

# NYU-NET<sup>3</sup>

## Our Third-Generation Campus Network

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### NYU-NET: WHERE WE WERE & WHERE WE'RE HEADED

NYU-NET, the campus-wide data communications network of New York University, was created in the early 1970s to support the computing and networking needs of the entire University community. NYU's network originated with a connection to the ARPANET, the predecessor of the modern-day Internet. A decade later, NYU was among the first institutions to implement Ethernet (a type of Local Area Network [LAN] architecture), and, by 1983, fiber optic technology was first used on campus for data communications, interconnecting two computing facilities via Ethernet, representing the first-generation NYU campus computer network.

As it grew over the following decade, additional departments—and, ultimately, entire buildings—were brought onto NYU-NET through the use of 10base5 (thick Ethernet), 10baseFL/FOIRL (fiber Ethernet point-to-point links), “5broad36” (5Mbps Ethernet over cable TV-based broadband technology) and Ethernet bridging technologies. With approximately 8,000 nodes<sup>1</sup> attached to

the campus network in the early 1990s, a bridged Ethernet approach to cross-campus networking was reaching its limits, and in 1994, the NYU-NET II project was begun. By the time of its completion, NYU-NET II had improved the University network in a variety of respects, including performance, resiliency, and security, through the replacement of the bridged Ethernet backbone with a router-based FDDI (Fiber Distributed Data Interface) ring which could automatically recover from link failures, in combination with a switched FDDI backbone focused on the high-performance needs of those using NYU-NET.

The NYU-NET II FDDI ring—a ring of fiber optic cable spanning the campus to interconnect routers located at POPs (points of presence, where departmental networks converge)—never experienced a single failure in its decade of operation, and has carried an estimated 2.5PB (1 Petabyte = 1,048,576 Gigabytes) of data to date. However, as usage of NYU-NET II has skyrocketed over the past decade, an upgrade of the 100Mbps FDDI backbone has become increasingly necessary to

meet the greater demands that are being placed on the network.

There have also been increasing concerns that due to NYU's urban location, routine emergencies and failures, such as steam pipe bursts, construction work accidents, or power outages, could wreak havoc on the campus network, which now serves more than 100 buildings and supports a variety of essential subnetworks and systems.

To address these issues, the NYU-NET<sup>3</sup> project (pronounced N.Y.U.-net-three) was begun in early 2001 to design a next-generation campus network that sought to meet the following criteria:

- meet or exceed the automatic resiliency features of ring-based FDDI technology;
- leverage four locations of fiber optic cabling convergence on campus for redundancy and failure protection;
- increase the performance capabilities of the University network;
- upgrade the dated router infrastructure which operated the network;
- bring new networking technologies to bear to allow for new services (such as the campus-

1. A “node” can be a computer or some other device, such as a printer.

wide NYUroam 802.11 wireless service);

- allow for greater access to high-bandwidth applications and services, such as those related to Internet2.

As the NYU-NET<sup>3</sup> project progressed over the past three years, the need for a vital campus network that is able to adapt to and evolve with the needs of the University community became increasingly evident. There are now approximately 35,000 active nodes attached to NYU-NET (representing more than a four-fold growth in the past ten years) and as this number continues to grow, NYU-NET<sup>3</sup> will be there to meet the demand.

#### A NEXT-GENERATION CAMPUS NETWORK: DESIGN CRITERIA

A variety of technologies and network architectures were considered when designing the next-generation University network. Unfortunately, ring-based technologies such as FDDI fell out of favor in the industry, and their use within campus networks has all but disappeared. Ethernet continues to be the prevailing technology in use, though it offers no failure recovery inherent within its technology. To address this problem, a rather challenging approach was developed, by which the resiliency of FDDI could be matched through the use of a high-speed gigabit Ethernet backbone.

One focal point of the new network design was the replacement of the existing FDDI backbones with a “core network” which would accept high-speed gigabit Ethernet connections for new routers<sup>2</sup> located in campus

POPs and server data centers. Another was that the design had to be downwardly compatible with existing NYU-NET II routers that continue to adequately serve the needs of the departmental LANs connected to them. (Such routers, which provide departmental and server network access, we call “Access Routers” or “Distribution Routers.”) Additionally, given the critical nature of this new core network, it was essential to avoid the possibility of a single point of failure, so that a single outage could not disrupt all connectivity on NYU-NET.

The goal of combining a single unified core network with redundancy and resilience, distributed across four discrete physical locations many city blocks away from one another in downtown Manhattan, posed some unique challenges. To satisfy this goal, given the primary building blocks of gigabit Ethernet switches and routers, the architecture of the new core network depended upon a combination of network hardware specification and implementation (i.e., how the switches and routers were assembled and configured) and physical network topology (i.e., how they were interconnected).

Working very closely with hardware designers and network engineers from Cisco Systems, Inc., we validated our hardware specifications to confirm that we were able to address the redundancy, performance, and feature requirements of our project. This was achieved through the use of several levels of redundancy within each Core Router that made up the new network core. This included features such

as redundant power supplies (to protect each Core Router from a single power circuit failure), redundant primary routing processors (to protect each Core Router from a primary CPU<sup>3</sup> failure), and redundant interfaces distributed across four interface boards (to protect each Core Router from an “interface processor” failure, and from the possibility of such an outage causing that router to become completely disconnected from the NYU-NET Core).

At the topological level, ultimately, concepts were drawn from parallel processor computer research to develop a means by which four Core Routers—each located at a point of fiber optic cabling convergence on campus—could be interconnected in a manner to meet the project criteria of redundancy and resilience, while maximizing the number of connected paths between them to offer the greatest amount of available bandwidth within the Core. Though some basic topologies such as a square encompassing all four Core sites, or a full-mesh (square with a criss-cross mesh connecting opposite corners), met the criteria with some success, a “partial-mesh” network topology did a better job.

In a partial-mesh network, only select nodes are interconnected, rather than all possible nodes, as they are in a full-mesh design. The key to achieving a partial-mesh network topology between our four Core locations, while maximizing the number of equal links between them, was to abandon two-dimensional designs such as “flat” squares and consider three-dimensional models. The additional “space” offered by three

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2. Devices that forward pieces of data along a network.

3. The Central Processing Unit (CPU) is essentially the “brains” of the computer, where most calculations take place.

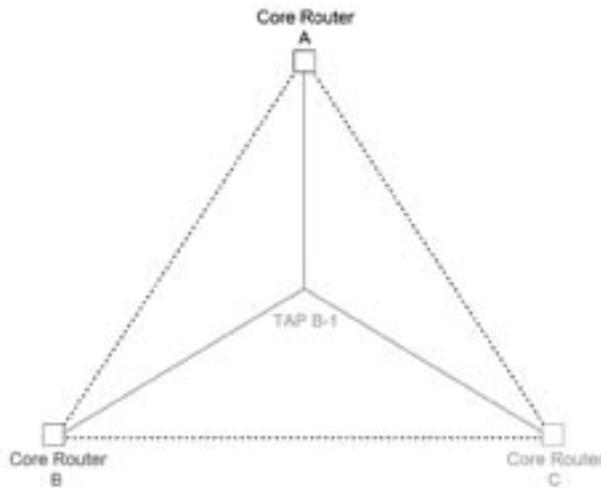


Figure 1. One face of the NYU-NET<sup>3</sup> Tetrahedron design.

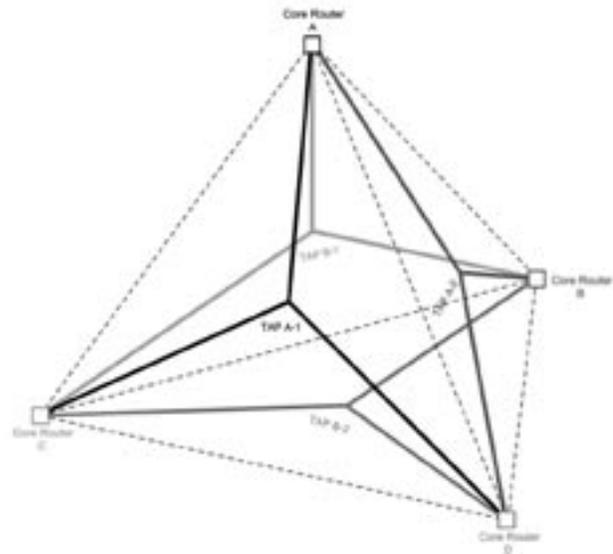


Figure 2. The Tetrahedron Core Network structure.

dimensions presented many different ways in which four redundant Core Routers in four different locations could be connected, similar to how 4, 16, 64, or more CPUs could be interconnected to create a parallel processing computer. Ultimately, the model adopted was the Tetrahedron: a four-cornered equilateral polyhedron.

### NYU-NET<sup>3</sup>: A THREE-DIMENSIONAL APPROACH

With a tetrahedron-style network, each of the four Core Routers is located on a corner, with three Core Routers interconnecting to establish each “face” of the Tetrahedron, with four faces in total (see figure 1). This interconnection occurs at the center of each face. The solid lines in the diagram represent fiber optic connections that converge in the center of each Tetrahedron face.

These connections can operate at any speed (even with simple modem-style PPP connections, if one were inclined to do so), which

means that this approach is highly scalable to any amount of bandwidth. The only requirement is that all links on all faces operate at the same speed, so as to ensure that the entire network is balanced and entirely symmetrical. The dashed lines in figure 1 do not represent fiber optic connections, but simply serve to give the perspective of the Tetrahedron face itself.

The four faces of the Tetrahedron, when assembled, exhibit the final three-dimensional network architecture (see figure 2). Once again, solid lines represent fiber optic connections, while the dashed lines simply provide a reference to the overall structure. The center of each face, called a TAP (Tetrahedron Attachment Point) marks the point on each face where the three constituent Core Routers interconnect.

For a substantially greater level of redundancy and performance, rather than using a single fiber optic connection from each Core Router to a TAP, each Core Router/TAP link operates at 8Gbps

full-duplex<sup>4</sup> and consists of eight redundant connections, each operating at 1Gbps full-duplex, distributed across four interface cards on each device. Using a technology called “802.1ad Link Aggregation”, the eight redundant connections act as one single connection between a Core Router and a TAP, with network traffic load-balanced across all eight fiber optic members. Once again, a single fiber optic link failure or an interface card failure will result in no loss of connectivity within the Tetrahedron Core Network.

Internally, within the Core, an Internet Protocol (IP) routing protocol called OSPF (Open Shortest Path First) is used, which, among other things, monitors the state of all Core connections. If one of the eight 802.1ad links between a single Core Router and TAP should fail, the amount of bandwidth on that link will be reduced, but OSPF will automatically adjust for that reduction by favoring the other higher speed Core Router/TAP links until the failure is repaired.

4. A mode that allows the transmission of data in two directions simultaneously.

If a complete failure of a Core Router/TAP link on any particular Tetrahedron face should occur, once again, OSPF will automatically favor the other available links. In any of the above failure conditions, or when the Tetrahedron Core is fully functional, network traffic is load balanced over all available links to offer the greatest amount of total Core bandwidth. The Tetrahedron Core contains 12 Core Router/TAP links. When implemented with each link operating at 8Gbps, as is the case on NYU-NET, a fully-loaded Tetrahedron has the bandwidth-carrying capacity of 96Gbps full-duplex, nearly .2Tbps (terabits per second) in total. Thus far, however, this Tetrahedron design represents only the Core of the campus network itself. The previously mentioned Distribution Routers, which provide network access to multiple local departmental subnetworks (subnets), must then connect to the Core in order to provide network connectivity to departments, servers, various network services, the Internet, and Internet2.

The TAP on each Tetrahedron face provides the interface to which a Distribution Router can attach to the Tetrahedron Core. Since the Tetrahedron provides four redundant interfaces for attachment to the Core, each Distribution Router is redundantly connected to a pair of TAPs. Since each Distribution Router can “see” or “peer with” three out of the four Core Routers with each TAP connection, linking each Distribution Router to two TAPs ensures that each one peers

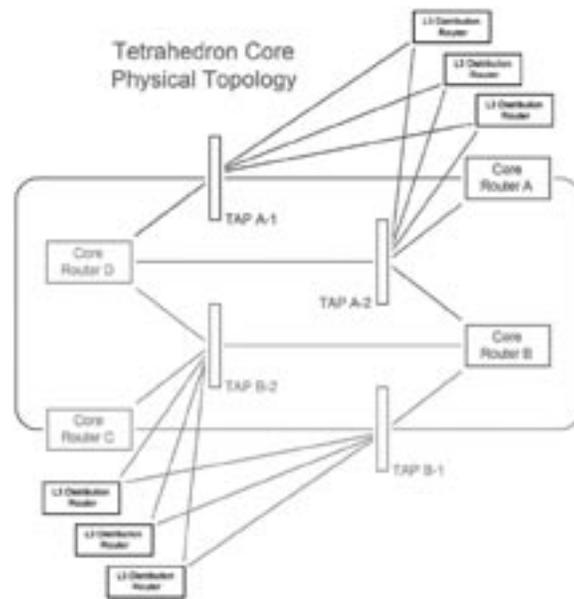


Figure 3. A two-dimensional representation of the Tetrahedron Core with Distribution Routers attached at TAPs.

with all four Core Routers. As a result, a failure of any fiber optic link will not result in any disruption of network connectivity for a department or service.

To offer yet another level of redundancy, each dual connection of a Distribution Router is, once again, established through the use of two different interface cards on both the Distribution and Core Routers, so that a single fiber optic or interface hardware failure will not result in a disconnection of a Distribution Router (and the departments and services connected to it) from NYU-NET. If a connection diagram of the three-dimensional Tetrahedron Core were adapted to lie flat on a sheet of two-dimensional paper, it would appear as shown in figure 3.

### CURRENT PROJECT STATUS

Due to the broad scope of the NYU-NET<sup>3</sup> project and the demands of running the existing NYU-NET II network while working on

the project, it has taken some time to develop, test, and begin implementing the Tetrahedron Core. Following the original design specification of NYU-NET<sup>3</sup> in early 2001, the author developed detailed hardware specifications and finalized the architecture design, which were then modeled in the ITS Network Services networking lab and tested on a production basis for six months without failure. The final design was presented to and certified by network architecture and hardware engineering experts at Cisco Systems. Catalyst 6500 Layer-3 switches/

routers were then procured for the project and installed in our networking lab, where they were put through a grueling set of tests and certification steps that lasted for another six months (see figure 4). In the meantime, as network usage continued to climb on the NYU-NET II FDDI backbones, the Friday night scheduled maintenance periods established by ITS<sup>5</sup> were used to develop and implement a temporary switched fast Ethernet backbone network to relieve network congestion problems.

Senior Network Engineer Keith Malvetti and Network Engineer Yoni Radzin from the Network and Systems Engineering Group within ITS Network Services provided critical assistance in enabling NYU-NET II to operate smoothly during this time, and were also involved in the testing of the Tetrahedron Core in its final stages (see figure 5).

As the final step before moving the Tetrahedron Core into public

5. See <http://www.nyu.edu/its/policies/maintenance.html>.



*Figure 4. A pair of Catalyst 6500 Core Routers located in our networking lab during testing, with their single mode fiber optic cable connections active.*

production service, several departments within ITS were connected to the new Core and participated in the testing of their applications and services on this new network, to ensure that it would perform as well as expected. Much to our satisfaction, tests of a wide variety of applications and services, such as NYUHome, NYURoam, *fame*, and SIS, all ran very smoothly. The Tetrahedron Core was then fully disassembled in our test lab, and the four constituent Core Routers were installed in their permanent locations at the four discrete Core sites. Mario Clagnaz, Manager of Infrastructure within ITS Network Services, and Manny Laqui, also in that group, then implemented the Tetrahedron Core reconstruction on-campus, which included physical installation of the Core Routers, establishment of electrical power services for them, and completion of the fiber optic connections to recreate the Tetrahedron structure.

When completed, 128 fiber optic connections had been tested and established in the Core itself, with a total fiber optic cable length—if laid end to end—of approximately 39 miles. Finally, after a few more weeks of testing the Core and confirming our results to ensure that the network behaved exactly as it had in our lab, we reached the beginning of the fall 2003 semester and were ready to launch NYU-NET<sup>3</sup>.

Since September 2003, Malvetti and Laqui have been busy using the ITS scheduled maintenance periods to both upgrade existing NYU-NET II Distribution Routers (in terms of software and in some cases, hardware) and connect them to the NYU-NET<sup>3</sup> Tetrahedron Core, one by one; Radzin has been busy rolling out new networks such as those recently installed in Bobst Library and the Kimmel Center; and the author has been working on the network design and implementation of the campus-wide 802.11 wireless network, NYURoam—all of which has been made possible by the Tetrahedron Core network.

#### **MOVING FORWARD...**

Looking to the future, NYU-NET<sup>3</sup> will support a variety of services not previously possible, at levels of high-performance. Some new services have already been implemented, such as MPLS (Multiprotocol Label Switching), in conjunction with 802.1q VLAN tagging, to make ResNet and administrative staff networks simultaneously active in student residence halls, and NYURoam services available to remote offices and buildings connected to NYU-NET via leased line T1 and T3 services. MPLS may also provide us with the ability to offer even



*Figure 5. Yoni Radzin and Keith Malvetti prepare a Core Router for deployment.*

greater levels of network security in the future. In addition, the Tetrahedron Core eliminates any bottlenecks on the NYU-NET backbone network, providing computers with modern, switched, fast Ethernet connections, and very high-speed access to the Internet and Internet2 research networks. Testing of high-speed IP multicast services is under way as well.

With NYU-NET's roots in academic research, it seems only fitting that the design of this innovative third-generation campus network has drawn upon computer processor research to solve the rather challenging problems associated with building a data communications network in support of the largest private university in the United States. NYU-NET<sup>3</sup> has achieved all of the goals specified at the outset of the project and will continue to evolve to meet the needs of the NYU community, acting as an enabler and facilitator of academic, research, administrative, and business applications and functions.

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