Moving Towards ATM: LAN/WAN Evolution and Experimentation at the University of Oregon

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Abstract

Between April of 1994 and March of 1995 the University of Oregon worked with U S WEST and a number of other participants in an extensive technical trial of ATM equipment and services. This paper shares experiences and lessons learned during that trial. A primary area of emphasis during the trial was a complex mixture of ATM LAN and WAN capabilities. ATM connectivity was extended to high-end desktop workstations as well as to routers which were located at participating institutions across Western Oregon. IP networking was stressed, along with a mixture of ATM PVCs and SVCs, both local and remote. This was accomplished within an environment which combined high-end routers and customer-owned ATM switches from two different vendors at the local level with public ATM services provided by U S WEST over the wide area. In addition, existing legacy LANs were also supported. This unique combination of legacy LANs, ATM LANs/WANs, IP networking, and ATM SVCs/PVCs placed the University of Oregon at the leading edge of these activities during 1994 and early 1995. This paper discusses the evolution of local networking capabilities at the University of Oregon over the past decade which led to the current need for ATM connectivity over the local and wide area. It then describes the related trial activities which were performed in the area of ATM LANs, WANs, PVCs and SVCs within the IP-based environment at the University of Oregon.

Introduction

LAN development and evolution have moved rapidly over the past decade. Less than 10 years ago the University of Oregon (UO) had only one ethernet LAN. Today the UO has more than 80 LANs spread across 70 buildings on the campus. A complex infrastructure of LANs, bridges, routers and high speed backbones has evolved over the intervening years to support the networks which have become an integral part of the UO environment. Work continues at this time on an extensive set of experiments which integrate ATM LANs and WANs, ATM permanent virtual circuits (PVCs) and switched virtual circuits (SVCs), and internet protocol (IP) networking in increasingly useful ways. Experiments conducted in cooperation with U S WEST and others during 1994 and early 1995 have placed the UO at the leading edge of LAN/WAN/ATM/IP integration efforts in this country. This paper describes those ongoing testing efforts.

The need for a fiber ring campus backbone

As previously mentioned, less than 10 years ago there was a time when the UO had only one ethernet LAN. It was not long before a second LAN was added and a bridge was acquired to connect the two LANs together. Additional LANs and bridges quickly followed as LANs proliferated in multiple buildings across the campus. It soon became apparent that some type of campus backbone would be needed to provide efficient and high speed connectivity between the bridges and LANs which were springing up in nearly every building on the campus.

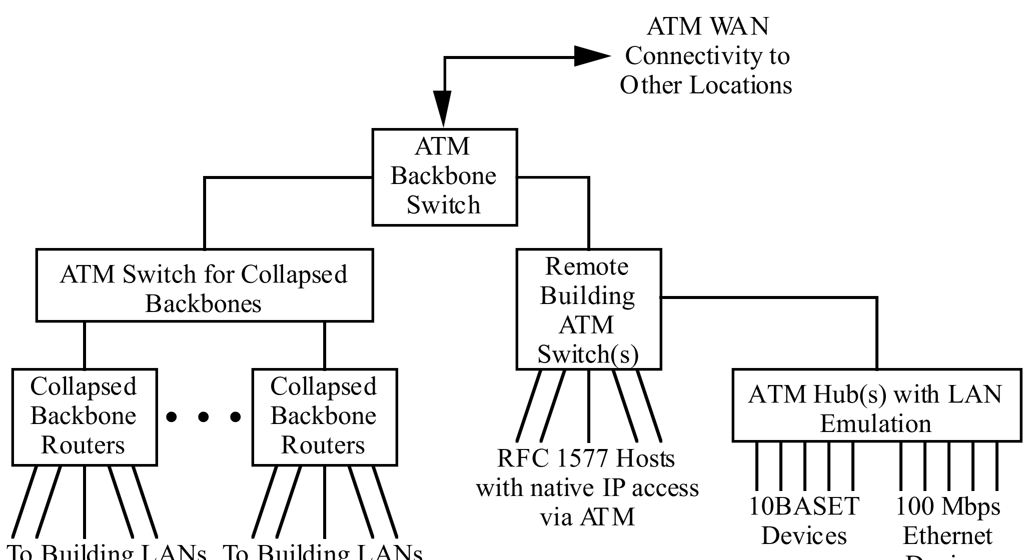

Figure 1
Integration of ATM Switches and Hubs at the University of Oregon

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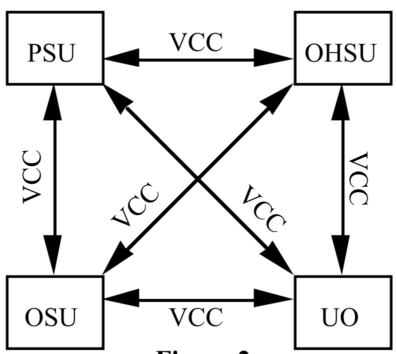

Figure 2
Phase 1 Connectivity:
A Complete Mesh of Virtual Channels.

In the mid to late 80's it was widely accepted that fiber rings were a good choice for campus backbone networks. FDDI was just emerging in mid 80s [1-3] and really started coming into its own in late 80s. [4-6] The UO implemented a proprietary fiber optic ring as its first high speed campus backbone. A bridge was located at each campus building, and the fiber ring provided high speed connectivity between the bridges. It was anticipated that this ring would eventually be converted to a standard FDDI ring as the equipment costs began to come down and the technology began to stabilize.

Explosive growth in LAN deployment resulted in the installation of a second backbone ring to handle the increased load. Interest in Internet connectivity combined with the need to interconnect the campus backbones resulted in the installation of the first IP router sometime in 1988. At about the same time, enthusiasm within the industry for FDDI campus backbones began to decline. With bridges and ring interfaces distributed to nearly every building on campus, fault isolation and problem resolution became increasingly difficult. A single failure was difficult, but resolution of multiple concurrent failures became nearly impossible.

Moving to a collapsed backbone

The decision was made to use IP networking to segment the campus into separate and independent IP networks, each roughly equivalent to a building location. Campus backbone rings were phased out in favor of a collapsed backbone which was actually the backplane of a single, centrally located router. The high speed backplane of a single high-performance router had now taken the place of the distributed fiber optic campus rings. FOIRL-based (Fiber-Optic Inter-Repeater Link) ethernet extenders were utilized to provide star-wired connectivity from the central router out to 10BASET ethernet hubs which in turn provided star-wired ethernet connectivity to devices located in each remote building.

This new star-wired scheme with the collapsed backbone was much easier to manage and trouble-shoot. SNMP (Simple Network Management Protocol) tools were utilized to diagnose and isolate problems. This topology and architecture worked extremely well as the number of campus networks continued to expand rapidly in the early 90s. However, although the centralized collapsed backbone was efficient and easy to manage, it gradually became unworkable as more than 70 building subnets eventually required connectivity. Not only did the one backbone router expose the UO to a single point of failure for all campus network connectivity, it soon became apparent that the increasingly large number of connections was outstripping the capabilities of even the largest available individual router devices.

As a result of this continued growth in campus LANs, the UO subsequently implemented a total of four collapsed-backbone routers in several campus locations. The implementation of multiple backbone routers and their distribution to multiple campus locations relieved congestion and addressed the single-point-of-failure problem, but in turn introduced other problems. Given the presence of four routers, each serving as a hub for approximately 25 ethernets, each centralized router was aggregating approximately 250 Mbps of ethernet bandwidth. How could these four routers be efficiently interconnected, given that each was aggregating 250 Mbps of bandwidth? As we moved into 1993, the four campus backbone routers were interconnected with a 10 Mbps ethernet, a severely under powered solution. Once again a high speed backbone solution was needed, this time for interconnection of the backbone routers. FDDI, which looked so promising just a few years earlier, was judged to be over-priced and under-powered as a solution to this problem.

Moving to ATM

The decision was made to turn to Asynchronous Transfer Mode (ATM) to provide centralized connectivity between campus routers. Local ATM switching would provide active, manageable devices which would again function as a collapsed backbone for the campus. This would continue the previous move towards star-wired building subnets which were star-wired into collapsed backbones, which would now be star-wired into local ATM switches. This migration path was not unique to the UO and was followed by other campuses during the same period. [7-9]

The UO's move to ATM was conducted within the context of the NERO project [10], a collaborative effort to link five widely dispersed graduate level engineering schools (Oregon State University (OSU), Oregon Graduate Institute (OGI) , University of Oregon (UO) , Portland State University (PSU) and Oregon Health Sciences University (OHSU)) via a high speed ATM network. Wide area ATM connectivity was provided by GTE and U S WEST. U S WEST was in the process of announcing its own 3-phase ATM strategy in October of 1993. [11] Key elements of U S WEST's strategy included small, scalable ATM switches which could be flexibly deployed in a distributed architecture, along with plans for several technical trials of

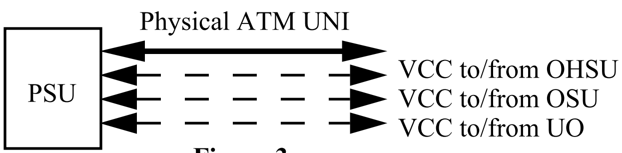

Figure 3
Phase 1 Connectivity: Three Virtual Channel Connections per Physical Connection.

associated equipment and customer applications. U S WEST engaged in two technical trials between April 1994 and March 1995, one with the UO and NERO, and the other in Boulder, Colorado. [12-13]

An integration of ATM LANs/WANs and IP networking

A primary area of emphasis at the UO during this trial was a complex mixture of ATM LAN and WAN capabilities. ATM connectivity was extended to high-end desktop workstations as well as to routers which were located at participating institutions across Western Oregon. IP networking was stressed, along with a mixture of ATM PVCs and SVCs, both local and remote. This was accomplished within an environment which combined customer-owned ATM switches at the local level with public ATM services provided by U S WEST over the wide area. This unique combination of ATM LANs/WANs, IP networking, and ATM SVCs/PVCs placed the UO at the leading edge of these activities during 1994 and early 1995.

Figure 1 illustrates the overall picture of the various components which were involved in this experimentation. Starting at the top of the Figure, there was an ATM backbone switch which provided connectivity between campus ATM switches and which also provided access to the wide area ATM network provided by U S WEST. One of the campus ATM switches provided connectivity between the previously-discussed routers which comprised the collapsed campus backbone networks. Other ATM switches located in remote buildings served two purposes. They provided direct ATM connectivity to workstations and hosts which were able to communicate directly over ATM using native IP per RFC 1577. [14] Examples of these types of devices which were widely utilized during the trial are SUN and SGI workstations which could be configured with ATM adapter cards and could benefit from the extension of high-speed ATM UNIs all the way to the desktop.

As shown in Figure 1, the remote-building ATM switches also provided connectivity to high-end hubs which provided various types of connectivity such as 10BASET and 100 Mbps ethernet to devices which do not directly support ATM interfaces. These devices participated in the extended ATM infrastructure via LAN Emulation. [15] LAN Emulation Services (LES) is an effort by the ATM Forum to provide interfaces and protocols that will allow LAN-like features to be emulated by interfaces and protocols built on top of ATM. The use of LAN Emulation and high-end hub devices allowed the UO to not only preserve their imbedded investment in legacy interfaces, but also allowed them to most efficiently utilize various types of cost-effective device interfaces which would emerge in the future.

Moving from PVCs to SVCs

The combined UO/U S WEST ATM trial actually proceeded in two phases. In phase one of the trial U S WEST provided Virtual Channel Connections (VCCs) between customer locations. Figures 2 and 3 show a simplified example using only four of the participant locations for illustrative purposes. A full mesh of VCCs was provisioned between locations as shown in Figure 2. As shown in Figure 3, the UO was provided with a single physical ATM UNI and three VCCs were pre-provisioned across this physical interface, one going to each of the other three locations. Thus each location could talk to every other location over pre-provisioned VCCs. Since these VCCs were pre-provisioned, phase 1 of the trial was utilizing permanent virtual circuits (PVCs) rather than switched virtual circuits (SVCs).

Although the use of PVCs is conceptually simple, in actual practice the management of these PVCs became extremely difficult. The situation was aggravated by the complexity of the local ATM configurations which were emerging. Figure 4 shows a typical local ATM configuration in use at the University of Oregon. Two types of local ATM switches were being used: three Cisco ATM A100s and two Fore Systems ASX-200s. Two Cisco routers and a workstation were connected to two of the Cisco A100 switches, while two workstations were connected to one of the Fore System ASX-200 switches. A total of seven PVCs were necessary for this basic configuration to function. Three PVCs were provisioned for router #1 so it could communicate with its counterparts across the wide area ATM network. It was necessary to pre-define each of these three PVCs in two Cisco ATM switches, a Fore Systems ATM switch, across the public network, and through a corresponding set of local ATM switches at the other ends. It was also necessary to pre-provision a PVC between the two routers, requiring configuration in two of the Cisco A100 ATM switches. Finally, each of the three workstations needed a pre-provisioned default route to one of the routers, again requiring configuration work across multiple ATM switches. When this level of complexity was multiplied by the other locations and compounded by projections of rapid expansion of ATM facilities, the future began to look grim indeed for those responsible for ongoing maintenance of the network environment.

The solution was to implement switched virtual circuits (SVCs) which could be dynamically established as needed without the need for extensive pre-provisioning of PVCs. The UO accomplished this during the second phase of the trial. During the second phase of the trial, U S WEST provided wide area switching capabilities which supported virtual path connections (VPCs) in addition to VCCs. VPCs are collections of VCCs which are transported and switched together, leaving the customer free to define their own VCCs within the VPC. The public network switches the VPCs as a unit, ignoring the internal construction of VCCs.

The UO implemented SVC capabilities across the local area and then extended this capability across the wide area, even though the public network provided by U S WEST did not support SVC capabilities. During the second phase of the trial the mesh of VCCs shown in Figure 2 was replaced by a mesh of VPCs, and the VCCs shown in Figure 3 were also replaced by VPCs.

SVCs over the local and wide area

Given that local ATM switches were the first to emerge in the marketplace, along with the fact that proprietary solutions are much simpler to initially implement, it is understandable that vendors of local ATM switches were the first to implement ATM SVC capabilities. Fore Systems was one of the leaders in these efforts, outlining and testing their approach to SVC capabilities in late 1992 and early 1993. [16-17] The SPANS (Simple Protocol for ATM Network Signaling) protocol provided the ability to establish SVCs between devices attached to a Fore Systems ATM switch. A companion protocol called SPANS-NNI provided the ability to establish SVCs between devices on a multi-switch network. [18]

The UO worked with both Fore Systems and Cisco Systems on early implementations of the proprietary SPANS protocol and the ATM forum standard protocols such as UNI 3.0 and IISP. [20] As the specifications matured they began to move to standardized solutions which would allow interoperability between multiple vendor's devices. In addition, the Fore Systems SVC capability provided the ability to tunnel over a full-mesh VPC PVC network. [19] This combination of abilities provided the opportunity to mix Fore Systems ATM switches, Cisco Routers, and public wide area ATM services in an ATM SVC environment which spanned most of Western Oregon. Thus it was possible to not only establish an ATM SVC between two devices located on the UO campus, but also to establish an ATM SVC connection between a device located on the UO campus and a device located at one of the other campuses such as OSU, PSU, or OHSU.

Logical IP subnets and ATM SVCs

It is interesting to note that the UO did not make wide use of the ability to establish SVCs over the wide area, even though it was possible. The reason is that most local networking environments at universities in Oregon are segmented into one or more "Logical IP Subnets" (LIS). [14] Connectivity outside of an LIS is almost never done directly via an ATM SVC. Rather, connectivity between LIS's is usually done via IP networking. The situation is probably best explained by referring to Figure 5. As shown in Figure 5, there are two hosts which are located on different campuses. Each is connected to a local campus ATM switch. A router is also connected to the local ATM switch at each campus. The local campus ATM switches have access to one another via the public ATM network. The public ATM network as provided by U S WEST in the second phase of the trial supported "public virtual path" switching, allowing VPC connectivity between customer locations.

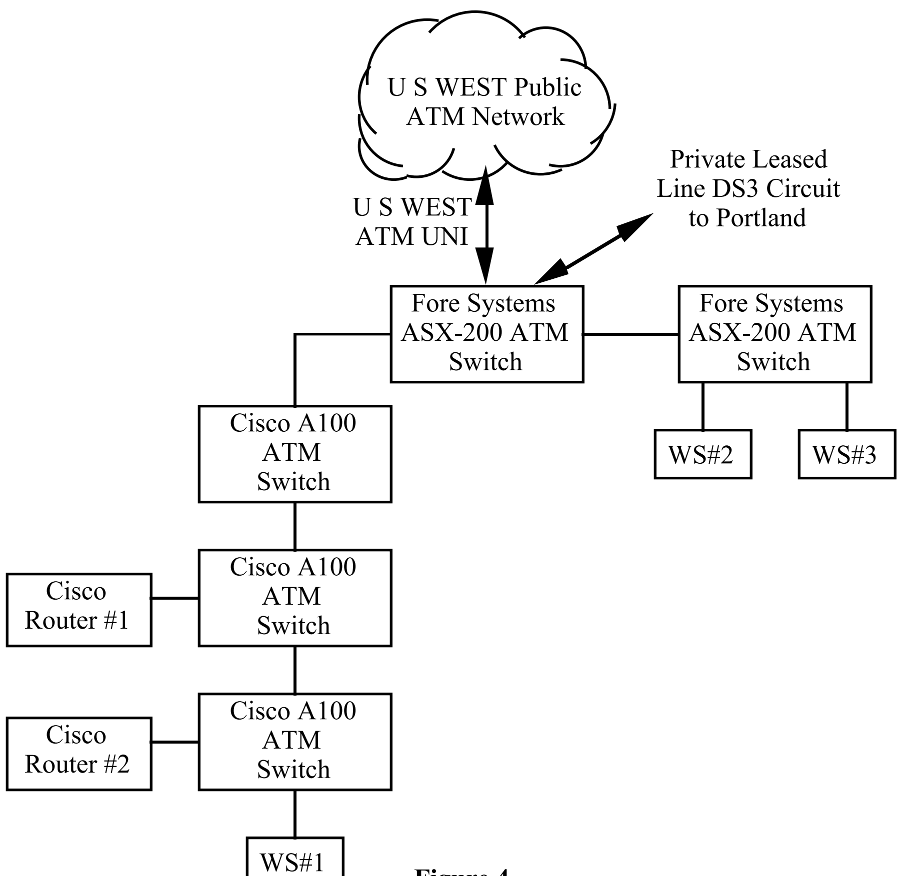

Figure 4
Typical Local ATM Network Configuration at the University of Oregon

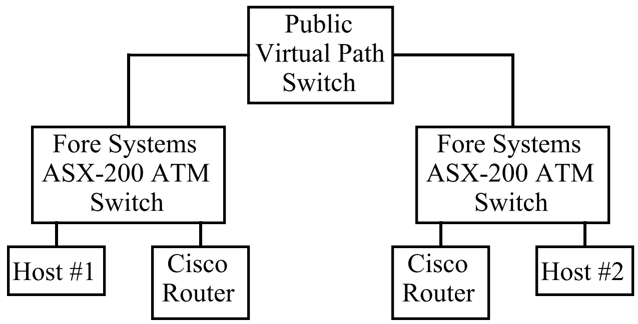

Figure 5
Typical Configuration for Host-to-Host Communication Between Logical IP Subnets

Let's assume that Host #1 wants to send a message to Host #2. It would be technically possible for Host #1 to dynamically establish an ATM SVC to Host #2. However, based upon the IP address, Host #1 recognizes that Host #2 is on a different LIS. It therefore sends the message to its default router via a previously established ATM SVC. Host #1's router realizes that it must send the message on to Host #2's router. In a PVC-based network, the message would be sent via a pre-provisioned PVC which would have been nailed up between the two routers. In the SVC environment, the message is sent via an SVC which has been established between the two routers using either SPANS-NNI or the Interim Interswitch Signaling Protocol (IISP). [20] Once delivered to Host #2's router, the message is delivered just like any other arriving message.

This combination of local and wide area ATM switches, IP networking, VPCs and VCCs, and SVC/PVC capabilities has proven to be extremely useful to the UO.

An opportunity for enhanced applications

A detailed examination of applications which were enabled by this new ATM environment is outside of the scope of this paper. However, it would be appropriate to mention the general trends which emerged as the trial progressed. In general, the UO utilized high speed ATM UNIs in close conjunction with IP networking to provide upgraded IP networking capabilities in Oregon. The ATM-based IP network which was created jumped from the old 1.5 Mbps T1-based internet to a new 155 Mbps OC3c-based internet. This 100-fold jump in raw speed and aggregate bandwidth enabled more efficient execution of a number of applications including delivery of video via MBONE, access to multimedia servers for educational purposes, desktop teleconferencing, telemedicine, remote control of robotics equipment, and access to supercomputers. For more details on these applications, please refer to [12] and [13].

Summary comments

In summary, the LAN environment at the University of Oregon has evolved rapidly over the past 10 years. The proliferation of campus LANs has led to an ongoing need for more efficient high-speed campus backbones which can adequately handle the traffic moving between individual LANs. Early use of fiber ring backbones was abandoned in favor of collapsed backbones which were initially implemented in routers, but which are now migrating to more specialized external ATM switches. These specialized ATM switches can provide not only campus backbone connectivity but also wide area ATM connectivity. The ability to implement ATM SVCs across both the local and the wide area has been extremely important to the UO as networking infrastructures have become more complex. Experimentation conducted jointly by the UO, U S WEST and others during 1994 and 1995 placed the UO successfully at the leading edge of developments in this area of networking technology.

References

[1] Ross, F.E., "FDDI - A Tutorial", IEEE Communications Magazine, vol. 24, no.5, pp.10-17, May 1986.

[2] Burr, W.E., "The FDDI Optical Data Link," IEEE Communications Magazine, vol.24, no.5, pp. 18-23, May 1986.

[3] Wallach, S., "FDDI Tutorial", LAN: The Local Area Network Magazine, March 1987.

[4] M. Moore, V. Oliver, "FDDI: A Federal Government LAN Solution", TELECOMMUNICATIONS, September 1989.

[5] F. Ross, "An Overview of FDDI: The Fiber Distributed Data Interface", IEEE Journal on Selected Areas in Communications, Vol. 7, No. 7, September 1989.

[6] M. Swastek, D. Vereeke, D. Scherbarth, "Migrating to FDDI on your next big LAN Installation", Data Communications, June 21, 1989.

[7] John Leong, "Managing the Distributed Computing Environment at Carnegie Mellon University", Presentation to CMU ATI Students, November 11, 1992.

[8] J. Mulqueen, "Looking Ahead, User Chooses ATM", Communications Week, September 7, 1992, pp. 1, 58.

[9] M. Zeile, "Expanding the Enterprise by Collapsing the Backbone", Data Communications, 21 November 1992.

[10] S. Owen, "Network for Engineering and Research in Oregon", Proposal submitted to Education Division of National Aeronautics and Space Administration, 23 September 1993.

[11] B. Wallace, "U S WEST plots ATM course with planned expansion", Network World, 18 October 1993, pp. 28, 31.

[12] R. Foldvik, D. Meyer, D. Taylor, "ATM Network Experimentation in the State of Oregon", Proceedings, IEEE International Conference on Communications, June 1995.

[13] R. Foldvik, O. McBryan, "Experiences with ATM: The Boulder Perspective", Proceedings, IEEE International Conference on Communications, June 1995.
[14] M. Laubach, "IETF Draft RFC - Classical IP and ARP Over ATM", RFC 1577, January 1994.
[15] LAN Emulation Over ATM, Version 1.0, The ATM Forum, (af-lane-0021.000), January 1995.
[16] Fore Systems , Inc., "SPANS: Simple Protocol for ATM Network Signaling", August 1992.
[17] E. Biagioni, E. Cooper, R. Sansom, "Designing a Practical ATM LAN", IEEE Network, March 1993, pp. 32-39.
[18] Fore Systems, Inc., "SPIRAL: Simple Protocol for Inter-Switch Routing in ATM LANs", January 1993.
[19] D. McDysan, D. Spohn, ATM Theory and Application, McGraw-Hill 1995, ISBN 0-07-060362-6, pp. 321-331.
[20] Interim Inter-Switch Signaling Protocol (IISP) Specification, Version 1.0, 13 December 1994, ATM Forum Contribution 94-0924R3.