BNL-NYSERNet ATM Project Report*

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July 1997

*Work performed partly under contract Number
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Inception of the Project

In 1994, Brookhaven National Laboratory (BNL) and NYSERNet, Incorporated embarked on a joint project to develop a prototype Asynchronous Transfer Mode (ATM) Regional Network testbed. This project was funded as a three-year effort under a Cooperative Research and Development Activity (CRADA) agreement between the parties, with half the funds being provided directly by the U.S. Department of Energy and the remainder as an in-kind contribution by NYSERNet. This report documents that effort as it comes to a close, providing an account of the original goals, the accomplishments of the projects, and the results as they might apply to the future.

It is useful to remember that, when the collaboration discussions first began in 1993, it was far from certain that ATM would be the technology of choice for the then-next generation of the Internet. That, of course, has turned out to be the case, which in retrospect makes this experience particularly valuable. The investigators were not totally prescient, however, and the project changed during its duration to account for changes in technology, available infrastructure, and other circumstances.

The first connection was to have been between Brookhaven and SUNY at Stony Brook, with a fiber-optic based infrastructure provided by Cablevision, Inc. The initial application was to involve the transfer of digitized medical images. Indeed, such a connection and demonstration did take place, but somewhat before the formal onset of this CRADA. As originally envisioned, the partners would eventually be able to reach other universities in the region, and take advantage of the other fiber conduits, notably that of NYNEX’s NYNET prototype, and the NYSERNet Sprint-based infrastructure.
The project had several goals from the outset. From Brookhaven's perspective, the outcome would be a robust, ATM-based high-speed regional network effected between the Laboratory and other major research institutions in the area. NYSERNet hoped to gain experience leading to providing a standard ATM high-speed offering to its clientele. Furthermore, it was hoped that this activity would help provide a stimulus to equipment providers and common carriers to offer products in this performance range. Progress was made toward the achievement of all of these goals in the course of this project.

Among the factors not originally considered were several which proved to be important in shaping the effort. Most significant was the minimal ATM connectivity. The Cablevision hookup was available for only a short period of time and, in any event, only connected Long Island institutions. The NYNET connection was not usable primarily because the Long Island segment was never linked to the upstate and downstate segments, and eventually a compromise connection was used to allow the project to progress. Lacking good connectivity between the principal partners, the work plan was modified to first concentrate on development of an ATM based Local Area Network at Brookhaven.

Another important factor was the number of distractions that both Brookhaven and NYSERNet experienced from elsewhere within their enterprises. Both were subject to remarkable network growth, increased service demands, new business plans, changes in personnel, and all the other occurrences that arise in a highly dynamic technological environment. It is indeed surprising that so much progress was made relative to the project's initial goals.

BNLnet ATM Core Implementation

In conjunction with the wide-area ATM investigation, the Brookhaven network engineering section set out to redesign the local BNLnet with the following goals in mind.

- Increase BNLnet backbone bandwidth.
- Increase aggregate intra-subnetwork bandwidth.
- Provide a wider array of network connection options by offering Switched Ethernet, Fast Ethernet and ATM connectivity options to the building, wiring closet and desktop.
- Migrate from shared media cable technologies to twisted pair and fiber optic host connections.
- Enable subnetworks to be deployed without existing physical location limitations.
- Lay the foundation for advanced services.
• Replace unsupported legacy network components.
• Tune performance without re-cabling.

It is interesting to note that the first goal listed, increasing the backbone bandwidth, which was used throughout the project as the "primary" justification for the upgrade was not realized. When the network redesign was completed, BNLnet was much improved, ATM was in the core of the production network, we met seven out of the eight original objectives, but still rely on an FDDI backbone ring to connect the backbone routers.

The FDDI backbone was preserved due to the low ATM OC3 port density available on the Cisco 7500 series routes (two per router). For this reason it was decided to use these high-speed interfaces exclusively to support Virtual LAN (VLAN) technology in the ATM core, each OC3 interface supporting approximately six VLANS. The ATM VLAN architecture had two immediate benefits; one was to increase the aggregate bandwidth available within a subnet and the other was to provide a wider array of network connectivity options at the end-station. By analyzing the Inter-VLAN traffic, the FDDI backbone load can be reduced by placing heavily communicating VLANS on the same router. This technique was not practical in the previous architecture, the routers were small and lacking ATM subinterface assignments, requiring recabling in order to move a subnet between two routers that could potentially be located in separate buildings. ATM based VLANS obviated the need to recable, merely reassigning one of the OC3 router subinterfaces allows it to route the VLAN. This same method will be used to provide router redundancy since multiple router subinterfaces can be assigned to each VLAN, all with no cable modifications. The use of larger routers is also a benefit here if deployed properly, reducing the number of routers from twelve to three reduces inter-router traffic on the FDDI backbone. These two characteristics make it possible to get the most out of the BNLnet FDDI backbone ring. The local configuration is depicted in Figure 1, below.

At this time ATM is being used primarily to uplink Ethernet switches to the core. At the station end, the Ethernet switches increase the aggregate intra-subnetwork bandwidth and provide the buffering necessary to mix different speed media on the same VLAN. The ability to deploy any VLAN switched in the core mesh on any of the VLAN capable Ethernet switches eliminates the rigid mapping of subnets to physical locations characteristic of other LAN implementations. Routers are used to forward datagrams between LANS. The removal of the geographical restriction on subnet deployment is advantageous for the Computing and Communications Division (CCD) because it allows for the placement of large servers within the well provisioned Brookhaven Computing Facility without incurring a router hop to get its client base; the server and clients are on the same VLAN. In fact, by multihoming the ATM connected servers via ATM subinterface assignment, CCD can place its systems directly on the VLANS where the demand is the greatest, again reducing router load.
On a campus with ninety one networked buildings, the ability to manage subnet assignments without running new underground fiber optic cable is a major advantage. Geographic flexibility combined with greater available bandwidth would permit most BNNet LANS to triple or quadruple in size and allow systems to be grouped by function rather than location. CCD’s Network Engineering plans to take advantage of these architectural features to reduce the total number of BNNet LANS and associated router hardware. Geographically dispersed Departments and Divisions will be brought together where appropriate, ultimately reducing the number of sub-networks.

While the ATM infrastructure so far only implements LANE and Classical IP, the foundation is in place for advanced ATM applications in the near term. The Laboratory’s FDDI backbone ring, which once linked routers in five separate buildings, has been
collapsed into a three router ring all in a single network lab. The ATM OC3 core now forms a star topology that spans the campus with high-speed fiber optic links.

Chronology of the Wide-area Network Connection

The earliest wide area ATM demonstrations utilized fiber and switches from Cablevision, Incorporated, in a testbed that served only the Long Island area. The goals of the project, however, called for the eventual inclusion of a statewide connection, and for that NYSERNet and Brookhaven looked to the NYSERNet/Applied Theory infrastructure partners, NYNEX and Sprint.

Installation of the DS3 ATM connection between Brookhaven National Laboratory and the NYSERNet/Applied Theory network really began with the letter of agreement signed by NYSERNet and BNL in August of 1996. This letter of agreement documented the duration and service levels associated with the trial and also provided a Service Description for participating partners (NYNEX, Sprint) to implement from. The service was described as a “DS3 ATM connection from BNL to NYSERNet using existing NYNET switches and circuits” and the following major components were identified:

- AIP interface in NYSERNet Deer Park router
- DS3 circuit from NYSERNet router to NYNEX Deer Park Newbridge ATM switch
- OC3 ATM service from NYNEX Deer Park Newbridge ATM switch to NYNEX Selden Newbridge ATM switch
- OC3 ATM service from NYNEX Selden Newbridge ATM switch to BNL ATM switch

The issue was also raised that the NYNET infrastructure was no longer being actively maintained by NYNEX. The trial proceeded with the understanding that this component which enabled a cost-effective infrastructure was the one component whose failure could not be accounted for in a support plan.

The letter of agreement also identified the following areas of responsibility:

- NYSERNet/AppliedTheory would provide “best effort” non-production DS3 ATM access for BNL to the NYSERNet Network. They would also work with BNL to design a proper routing and connection plan to minimize production network interruption on the BNL and AppliedTheory networks. In addition, NYSERNet would be responsible for the overall coordination of this effort and of the three other participants (BNL, NYNEX, Sprint). Support for the connection after installation would be handled by the AppliedTheory Customer Support Center, which would receive all trouble calls on the connection and coordinate restoration of service.
AppliedTheory would also monitor the connection insofar as existing systems were capable of considering the experimental nature of the service.

- BNL would provide, maintain and configure all customer premise equipment required for the ATM trial connection. They would also provide demarcation extension if necessary and local network integration. Finally, BNL agreed to provide the network engineering and support staff necessary to coordinate the installation and management of this service at the local level.

- Sprint would be responsible for and monitor the connection from the AppliedTheory production network up to and including the AIP interface in the AppliedTheory router at Deer Park. Sprint would also be responsible for the configuration of the router and the AIP interface.

- NYNEX would be responsible for and monitor the connection from the ATM Interface Processor (AIP) in AppliedTheory's Deer Park router to the AIP connection in the BNL router or switch (whichever BNL chose to deploy).

In September of 1996, the following proposed configuration, including AppliedTheory, BNL, and NYNEX components, was reviewed:

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+-----------------+      +-----------------+      +-----------------+
| DP2 (Cisco Router) |      | ATM Switch   |      | ATM Switch   |
|                   |      |               |      |               |
|                  |      | Deer Park CO |      | Selden CO    |
|                  |      |               |      |               |
|                  |      +-----------------+      +-----------------+
|                  |      | ATM LAN       |      |               |

AppliedTheory Production Network

Brookhaven National Laboratory
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Work began on specific tasks in support of those steps. The implementation actually spanned the next four months, resulting in successful passing of IP traffic between the AppliedTheory production network and a test router at BNL in January of 1997. A summary of some of the issues dealt with during those four months is included here to underscore their complexity and variety:

- Information and ideas were exchanged in preparation for creating a support plan to maintain the connection once it was up. Of primary concern was the issue of how to fix problems where all "pieces" of the connection seem to be working, but the whole does not. It was agreed that technical staff from each organization directly involved in maintenance (BNL, NYNEX, Sprint) would share information as to the diagnostic tools each had available to them for their part of the connection.
• It was necessary to make provisions for handling the capacity differences between the ATM local loop (155 Mbps) and the AppliedTheory production network backbone (45 Mbps). NYNEX determined that “traffic shaping” could be enabled on the switch such that traffic being passed through the interface would be limited.

• NYNEX expressed interest in using this project as a trial for their ATM service in addition to the testing being done by BNL and AppliedTheory.

• AppliedTheory struggled with the very serious issue of how to connect this trial link to their production network with minimum risk and impact on existing customer connections.

• NYNEX initially required detailed ATM configuration information from BNL in order to set up the connection across the two switches involved (i.e., configuration type and quantity of PVCs). Due to the fact that NYNEX and BNL had the most ATM expertise among immediate project participants, all communications occurred directly between NYNEX and BNL for this part of the implementation.

• Due to regulations involving equipment housed in telephone company providers’ central offices, some investigation and discussion was required before equipment could actually be ordered. In the final determination, it was agreed that NYSERNet would purchase a Cisco Single Mode OC3 ATM Interface Processor (CX-AIP-SS) from Sprint for installation by NYNEX into AppliedTheory’s DP2 router. It was also agreed that NYNEX would order and install the appropriate fiber jumper to connect the card to the Deer Park ATM switch.

• Much discussion surrounded the central issue of how to integrate those with the most expertise into the troubleshooting process while keeping call tracking and initial customer contact as “regular” as possible. This proved to be a struggle for each organization directly involved in support and illuminated the need to commit dedicated resources, at least initially, for the most effective support of such new services.

The application to be run over the test network, which is described below, required a high speed path between Brookhaven and Cornell University. At Brookhaven, the major issue for accommodating the test bed traffic concerned routing. Specifically, it was necessary to distinguish the T3 testbed project traffic from that of the production T1 connection. The following BGP advertisement filters and interface weighting provide the ability to control the routing of traffic between Cornell and the BNL test subnetwork from the BNL border gateway router. This control of all routing was performed from the BNL border gateway router. The following routing discipline was used:

BNL Production T1
Out - Filter out the BNL test subnet (130.199.6.0) advertisements from the production T1.
In - Accept all incoming advertisements.
**BNL experimental T3 over ATM**

*Out* - Only allow the BNL test subnet (130.199.6.0) to be advertised from the T3.

*In* - Filter all incoming BGP advertisements except those from Cornell.

Weight the T3 more favorably than the T1.

Accepting the Cornell BGP advertisements on both the T1 and T3 links resulted in automatic failover to the T1 link in the case of a T3 outage. The Cisco IOS weight command was used to favor the T3 link for Cornell traffic. In the event of a T3 failure, the BNL test network was isolated until the filter blocking its advertisement was removed from the BNL border gateway router. In the outbound direction, the BNL test subnet was filtered out of the T1 interface advertisements and only the BNL test subnet was allowed to be advertised via the T3. Any host outside BNL used the T3 line to reach the BNL test subnet; the return path would be the T1 unless they were at Cornell. All BNL traffic to Cornell traversed the T3 if it was operational.

**Application Demonstrations**

The initial set of applications used to explore the use of ATM were run over Fishnet, which was implemented by Cablevision and used their fiber and Fore switches to link Brookhaven, SUNY-Stony Brook and Grumman Data Systems in a small ATM network. In February of 1994, three projects involving collaboration between BNL and Stony Brook were demonstrated and are described below.

- Transvenous Coronary Angiography poses less risk than the standard technique that uses x-rays to view a contrast agent injected into the coronary arteries via a catheter. The high x-ray intensity available at the BNL National Synchrotron Light Source (NSLS), coupled with advanced imaging and venous injection techniques, reduces the risks of the current arterial injection method. An ATM network based imaging session involves the patient at the NSLS and collaborators at the NSLS and Stony Brook being able to view and comment on the images as they are acquired and while being processed. Having a high speed ATM link between the two locations greatly enhances the research program.

- Numerical modeling is an important tool for predicting and planning groundwater management programs and remediation strategies. The computational capacity required for this modeling can be realized in an economically affordable manner by the application of parallel computing systems. Brookhaven researchers make use of a 56 processor Intel Paragon system located at Stony Brook. One of Brookhaven's goals is to enable local researchers to interactively visualize the results of groundwater simulations as they are being run on the Stony Brook system. The data communication requirements for this require the bandwidth achievable with wide area ATM.

- Oncology researchers at Brookhaven and Stony Brook use a number of diagnostic tools - the PET and SPECT facilities at BNL, and CT and MRI at Stony Brook, for the precise determination of tumor location and treatment planning.
researchers to view images from these different modalities at the same time provides
gains in patient treatment and plays an important role in reducing the time, expense and
tavel required to conduct joint research.

These three applications proved very useful in demonstrating the potential of high-speed
ATM networking, but have yet to be integrated into a production setting.

At about the same time Fishnet was implemented, NYNEX began to develop the NYNET
ATM testbed, which was much more extensive than Fishnet. NYNET consisted of three
graphic clusters of research institutions, centered in upstate New York, New York
City and Long Island. The Long Island group consisted of Brookhaven and Stony Brook,
with plans for adding the Cold Spring Harbor Laboratory. The initial expectation was that
the three clusters would be linked together; eventually the NYC and upstate sites were
linked, but the Long Island group remained isolated.

The Long Island NYNET testbed on Long Island was based on Fore ATM switches at
BNL and Stony Brook connected by fiber to Newbridge switches in the NYNET "cloud".
In addition, NYNEX supplied BNL with a Cisco 7000 router equipped with two ATM
interfaces, one utilizing a second fiber path into the NYNET cloud and the second
connected to the BNL local ATM network. Adding an FDDI interface to the Cisco 7000
extended the effective reach of the testbed to the entire BNL LAN. The Newbridge
switches used by NYNEX were basically first generation ATM equipment which was
never upgraded, so that there was no support for UNI signaling - all connections were
based on setting up PVCs. An additional problem was the lack of remote access to these
switches; maintenance and diagnosis of problems required scheduling NYNEX personnel
to visit each of the switch sites. Despite these problems it was still possible to use these
circuits with some success, in part due to the good cooperation received from NYNEX
personnel.

The ability of ATM to carry isochronous traffic makes it particularly suited for distance
learning applications. A demonstration of this capability was set up in collaboration with
the Stony Brook Computer Science Department. A lecture given at Stony Brook in April
of 1995 was transmitted to a seminar room at BNL, using the ATM infrastructure. We
were able to borrow equipment from Fore (AVA-200 and ATV-200) which converted
video and audio signals to ATM cells at the originating end and performed the inverse
operation at the receiving end. This configuration had the potential of providing high
quality audio and full motion video. The full potential was not realized because of
inadequate time and lack of experience with production values, but the results were
encouraging enough to lead us to acquire the current generation AVA product to explore
similar applications.

The final application was to have been based on providing BNL researchers at the
Brookhaven based Protein Data Bank with access to high performance graphics systems
at the Cornell Theory Center. Visualization researchers at Cornell have developed
software tools to provide interfaces for application steering and immersive visualization.
The specific application involved the study of Acetylcholinesterase, an enzyme that plays
a key role in the human nervous system. Unfortunately, by this time, support for NYNET had been largely abandoned, and NYNEX was providing maintenance on a best-effort basis. An elusive attenuation problem which cropped up in the final days of the project duration was therefore not able to be repaired, and consequently this demonstration did not take place.

Conclusions

By the time this project was concluded, it was hardly necessary for any research project to ratify the importance of ATM; this technology has become ubiquitous. There were a number of useful lessons learned, nevertheless. The project underscored the need for high bandwidth, high quality-of-service network access for scientific applications among research institutions. It gave impetus to Brookhaven installing a local area infrastructure to accommodate this level of service. Similarly, it provided NYSERNet with experience in confronting the issues of introducing new levels of service while maintaining an operational network. It also provides an object lesson in not placing great reliance on a facility over which one has little control, i.e. NYNET.

NYSERNet and Brookhaven are both now looking to deal with the Next Generation Internet (NGI). NYSERNet is in the process of developing an experimental service called NYSERNet 2000, which will be implemented using a wide area ATM bearer service. Brookhaven is very interested in participating in NYSERNet 2000 and also looking forward to NGI implementation via Esnet, its other Internet Service Provider. The BNL-NYSERNet ATM project, for all its problems, is viewed as an important and valuable experience toward NGI.