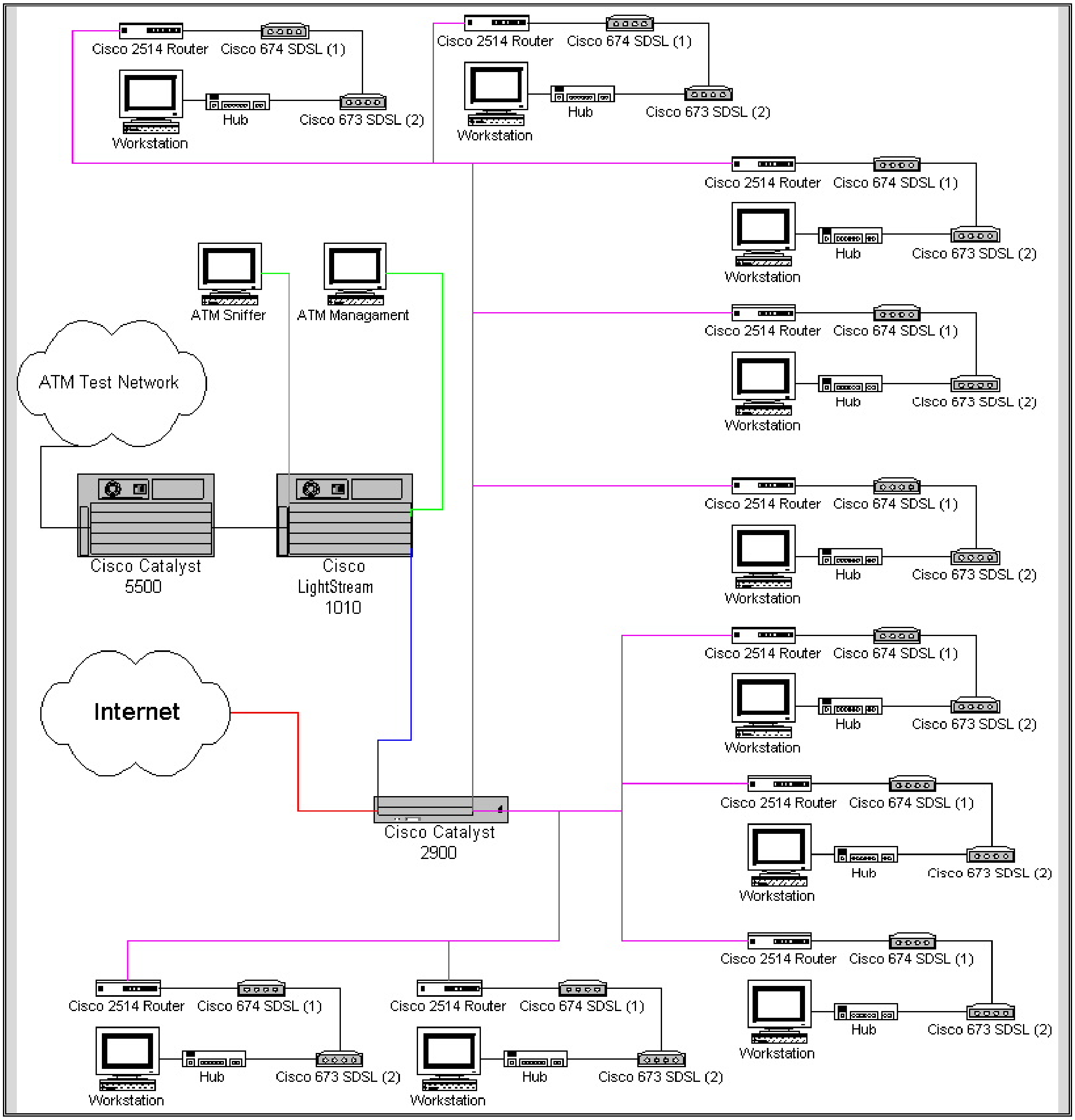
In order to implement the three configurations, ten Cisco 2500 series routers are integrated into a networking lab that is set up with ten equipment racks. Each rack and associated equipment is designed to provide hands-on networking experience for teams of three students, matching or exceeding the planned capacity of most advanced networking courses. These routers serve as the "brains" of the students' networking projects. These boxes can be programmed to control the flow of data and allow the students to make decisions regarding how to optimize this flow.

The DSL modems allow students to learn the new higher speed technology and gain experience linking a secondary device to a primary router. The ATM technology (the Lightstream switch) can be linked to the catalyst switch via an ATM module. The ATM switch allows students to link their router to a high-speed backbone and gain experience dealing with cell rather than packet relay. The ATM switch in turn is connected to secondary ATM switch that increases the total ATM capacity and provides students with an opportunity to learn ATM to ATM switching techniques. Furthermore, this scenario provides a platform from which students can learn and experiment with important optimization concepts such as quality of service and reservation bandwidth

Lightstream 1010 Switch

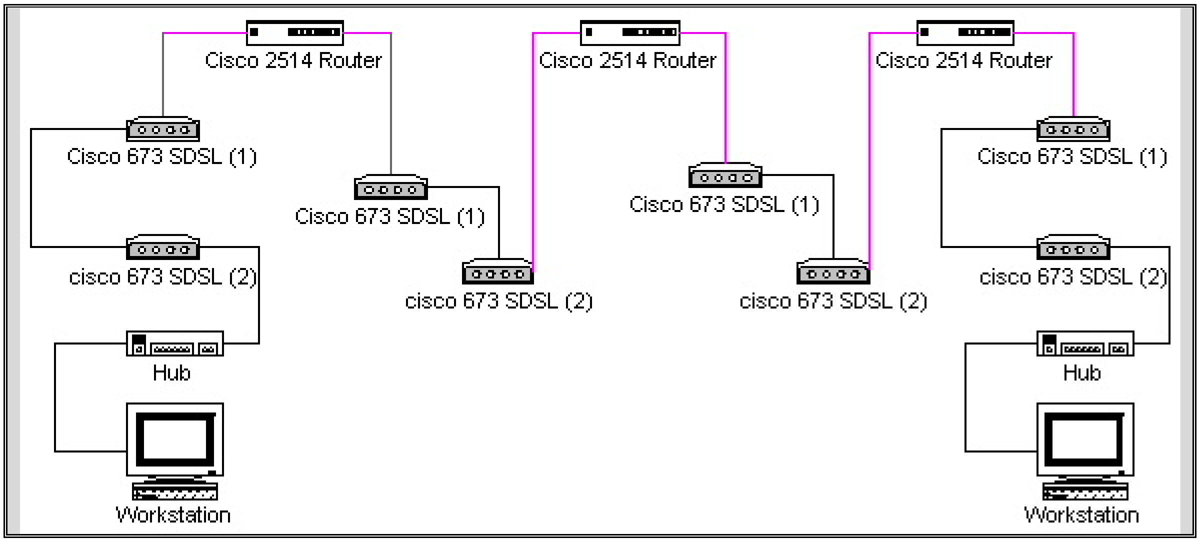
The Cisco lightstream switch is placed at the top of the hierarchy. This high-capacity open architecture switch features numerous slots for expansion and hence a high degree of flexibility

Figure 2.
Multiple Router Setup with ATM Connection.



Due to space limitations, all connections are not shown. For example, each of the 10 Cisco 2514 Routers is connected individually to a separate termination point on the Cisco 2900 Catalyst Switch.

Figure 3.
Cascading Router Setup.



regarding configuration options. Its primary purpose is to link existing ATM traffic within the current domain to the ATM/DSL project described herein. A configuration with only four ATM-OC3 ports is adequate for the current design, and additional ports can easily be added if additional capacity is needed for other projects. The following components are connected to the lightstream switch. First, a catalyst 2900 switch concentrates ethernet traffic from all of the ten Cisco 2514 routers and switches it to an ATM port that in turn is linked to the lightstream switch. Second, a preexisting Catalyst 5500 ATM switch is connected to the lightstream switch to allow existing workstations with ATM NIC's access to the new ATM backbone. Third, an ATM equipped workstation is directly connected to the lightstream switch for management purposes. Last, a Linux-based ATM NIC equipped host is directly connected to the lightstream switch to serve as a packet sniffer and performance monitor.

Catalyst 2900 Switch

This switch provides the second layer in the hierarchy and serves to concentrate the 10Mbs ethernet traffic from each of the Cisco 2514 routers into a single 155 Mbs stream. A workstation is connected directly to this switch at 100 Mbs to perform management and packet sniffer related functions. Each self-sensing Ethernet port can accommodate either 10BASET or 100 BASETX traffic.

Cisco 2514 Routers

The Cisco 2500 series router has been a well-respected component in many low end WANs over the past 10 years. Although originally designed for T1/DS1 applications, it is still present in a multitude of WAN applications worldwide. The 2514 model selected herein features two high-speed serial and two 10Mbs Ethernet connections. Its purpose is to simulate a termination point on the carrier side of a DSL connection.

Cisco 673 Symmetric DSL Modem

The Cisco 673 modem is designed to provide the user termination point in a simulated digital subscriber loop. These modems are capable of sending a digital signal at 1.168 Mbs over a standard phone line or in the case herein a simulated phone line. The plan to integrate these devices follows. A DSL modem is attached to one of the Ethernet ports on a Cisco 2514 router. A simulated phone line is extended to a second Cisco 673 DSL modem and a workstation or hub connected to it.

INTEGRATION INTO EXISTING WIRING SCHEME

Once fully tested on the bench the lightstream switch is rack-mounted along with the catalyst switch and the ten Cisco 2514 routers. Multimode fiber pairs and CAT 5 cable are available to connect the devices. If devices are supplied with only UTP ports, Transition Network's ATM media converters can be applied on each side of the link.

Connectivity from the 2514 routers to the catalyst switch is accomplished with CAT 5 cable. Similarly connectivity from the Cisco 673 modems is also accomplished via Cat 5 cables. In all cases distances are relatively short between racks, and either standard patch cables or punching down to the existing patch panels mounted on all racks could be used. Because the configuration of these devices will vary throughout the semester, this solution was selected to provide the flexibility necessary to accommodate a wide variety of different configurations.

OSI NETWORK LAYER

An important part of the networking class is student familiarization with addressing for various devices in a specific configuration. Table 1 provides insight into how the network layer in the proposed WAN illustrated in Figure 1 is configured. Because it is a simulation designed for student lab activity and not a production system, it is isolated from the production network and for the sake of simplicity uses only one router.

The network layer addressing is accomplished by using bogus class A licenses, masked like a class C, on the internal side. This 10.0.0.0 address is universally accepted as a private network and is usable by anyone worldwide. This private class A license was selected to provide isolation from the internet. Two subnets are used and connectivity to the outside world would not initially be available in this scenario, but could be added at a later date if desired.

Table 1 also reflects how the interfaces on each device will be linked to an IP address in scenario 1. The left 2514 interface is eth0 while the right interface is eth1. SDSL A is connected to eth0 while SDSL B is connected to eth1.

In scenario 2, as Illustrated in Figure 2 and described by Table 2, a more complicated subneting scheme is required because multiple 2514 routers are connected together. Specifically, each router has an internal network to support the SDSL traffic which uses 10.1.0.0. series subnets, and an external interface (back to the catalyst switch) to provide 2514 to 2514 communication. This example is further complicated by the fact that each internal Ethernet interface on each router requires a separate network address. Therefore, the internal interface (eth1) on router 1 is given 10.1.1.0 and on router 2 it is given 10.1.2.0. The external interfaces (eth0) however all point to the same network. In other words, each external interface is on the same subnet (192.168.1.0) but has a different node address. Each of the ten groups of components follows a similar structure with node and network addresses incremented accordingly. If desired, internet access can be provided in this scenario by hooking up an internet connection to the Catalyst switch.

Table 1

IP Addresses: (Assume the subnet mask for all addresses is 255.255.255.0, unless noted)

Networks 10.1.1.0 and 10.1.2.0
2514 Router Interface e0 - 10.1.1.1
2514 Router Interface e1 - 10.1.2.1
673 SDSL A Interface e0 - 10.1.1.2
673 SDSL A Interface wan0 - 10.1.1.3
673 SDSL B Interface e0 - 10.1.2.2
673 SDSL B Interface wan0 - 10.1.2.3

Table 2

IP Addresses: (Assume the subnet mask for all addresses is 255.255.255.0, unless noted)

Router 1
2514 Router Interface e0 – 192.168.1.1
2514 Router Interface e1 - 10.1.1.1
673 SDSL A Interface e0 - 10.1.1.2
673 SDSL A Interface wan0 - 10.1.1.3
Router 2
2514 Router Interface e0 – 192.168.1.2
2514 Router Interface e1 - 10.1.2.1
673 SDSL A Interface e0 - 10.1.2.2
673 SDSL A Interface wan0 - 10.1.2.3
Router 10
2514 Router Interface e0 – 192.168.1.10
2514 Router Interface e1 - 10.1.10.1
673 SDSL A Interface e0 - 10.1.10.2
673 SDSL A Interface wan0 - 10.1.10.3

In scenario 3, as depicted by Figure 3 and Table 3, a separate subnet is required for each interface on each router. Initially, this scenario is configured as a standalone network. However if desired it could be connected to the internet via a high speed serial interface on one of the routers. This standalone setup is best accomplished by teams of students working together, with a team assigned to each router.

Table 3

IP Addresses:(Assume the subnet mask for all addresses is 255.255.255.0, unless noted)

```
Router 1
2514 Router Interface e0 – 10.1.1.1
2514 Router Interface e1 - 10.2.1.1
673 SDSL A1 Interface e0 - 10.1.1.2
673 SDSL A2 Interface wan0 - 10.1.1.3
673 SDSL B1 Interface e0 - 10.2.1.2
673 SDSL B2 Interface wan0 - 10.2.1.3

Router 2
2514 Router Interface e0 – 10.2.1.6
2514 Router Interface e1 - 10.3.1.1
673 SDSL A1 Interface e0 - 10.2.1.4
673 SDSL A2 Interface wan0 – 10.2.1.5
673 SDSL B1 Interface e0 - 10.3.1.2
673 SDSL B2 Interface wan0 - 10.3.1.3

Router 3
2514 Router Interface e0 – 10.3.1.6
2514 Router Interface e1 - 10.4.1.1
673 SDSL A1 Interface e0 - 10.3.1.4
673 SDSL A2 Interface wan0 - 10.3.1.5
673 SDSL B1 Interface e0 - 10.4.1.2
673 SDSL B2 Interface wan0 - 10.4.1.3
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Only IP address entries for DSL's directly connected to a routers are listed in Table 3.

SUMMARY

Given the limited fiscal resources typically available for university instructional programs, keeping pace with the technology in computer networking advances is a difficult undertaking. The setup described in this paper has been successful in simulating the ATM backbone to DSL configuration currently used by many carriers. It avoids the high cost of a multi-port DSLAM by concentrating the traffic using inexpensive Cisco 2514 routers. However, it still provides students with the environment to gain experience with both the DSL and ATM technologies. The cost savings, shown in Appendix A, are significant. A setup capable of providing similar instructional opportunities but using the expensive DSLAM switch might cost three times as much as this one.

But this particular configuration also provides potential benefits other than cost. In this configuration, equipment is also available to support other activities such as basic routing configuration, network performance monitoring and computer and network security projects with only minimal changes. In addition, because the current backbone of the instructional domain is 100 BASE TX based, this project provides an excellent opportunity to learn ATM technology and evaluate it as a candidate to replace the existing Ethernet backbone.

The three basic configurations provided in this paper mimic real-world installations both simple and more complex. Students become familiar with the addressing schemes for a number of devices configured in various ways. The setups allow students to learn the new higher speed technology and gain experience linking a secondary device to a primary router. The ATM technology (the Lightstream switch) can be linked to the catalyst switch via an ATM module. The ATM switch allows students to link their router to a high-speed backbone and gain experience dealing with cell rather than packet relay. The ATM switch in turn is connected to secondary ATM switches that increase the total ATM capacity and provide students with an opportunity to learn ATM to ATM switching techniques. Furthermore, this scenario provides a platform from which students can learn and experiment with important optimization concepts such as quality of service and reservation bandwidth. Students also get to learn the command language for the ubiquitous (industry standard) Cisco routers. There is also an opportunity to work with alternative operating systems such as Linux and students can learn to install network interface cards for both ATM and Ethernet systems. Finally, the third configuration requires communication among groups if connectivity is to be established across the three routers. Working with this topology provides students with a better understanding of the value of redundant networks.

In summary, this paper shows how these configurations provide these benefits without the need to discard older technology currently owned by educational institutions. By using widely available, current technology, and adding the elements outlined in this paper, educational institutions are able to provide quality educational experiences in newer ATM and DSL technology in a less-expensive fashion.

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Appendix A

Price Comparison Using Proposed Configuration Versus DSLAM

Proposed Configuration			DSLAM Used		
#	**Item**	**$**	**#**	**Item**	**$**
1	Lightstream Switch	38,000	1	24 port DSLAM	235,000
1	Catalyst 2900	2,000	10	DSL's	5,000
10	2514 Routers	20,000			
20	DSL's	10,000			
	Total	**$70,000**			**$240,000**