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The ATM Conversion at Sandia National Laboratories

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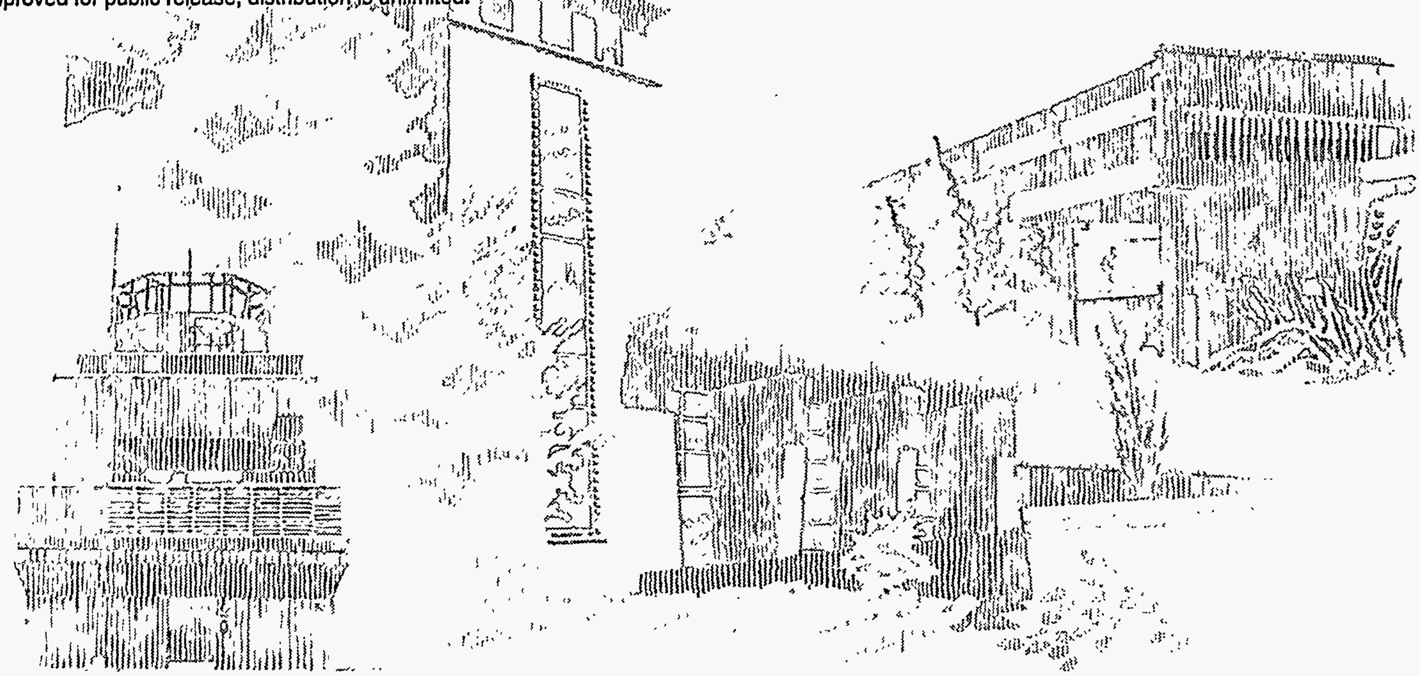

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Abstract

Converting a large, heterogeneous, networked, environment to ATM (Asynchronous Transfer Mode) can yield many benefits. Before these benefits can be reaped, however, numerous decisions must be made and implemented. This paper presents a case study which describes the steps that were necessary to convert a backbone network at Sandia National Laboratories in Albuquerque, New Mexico to ATM. It presents each step by explaining its importance and what options were considered along with their tradeoffs. It is hoped that organizations contemplating converting to ATM will have a better understanding of how the transition is implemented after reading this paper.

The ATM Conversion at Sandia National Laboratories

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1.0 Introduction

Converting a large, heterogeneous, networked, environment to ATM can yield many benefits. Before these benefits can be reaped, however, numerous decisions must be made and implemented. This paper presents a case study which describes the steps that were necessary to convert a backbone network at Sandia National Laboratories (SNL) in Albuquerque, New Mexico to ATM.

Building a new ATM network or converting an existing network to ATM can be a complex, time-consuming task. In order to implement ATM, numerous decisions must be made which include, but are not limited to:

- how much of the network will become ATM,
- what network topology will be implemented,
- what type of ATM signaling will be used,
- what ATM equipment is needed,
- what type of media will be used to provide network connections,
- what type of routing will be used,
- what type of traffic shaping or Quality of Service is needed,
- how will the network be managed,
- and how will the network be repaired if problems arise.

Each one of these topics requires a separate paper or even a book to address them thoroughly. This article will address just enough of each item to illustrate why the topic needs to be addressed, what alternatives are available, and what are the tradeoffs. These topics will be explored by using the conversion of Sandia National Laboratories' network as a case study.

2.0 Implementing ATM at Sandia National Laboratories

Computing is extremely important at SNL, and it is used in many areas from simulation and CAD/CAM to payroll and inventory. The Sandia Albuquerque location has over 10,000 personal computers and workstations, numerous file servers and midrange computers, and several high end file servers and supercomputers which include an Intel Paragon (which once held the record of being the world's fastest computer), three Cray J90s, a High Performance Storage System (HPSS) with a 10 Terabyte storage capacity, and an IBM 3090 mainframe. The Sandia Livermore computing environment is similar, but on a smaller scale.

Networking is very important because of the large number of computers (over 10,000 total) and the campus-like environment of SNL. Each location consists of two main computing environments: scientific and administrative. The scientific environment is much larger than the administrative which is used mainly for payroll and inventory. The scientific environment is further subdivided into two separate environments: secure and unclassified. The secure environment is used for classified computing and is interconnected via a physically separate, independent network. The unclassified environment is used for general purpose computing and also connects to the Internet. The unclassified environment comprises the bulk of the computing done at SNL with over 8000 nodes. The scientific environments of the two sites are connected via a private DS3 (45 Mbps) network.

SNL has been involved with ATM from 1992 and is a principal member in the ATM Forum. SNL has characterized ATM equipment including modeling flow control, developed ATM encryption, has built several prototype ATM LANs, and staff members have published numerous papers on ATM.

2.1 Defining the Domain of the ATM Network

In order to fully exploit the numerous benefits of ATM, including the increased throughput and the ability to handle data, video, and voice, a large scale ATM implementation was required. The first major issues to be decided was how much of the SNL network would become ATM based and where to introduce ATM switching.

SNL decided to work from the core outward for the following reasons:

- Fewer parts of the ATM standards needed to be completely functional and commercially implemented;
- It would have the largest impact and benefit to the users;
- It would benefit SNL topology by
    - flattening the existing network,
    - improving reliability,
    - improving visibility,
    - simplifying router tables.

Because of the maturity of the ATM specifications and the products available, converting only the backbone required lower levels of functionality than doing total end-to-end ATM. For example, by using Permanent Virtual Circuits to connect backbone routers meant that specifications and products for LAN Emulation (LANE) need not be fully functional. Because of the large number of nodes at SNL, and the cost involved, with approximately $1000 for a OC-3c network interface card (NIC) and $1000 for a port on an ATM switch, converting every node to ATM was not practical from an economic standpoint. Also, not everyone needed or desired ATM to the desktop. From surveys conducted internally, it was determined that only between 10 and 20 % of the total user population needed ATM to the desktop initially. Finally, many of the older machines do not have ATM interfaces commercially available for them. For these reasons it was decided to convert only the backbone of the SNL Unclassified Network at New Mexico initially. This network is comprised of the External Open Network (EON) and the Internal Restricted Network (IRN).

A simplified diagram of this network is shown in Figure 1. As illustrated by the diagram, this network was in need of fewer layers and simplifying.

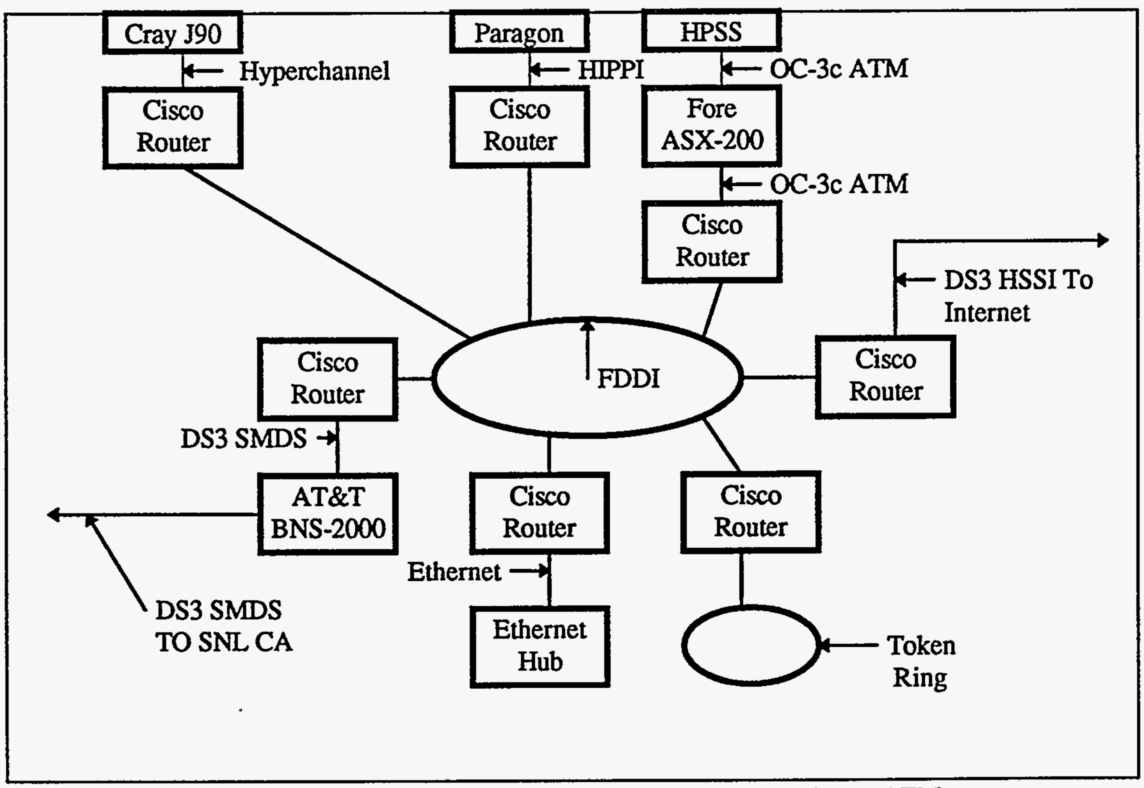

Figure 1. The Unclassified Network at SNL in Albuquerque before converting to ATM.

To be more specific, because the backbone of the SNL Unclassified Network was based heavily upon Cisco routers, the networks which connected them were converted to ATM first. The other high performance nodes, such as the supercomputers which used technologies such as FDDI, Hyperchannel, and HIPPI, were also converted. If SNL consisted of one small office; however, the solution could be different; convert all of the nodes to ATM, if possible.

2.2 Selecting ATM Equipment

Once the domain of the ATM network was defined, the ATM equipment had to be selected. This equipment included the ATM switch or switches, the network interface cards (NICs) which connect a node to the ATM network, any special software such as drivers, and transmission media such as fiber or cable. It should be pointed out that many factors influenced the equipment selected. The equipment had to be selected as an integrated group, not as disjoint pieces of equipment.

2.2.1 Choosing an ATM Switch

It was estimated that over 100 backbone nodes would need to be interconnected via ATM within 36 months. The conventional approach to this was to stack several small, relatively inexpensive switches together. Although on the surface this appears to be an easily implemented, inexpensive solution, it does have several drawbacks. First this solution does not scale well. SNL needed a large switch to start, with the capacity to grow larger. Ports on the switches are used to interconnect the switches. This reduces total capacity. Other drawbacks include network management; it is more difficult to manage several switches than one switch. Reliability of the network decreases as switches are added. Maintenance is also a problem; many of the small switches do not have hot swappable modules, good diagnostics, or full featured management systems. For these reasons SNL decided to take the alternate approach of one large central ATM switch for its backbone.

Because of that approach choosing an ATM switch or switches depended upon many factors. Major items were: capacity, number and types of ports, switching system availability, hot swappable modules, interoperability with Cisco routers, and compliance with ATM Forum standards.

To convert the existing SNL Unclassified Network, and allow for expansion as well as supporting new ATM applications, it was determined that the switch needed to be able to support 128 OC-3c (155 Mbps) ports. This required the switch to have 20 Gbps (128 x 155 Mbps) aggregate capacity. The actual switch architecture was not a requirement, although non-blocking was preferred. In a non-blocking switch, each input port has an independent path to each output port ensuring that cells are not blocked by the switch fabric. SNL needed a powerful architecture because the actual traffic parameters were not well known other than peak data rates.

The types of ports were also important for the SNL ATM switch. The switch was required to have OC-3c ports that would run over the SONET transport network infrastructure which was already in place at SNL. In addition, the switch was also required to support DS3 (45 Mbps) ports. These ports were needed to provide intersite ATM connectivity between the two SNL locations. Because the ATM switch was going to be used as a backbone switch, lower speed ATM interfaces such as the 25 Mbps interface were not immediately required. If, in the future, lower speed ATM access is needed, it will be provided by edge switches.

Compliance with the most current version of the ATM Forum signaling specifications for the User Network Interface (UNI) and Private Network to Network Interface (PNNI) was required. The UNI specifications define the method for connecting a single node to an ATM network. The PNNI specifications define the method to connect ATM switches together. These requirements were necessary to insure compatibility with equipment from other vendors who adhere to the ATM Forum standards. SNL did not desire to have its backbone switch incompatible with the majority of ATM equipment.

In addition to being compliant to ATM Forum standards, SNL wanted to ensure compatibility with its inventory of Cisco routers. SNL had over 50 Cisco routers which it planned to connect to the ATM network within a several month time period. Therefore, at a minimum. the ATM switch had to be able to operate over SONET using Permanent Virtual Circuits (PVCs) between the Cisco 7000 routers equipped with the single mode fiber version of the ATM Interface Processor (AIP).

Since this switch would become the main hub for the SNL backbone, switching system availability was critical. The switching system was comprised of the ATM switching fabric, line cards (which contain the I/O ports), other switch equipment, power supplies, management system and software. Availability was defined as:

$$\text{Availability} = (\text{MTTF} / [\text{MTTF} + \text{MTTR}]),$$

where MTTF = Mean Time To Failure and MTTR = Mean Time To Repair.

The availability requirement of 0.9999 was chosen after discussions with SNL users who would become dependent upon this switch and who also provide the funding. This equates to about 53 minutes of unavailability per year.

The last major requirements were redundancy and hot swappable modules. Redundancy was needed in all of the critical components. Also, in the event of a failure, the switch was required to have hot swappable modules. It was not acceptable to power off the ATM switch to replace a faulty module or add new equipment such as line cards. The intention behind these requirements was continuous operation.

Many of the requirements discussed were necessary because the ATM switch was to be used as the backbone switch in a large, diverse, campus-like environment. If, for example, the switch were to be used in a smaller environment, connecting workstations and/or personal computers, a single vendor approach would also have its merits. In this approach the ATM switch, NICs, and software are selected from a single ATM equipment manufacturer. This almost guarantees a highly compatible system. The drawback is that it may sometimes limit future equipment options by "locking in" the user to a single ATM equipment manufacturer. Throughput Vs cost is another important issue. This is especially important for long haul ATM links which are leased from a service provider.

The contract for the ATM switch was awarded to AT&T/Lucent to provide its GlobeView-2000 switch. This switch met all of the demanding SNL requirements.

2.2.2 Choosing a Network Interface Card

A Network Interface Card (NIC) is used to connect a node such as a host computer, router, or other device to an ATM network. Adding a NIC to a node involves physically adding the card and driver software to support the card. Depending upon the operating system involved, a new kernel may need to be built. NICs vary in their throughput, physical connection to the network, the way they convert packets into ATM cells, which is called Segment Assembly and Reassembly (SAR), and other parameters. The first generation NICs were not very efficient which was why the early ATM interfaces in a node were not as fast as a similar nodes with FDDI interfaces. Now that the ATM industry is producing second and third generation NICs, the ATM advertised speeds are more easily attainable.

The NIC cards used to convert the SNL backbone to ATM were the single mode fiber version of the ATM Interface Processor (AIP) which was used in the Cisco 7000 routers. Using NICs from the same manufacturer as the machine in which it will be used helped insure compatibility. For SNL, however, it was the only option available because no other vendor made NICs for Cisco routers. This was also the case with the Crays. SNL had no other purchasing alternative except Cray. The Cray NIC was really built by Fore Systems but uses a Cray developed driver. A very unusual case was the Intel Paragon. SNL wrote the Statement of Work and GigaNet designed and built the interface jointly with Intel. For other machines such as workstations there were more choices. Many ATM switch manufacturers marketed NICs for them. Also several workstation manufacturers offered NICs for their workstations.

2.2.3 Cabling or Wiring the ATM Network

Another important issue for all ATM networks, including the one at SNL, is wiring or cabling. As mentioned earlier, SNL is a diverse campus-like environment. Because of that, the choices of cabling that would support moderate distance (less than 5.0 KM) high speed (OC-3c) ATM traffic were somewhat limited.

Basically, there are two types of media used to wire ATM networks. They are Unshielded Twisted Pair (UTP) wiring and fiber optic cable. UTP wiring comes in 5 categories ranging from Category 1 UTP (lowest quality) up to Category 5 which is the highest quality. UTP is a popular media and there are specifications which allow the use of UTP with other networking technologies such as FDDI, Token Ring, Ethernet, and Fast Ethernet. UTP is relatively inexpensive and is easy to install and maintain. Several ATM switch vendors have switches that contain interfaces for UTP-5 copper which operate at OC-3c rates (155 Mbps).

There are however, several drawbacks to UTP. Due to the physics inherent in twisted pair wire, data transmission rates will be limited. Newer high speed technologies will probably require other media. Another problem is that because copper has an electrical resistance in direct proportion to its length, UTP can not be used exclusively to interconnect a campus or metropolitan type network.

Fiber optic cable is the other method used to interconnect ATM gear. The diameter of the inner core determines if the fiber is multimode or single mode. New multimode fiber is typically has a 62.5 micron inner core. Single mode fiber has an inner core diameter in the 8.3 micron range. Because light travels in the inner core of single mode fiber with very little refraction, it is often used for long distance transmission.

Fiber offers many advantages over copper wiring. These include capacity to carry more traffic, and immunity to electrical, magnetic, or radio frequency interference. If security is an issue, fiber is also safer. It is more difficult to extract a signal from a fiber than UTP wiring. SONET multiplexers can be used with fiber to run several independent circuits over a single fiber. This utilizes more of the available bandwidth. These multiplexers can also extend the distance the signal can travel by regenerating the signal at each multiplexer.

Fiber also has several drawbacks. The first is the installation. To upgrade a cable plant of a building to fiber involves running fiber throughout the building and terminating the fiber. Compared to copper wiring, fiber is more easily damaged. Although this is changing rapidly because due to more rugged cable. If damaged, the error rate will increase dramatically. Terminating fiber is also important. For short runs, fiber can be purchased with the ends pre-terminated. If fiber must be terminated, it is best to have it done professionally, because improperly terminated fiber will often suffer performance degradation due to light escaping at the connection. The connectors must also be of the correct type for the ATM gear being used. Finally, mixing single mode and multimode fiber or fiber with different inner core diameters can have unpredictable and, in many cases, disastrous results.

Fiber optic cable was the only choice at SNL because of security and the SNL campus-like environment. To upgrade the fiber plant at SNL to support ATM required several steps. SNL already had most of its routers connected with other technologies using point to point and multiplexed SONET. However, it was necessary to run single mode fiber from an existing fiber distribution unit to a fiber patch panel which was near the GlobeView-2000 ATM switch. It was also necessary to run fiber from the patch panel to the line cards on the ATM switch. This permitted a cleaner looking installation and made troubleshooting easier by having all of the fiber to the GlobeView-2000 come from a well documented patch panel. Single mode fiber was used throughout because both the Cisco routers and the Globe-View-2000 switch were equipped with single mode fiber interfaces. At the time of the actual conversion, the multimode fiber used to connect the routers to the existing FDDI ring was converted to single mode fiber and connected to the ATM interface. This is illustrated in Figures 2 and 3. It should be noted that these views are for locally connected routers. For remote routers, SONET multiplexers are used between the routers and patch panel.

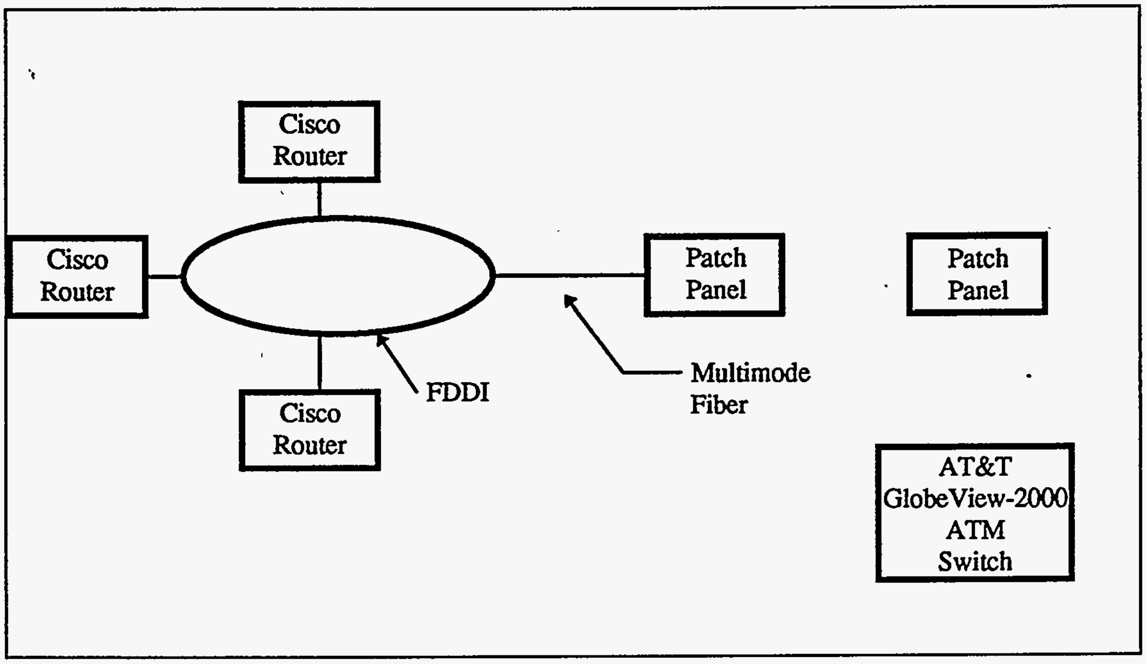

Figure 2. Fiber connectivity before the ATM cutover.

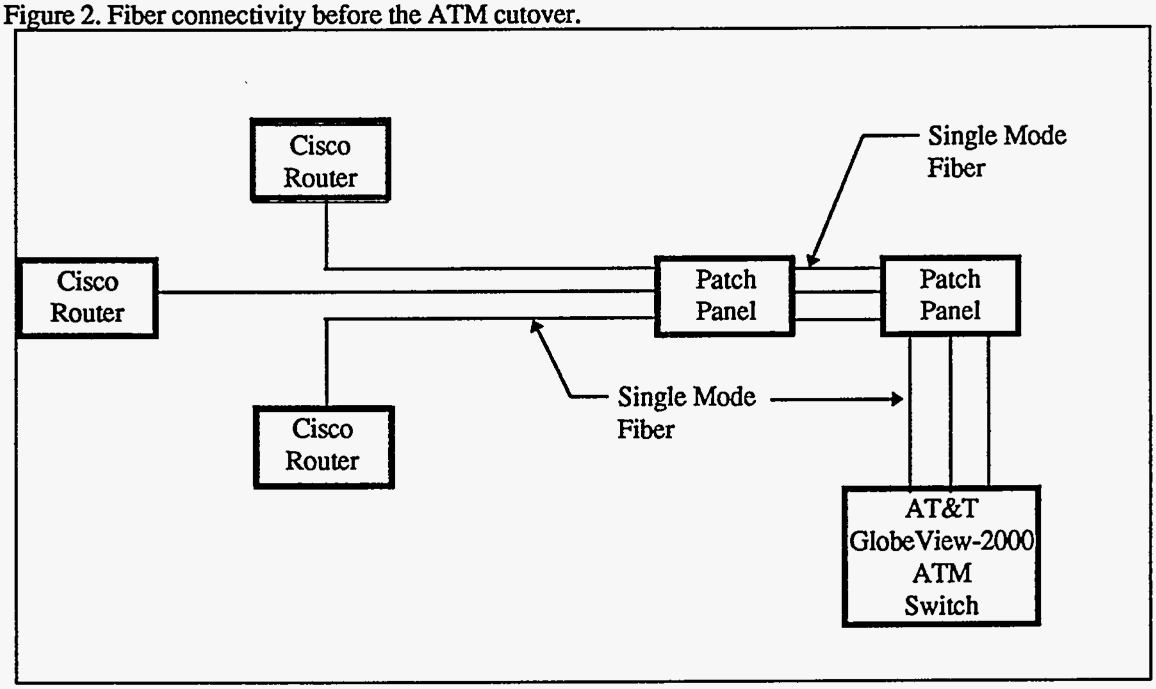

Figure 3. Fiber connectivity after the ATM cutover.

3.0 ATM Network Configuration

Although selecting the right ATM equipment was an important step in designing an ATM network, there were several other steps that needed to be addressed. One of these steps was ATM network configuration. The areas encompassed in network configuration included ATM connection establishment, quality of service, higher level protocols, routing, and LAN Emulation.

3.1 ATM Connection Establishment

In order for one ATM node to communicate with another ATM node, an ATM connection must be established. As mentioned earlier, there are two main types of ATM connections: UNI and PNNI. There are two methods in which connections are established: static or dynamic. Static ATM connections are called Permanent Virtual Circuits (PVCs) or Permanent Virtual Paths (PVPs). A PVC is one individual circuit, while a PVP is a group of PVCs. Static connections are manually set up by the switch operator and will remain in place until they are manually removed.

Dynamic ATM connections are called Switched Virtual Circuits (SVCs). The connections are created when needed and only remain until the call is completed. Once the call is completed the SVC is removed or "torn down". There are different methods of performing signaling. Several switch vendors have developed their own proprietary signaling. An example of that is Fore Systems switches which perform a signaling called SPANS. The ATM Forum has developed signaling standards UNI 3.0 - UNI 4.1. Vendors adhering to these standards insure that their equipment will interoperate with other vendors equipment which also adhere to this standard. It is sometimes possible to use PVCs, PVPs, proprietary, and ATM Forum compliant switching on the same switch at the same time, but it should not be encouraged due to network management complexities.

The version of the GlobeView-2000 that SNL purchased did not support SVCs. Because of that, SNL had to use PVCs for the initial ATM cutover. SNL will migrate to SVCs when they are supported on the GlobeView-2000 later in 1997.

3.2 Quality of Service

Because it is usually necessary to provision one ATM physical interface for more than one ATM circuit, Quality of Service (QOS) parameters which allocate bandwidth to the individual circuits need to be addressed. There are four different types of QOS: Constant Bit Rate (CBR), Variable Bit Rate (VBR), Unspecified Bit Rate (UBR), and Available Bit Rate (ABR). CBR allocates a fixed percentage of the total capacity of the interface to an individual ATM circuit. VBR sets a guaranteed service for a certain percentage of the interface, but allows more traffic if there is extra bandwidth available. UBR doesn't allocate any bandwidth; it allows ATM circuits to use the bandwidth that is available. ABR is similar to UBR, but provides flow control. For all these four QOS, the total bandwidth used can not exceed the bandwidth provided by the interface. When any ATM connections attempt to use more bandwidth than allocated or available, ATM cells are dropped according to a traffic policing policy. QOS is still an area of active debate within ATM forum.

For the initial phase of the ATM cutover, SNL attempted to simplify matters and chose to use UBR. SNL monitors the traffic closely and has not had any problems with this QOS.

3.3 Higher Level Protocols, Routing, and LAN Emulation

Even though ATM was being used as the networking technology, there were still higher level issues that needed to be resolved; these included higher level protocols, routing, and LAN Emulation.

The Internet Engineering Task Force (IETF) wrote RFC 1577 which provided a standard method for ATM networks to support IP. Most vendors have adopted RFC-1577 and therefore IP over ATM works well. Other protocols such as IPX or Appletalk do not have similar support; therefore it was necessary for the individual vendor to support them. Cisco supported these protocols, so all of the existing protocols used at SNL remained viable.

Routing was also an important issue to be solved. Two routing schemes were considered. The first method was called the full mesh. In the full mesh, every node is connected via a virtual circuit to every other node through the ATM switch. There is no single bottleneck for traffic and therefore this method provides the most aggregate bandwidth for the backbone. For traffic to travel from one LAN to another LAN, it will only need to traverse a maximum of two routers.

The other method is a star topology. Using the star topology one router acts as the central node with all of the other nodes connected to it. This configuration allows for simple routing tables with minimal changes whenever a node is added or removed. This simplicity applies to IP only. Other protocols would still require significant changes whenever the network is modified. A disadvantage of this method is that one router will become a bottleneck because all of the nodes will need to communicate with it for routing information. This can also cause a single point of failure. Another disadvantage is that three router hops would be necessary to connect two LANs if they are not connected to the same router. Both topologies are illustrated in Figure 4.

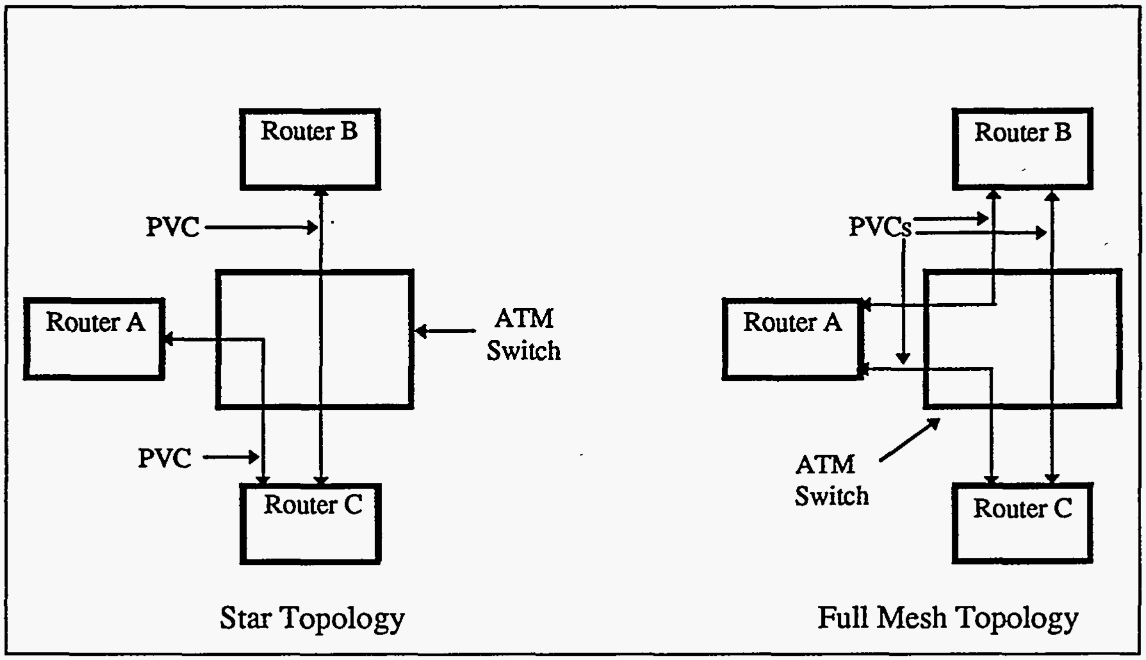

Figure 4. Diagram illustrating Star Topology on left and Full Mesh Topology on right.

Although the router tables were larger in the full mesh configuration, SNL decided that the benefits of increased throughput and reliability outweighed the costs of simplicity. For that reason, the full mesh was chosen to be the method used to interconnect the ATM nodes.

LAN Emulation, or LANE as it is sometimes referred to, is a standard developed by the ATM Forum to allow communications between ATM and Legacy networks independent of the upper layer protocols. Several vendors have devices to perform this task. These devices bridge networks instead of route. They tend to have small buffers and therefore force the ATM device to use the MTU (Maximum Transmission Unit) size of the legacy LAN. Experiments performed at SNL showed up to a 40% degradation in performance. Because the initial SNL conversion to ATM encompassed the backbone routers and a few computers, LANE devices were not considered necessary and therefore were not used.

4.0 Operations and Management

Once any network is built, it needs to be managed properly in order to insure reliable operation. The ATM network at SNL was no exception. Rather than listing all of the ATM network management and operations issues, only areas that were changed are discussed. These issues include staffing and training, network monitoring and troubleshooting, and vendor support.

4.1 Staffing and Training

Staffing was considered to be a very important issue for the success of the ATM network at SNL. At SNL there are separate internal organizations that operate different portions of the network, i.e. routers, infrastructure (wiring, fiber, and SONET), ATM switches, network management, etc. It was necessary to obtain representatives from all these organizations in order to both install and operate the ATM network. ATM was a relatively new technology, so it was necessary to provide training courses from the switch vendor (AT&T/Lucent) to several of the key operations personnel from each of the different organizations. It was considered necessary for the success of the network to have a "critical mass" of personnel trained in

ATM switches. Because SNL already had enough people trained in Cisco routers, no additional training was required in that area.

4.2 Network Monitoring and Troubleshooting

Due to the size and overall complexity of the networks at SNL, enterprise network management using a single network management package was not feasible. Several vendors of the equipment in use in the ATM network at SNL had their own package which managed their own equipment. These packages were required to manage the equipment from that vendor. However, these packages were only able to manage equipment from the specific vendor. They could not manage equipment from other vendors. Because of that, several network management packages were used, including an SNMP based package.

To monitor and manage the AT&T/Lucent GlobeView-2000 ATM switch it was necessary to use the GlobeView-2000 ATM switch management application. This package consisted of a HP 725/100 workstation and several software modules. There were separate modules for switch provisioning, alarm monitoring and troubleshooting, and performance reporting. Also included was an SNMP proxy agent. This allowed the switch to be monitored by an external SNMP based network management package. The Cisco routers were managed with a package named Cisco Works from Cisco Systems, Inc. This package allowed all of the routers to be configured from a common workstation, in this case a Sun Microsystems Sparc 2. This package has turned out to be a very valuable tool at SNL due to the large number of routers that must be managed.

The network management package which was used to manage the overall health of the SNL network was Seagate Enterprise Management Software which was formerly DiMONS by Netlabs. This package was SNMP based and was used to not only monitor the routers and the ATM switch but the individual LANs as well. Monitoring of the GlobeView-2000 ATM switch was accomplished indirectly via the AT&T supplied proxy agent.

4.3 Vendor Support

Because the ATM network became the networking backbone at SNL, vendor support from all the vendors whose products were being used was considered essential. If equipment was not under warranty, maintenance contracts were placed. Telephone hotline support was also purchased for problems that were more difficult to diagnose.

5.0 The SNL ATM Backbone

Figure 5 is an illustration of the SNL ATM backbone. The GlobeView-2000 supports two production environments: EON and IRN. Every node in each environment is connected via PVC to every other node in the same environment. This drawing is simplified. There are actually over 40 Cisco 7000 routers connected. All nodes other than those specifically noted, are interconnected using OC-3c ATM links with fiber optic cable using SONET as the underlying transport technology. Note how ATM simplified the network by eliminating the FDDI, Hyperchannel, HIPPI, and SMDS technologies. Also note that a Fore ASX-200 was added to connect the Paragon and another was added as an edge switch. It should also be noted that the Cray J90 will be connected via ATM later in 1996.

The SNL ATM Backbone has been quite reliable. There have been no service affecting outages in several months. It was also easy to manage once everyone had the proper training. Performance has been outstanding and there was also enough reserve capacity to encourage further growth.

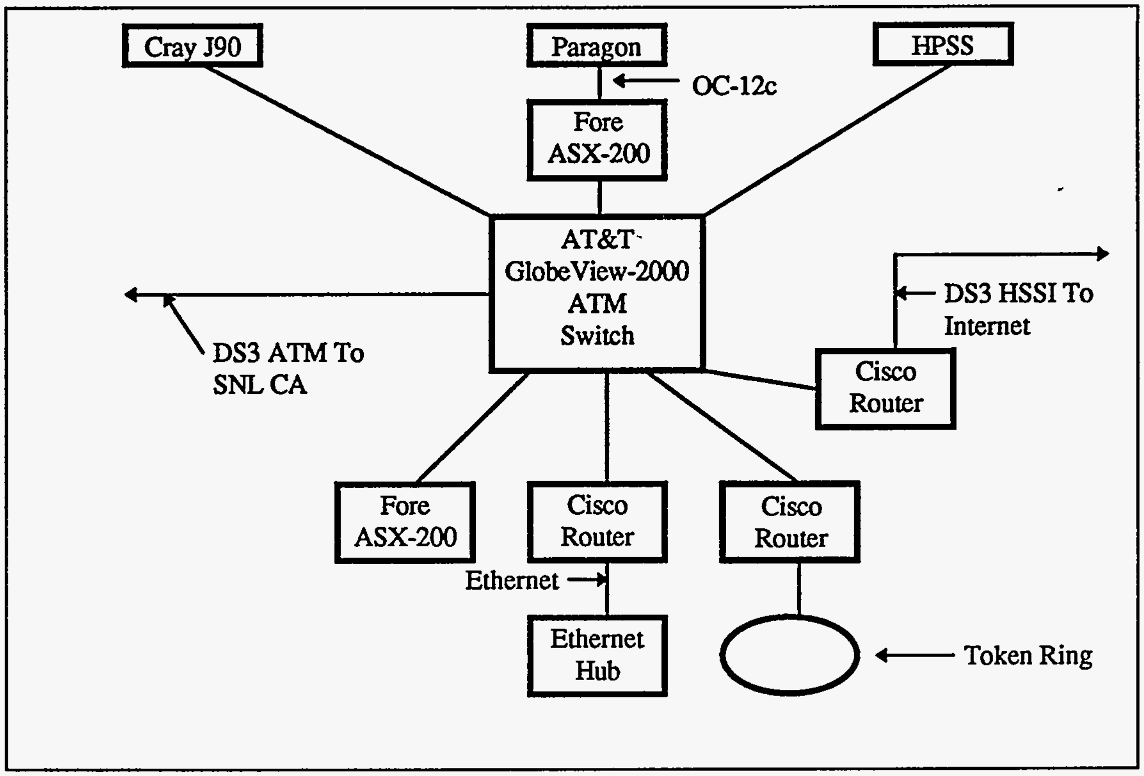

Figure 5. The Unclassified network at SNL in Albuquerque after converting to ATM.

Future plans are to acquire more OC-3c interfaces which will enable SNL to put another separate computing environment on the GlobeView-2000. An OC-12c interface will be added when it becomes available. In late 1997, the GlobeView-2000 will be upgraded to support SVCs. SNL will also connect more high end servers, including video, to this network as well as several ATM edge switches.

6.0 Lessons Learned

This paper presented a case study of how an existing shared media backbone at Sandia National Laboratories was converted to ATM. Sandia had several years previous experience with small ATM switches, so it already was aware of some of the problems that might occur and therefore was able to make many of the right decisions on the first implementation.

The only area that caused major difficulties was the version of the Cisco 7000 operating system or IOS. The routers were initially loaded with IOS 10.2(8). There were, however, problems with that IOS for the SNL multiprotocol ATM environment. Upgrading to IOS 10.2(11) solved these problems.

There were other issues that could have been improved. One area was estimated time to complete the conversion. It generally took longer than expected to get all of the necessary fiber run, equipment configured, staff members trained, and operating procedures in place. Another area which could have been improved is the fact that the GlobeView-2000 needed the network management platform to boot. For a fully redundant system, a backup network management platform for the GlobeView-2000 was required.

The final area that could be improved is signaling. The GlobeView-2000, when acquired, did not perform automatic signaling with SVCs. Instead a PVC for each connection was required. This required PVCs to be manually entered on each node and the end switch. The number of PVCs required for a full mesh is:

$$\text{Number of PVCs} = (N (N - 1))/2,$$

where N = the number of nodes. Dividing by 2 is possible because the circuits are bi-directional.

There were 24 nodes which were connected to the GlobeView-2000 initially. Therefore, 296 PVCs had to be created on the GlobeView-2000 and 23 PVCs created on each node. From this example, it should be apparent that PVCs may not be as convenient as SVCs for building a large ATM network.

This problem was alleviated by the fact that AT&T/Lucent provided a programming interface for the GlobeView-2000 so the PVCs could be provisioned and unprovisioned much faster than if done manually. Future releases of the GlobeView-2000 will support SVCs and SNL plans to upgrade when SVCs become available.

7.0 Conclusion

This article presented a case study of how an existing network at Sandia National Laboratories in Albuquerque, New Mexico was converted to an ATM backbone. It presents most of the relevant issues which must be solved before an organization can convert to ATM. It presents each issue explaining its importance and what options are available and their tradeoffs. It then describes what decision was made at Sandia National Laboratories. This paper should provide any organization contemplating installing an ATM network with a valuable tool to insure that an ATM network gets designed, installed, maintained, and managed properly.

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Bibliography

Davidson, Robert P and Muller, Nathan J 'The Guide To Sonet: Planning, Installing & Maintaining Broadband Networks', Telecom Library, Inc. 1991 ISBN 0-936648-29-5

Gossage, Steven A 'Delivery of Very High Bandwidth With ATM Switches and SONET', Sandia National Laboratories Internal Report, SAND92-1295, 1992

Naegle, John H 'Rough Draft On ATM Network Configuration', Sandia National Laboratories Internal Document, 1996

Naegle, J H, Gossage, S A, Testi, N, Vahle, M O, and Maestas, J H 'Building Networks for the Wide and Local Areas Using Asynchronous Transfer Mode Switches and Synchronous Optical Network Technology', IEEE Journal on Selected Areas in Communications, Vol. 13 No 4 (May 1995) pp 662-672

Onvural, Raif O 'Asynchronous Transfer Mode Networks: Performance Issues', Artech House, Inc., 1994, ISBN 0-89006-662-0

Partridge, Craig 'Gigabit Networking', Addison-Wesley Publishing Company, Inc., 1994, ISBN 0-201-566333-9

de Prycker, Martin. 'Asynchronous Transfer Mode Solution For Broadband ISDN Second Edition', Ellis Horwood Limited, 1993, ISBN 0-13-178542-7

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