The Opportunity

Modern scientific research methods are creating surging requirements for computational power, data storage, and transmission. The preeminent stature of the United States in fundamental areas of research and innovation is challenged by increased global competition. Japan now operates the world’s most powerful non-classified supercomputer engaged in climate modeling. The incessant upward spiral of computational and transmission needs is driving the necessity to find new ways for increasing capability more quickly and at lower cost. Increasingly, scientists are relying on distributed processing power and storage facilities tied together using optical communications “grids” to create flexible, scalable, powerful, low cost computational infrastructure. Access to this new optical infrastructure is already a key advantage for a relatively few research institutions. In the near future, it will be a fundamental requirement for competitiveness and relevance in all areas of scientific research including biotechnology, atmospheric research, nanotechnology, oceanography, space, defense, and others.

The NSF sponsored Distributed and Extensible Terascale Facilities project is a multi-year (FY2000 – FY2002) $120 million set of initiatives to develop terascale computing in a scalable distributed computer grid enabled by the latest emerging optical network technologies. In addition, NSF, DOE, and other agencies are funding multi-million dollar projects to develop software environments that enable the petascale computation necessary to model and solve the most complex science and engineering problems. Nanoscale assemblies of materials, the design and construction of fusion power plants, and innovative and exceptional solutions to our most enduring medical, biological, and environmental problems are possible through the leveraging of evolving computational grids enabled by terascale optical networks. Major sponsored research projects are funded at the federal level, addressing these problem sets and many more, all dependent upon access to the nations most advanced computational facilities.

With the appropriate level of access to developing experimental network infrastructure, in the short-term, the major research laboratories and universities can leverage the most advanced computational capabilities at facilities like: the Pittsburgh Supercomputing Center; and at the Argonne National Laboratory in Chicago; at the National Center for Supercomputing Applications in Urbana, Illinois; at the San Diego Supercomputer Center; and at the National Center for Atmospheric Research. With access to the developing third generation compatible networks, efforts by Oak Ridge National Laboratory and others to develop competitive computational facilities that would become resources in the national grid would gain great impetus.
Increasing bandwidth and control requirements of scientific research and other applications concurrent with the evolution of optical network technology are driving development of global optical network systems beyond the capability of the commodity infrastructure. Advanced optical network programs are well underway in competing areas around the world including Canada, Asia, Europe, and South America. The National LightRail (NLR) is an initiative by key public and private research entities in the U.S. to create a national optical research network capable of meeting the most advanced research requirements over the next five to ten years. It has been described most succinctly by Peter O’Neil of the University Corporation for Atmospheric Research, “The fundamental and overriding goal of NLR is to provide an enabling experimental infrastructure for new forms and methods of science and engineering.”

The Problem

In the context of its broad and diverse membership, the University Corporation for Advanced Internet Development (UCAID) deployed Abilene as its national apparatus for the development of Internet2 applications and capabilities. Abilene is deemed by many participants to be a mission critical element of their telecommunications networks. As a result, Abilene cannot meet many of the research objectives for which its existence was originally justified. It cannot support many current objectives of network layer research and due to protocol limitations it hasn't been able to deliver the QoS capabilities critical to certain computational applications. Abilene does play an enabling role in the development of middleware, and in the development of certain high bandwidth dependent applications (e.g. remote collaboration environments such as the Access Grid, etc.). The membership dictated requirement for a production quality IP service is at the root of Abilene's limitations in meeting a subset of the “big science” and computational science research and development goals.

Remembering the primary goal of the National LightRail, to provide an enabling experimental infrastructure for new forms and methods of science and engineering, there are two broad areas of research activity that the proposed NLR infrastructure would facilitate:

1. High-performance Computational Science and Engineering Research

Applications of this class, dependent upon the availability of an adaptive and scalable network infrastructure proposed in the National LightRail initiative, require access to very substantial computing power. Tying multiple (local and remote) clusters together via very high performance networks is an enabling approach for such applications, and would support important research in related computer science research areas as well, e.g., grid computing, load migration, latency tolerant algorithms, resource aware algorithm selection and scheduling. Most of the important computational science research efforts of this century are multidisciplinary, involving multiple length and time scales in the simulations and multiple science and engineering disciplines. Expertise in the various sub-disciplines is located at many places. The simulation codes and algorithms of these
various groups must be linked, often in a very tightly-coupled way (not to mention their data sensing and collection elements, data repositories, visualization environments, etc.).

The type infrastructure proposed will lead to new cross collaborations and linkages with great potential to yield new insights, discoveries, and benefits. As a very simple example - in this list of four current projects by faculty identifying applications dependent upon access to adaptive lambda level network capabilities, distributed petascale computing and wide-area collaboration - combinations of the first two projects or the second two projects would be at best unique and at worst tedious in the current computational and network environment, but facilitated and very interesting in the NLR enabled environment:

- Nanoscale electronics. First-principles atomistic simulations of the electronic, optical and transport properties of molecular electronics devices.

- Molecular statics and dynamics. Studying the atomic structure of grain boundaries and dislocations in novel ordered intermetallic alloys.

- Molecular modeling of protein structure and function. Modeling of the dynamics and interactions of proteins, which in turn will yield insight into protein function.

- Cell cycle modeling. Modeling the information flow and chemical reactions in complex biochemical regulatory systems.

### 2. High Performance Networking Research

In an optical network as envisioned by the National LightRail initiative, it will be possible to conduct network layer or link-layer research on some wavelengths, while maintaining a stable link layer and network layer on other wavelengths to conduct research at the transport layer or higher layers.

For example, innovative approaches to build the next generation of network protocols require a protocol development environment (PDE) that can faithfully create network infrastructures of the scale and complexity of the current Internet. The current Internet while in its infancy was used as an active development platform, its rapid expansion and advent of commercial interest in the early nineties has stabilized the core platform. Its effects can be clearly seen in protocol development efforts - in the eighties, the turn around time was in the order of months, whereas currently standardization and deployment of new protocols takes years! Furthermore, development of new protocols is constrained by the need to maintain the operational integrity of the Internet, which precludes modifications to the core protocols. This bounds the scope of research efforts within the tight confines of the current Internet architecture. To build the next generation of networking architectures and protocols, we need a reconfigurable approach that...
enables researchers to pursue several different directions, without constraining them to a particular network protocol infrastructure.

The last several years have seen the deployment of protocol development environments that allow users to create complex controlled experimental test-beds to verify and validate network protocols. Protocol development environments can be broadly classified into (a) Network simulators and (b) Direct code execution environments (DCEE). While simulators such as NS, OPNET, REAL, x-kernel PARSEC, SSFnet, and dummynet offer an efficient event-driven execution model, they require that the protocol under test be written in their event driven model. The simulated protocol can be refined and then converted to a real-world code implementation. But without a large-scale, adaptive network infrastructure and architecture for experimentation, the basic problem is that there is no easy way to ensure the equivalence of the simulated protocol and its real world code version.

With additional fibers (i.e. physical layer isolation) it will be possible to conduct research activities in the optronics space itself. Or if participants don't expect to get a production-quality IP extranet (institution-to-institution), it should be feasible to conduct optical experiments on a scheduled basis that completely break all of the existing lambda-level connectivity in the network.

Any reasonable definition of "research" in the context of an advanced optical network like the National LightRail initiative should incorporate the Aiken, et. al., Morphnet concept, as it provides the fundamental basis for sharing the infrastructure for different valid interpretations of what constitutes research. In this context, few of the research community close to the National LightRail initiative see significant utility in the initial four lambda national footprint. However, they are universally intrigued at the potential effect of the base infrastructure on the marginal cost of establishing application specific, point-to-point lambdas. At a minimum, with that basis, the determination as to how much of the infrastructure is used for “research” is easy to determine -- simply count the wavelengths that don't provide a stable link layer or network layer.

**Conclusion**

Some may see this initiative as the equivalent to the broad scale deployment of TCP/IP technologies via NSFnet in the 1985-89 timeframe, which very quickly involved hundreds of colleges and universities across the nation. It is not. This is not about the deployment of higher capacity IP services, or multi-gigabits per second Ethernet. It is about manipulating point-to-point lambda level optical technologies to create application specific, user controlled, optical networks. In the context of the current state of the enabling technology, there is nothing routine or easy in meeting this expectation. It will require significant manual manipulations, cooperative vendor partners, and leading-edge, innovative network engineers and computational scientists. Even in the context of the early potential utility to UCAID and others in deploying IP over lightwave services, due...
to the high risk reflected in the state of art in creating robust network systems from these components, the early drivers are a very few “big science” and computational science based applications homed in a few of the federal labs and research universities. In the context of the state of the requisite technologies in optical communications, and in computing, and in the driver applications, the development stage we are at is significantly more primitive – probably more analogous to the initial deployment of TCP/IP in ARPAnet and the Defense Data Network in 1983. We experienced a 10 to 15 year cycle from initial deployment to commodity level utility for the Internet. Likewise, a prediction of a minimum of 5 to 10 years before commodity level utility for optical networking is defendable. Virtually every activity, service, and application anticipated in the first 3 to 5 years of the National LightRail initiative will be experimental, and will involve multi-disciplinary research.