Technical and Strategic Issues

in Implementing Internet2 in Brazil

by

Shiu-chung Au

Submitted to the Department of Electrical Engineering and Computer Science

in Partial Fulfillment of the Requirements for the Degrees of

Bachelor of Science in Computer Science and Engineering

and Master of Engineering in Electrical Engineering and Computer Science

at the Massachusetts Institute of Technology

[June 1998]

December 8, 1997

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ABSTRACT

Implementing a high speed Internet in Brazil requires consideration of both technical and strategic issues. Technical issues include hardware required to connect the various networks in Brazil and how to make such switching fast and affordable, as well as the software that must be installed to be compatible with new Internet Protocol upgrades. Strategic issues examine the need for the upgrade by evaluating the added value in societal, economic and academic fields. Current trends in Internet development in the US and other more developed nations serve as the basis for the evaluation of technical and strategic options that are pertinent to Brazil at this stage.

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Acknowledgments

I would like to thank a number of people for contributing in very real and significant ways to the writing of this thesis.

Firstly, I would like to thank my parents, Eva and Allan Au, for their selfless support all these years at MIT. You never let me be in want for anything material and provided everything for me. Thanks also to my brother, Shiu-yik Au, for his business mind and insight into finance. I love you all very much.

I would like to thank Dr. Amar Gupta, Aparna Upadhyay, and Guilherme Xavier for all their help in reading and editing this document, as well as for their extensive intellectual contribution to this thesis. In particular, Section 10 was written in conjunction with them. I very much hope to continue working with you in the future.

In addition, I would like to thank the team from Brazil, Prof. José Carlos Cavalcanti, Dr. Eduardo Costa, Dr. Ivan Campos and Mr. Angelo Menham, all of whom provided much valuable insights and advice for this thesis.

I would also like to thank all of my friends and my fellowship CBF here at MIT that have encouraged me to continue on emotionally and spiritually, whenever the Institute or people got me down. Vanessa Wong, David Shue, Emily Liu, David Sun, Jasen Li, Jeannie Chao, Eric Ding and many others in the class of '00 and '01, you are all very dear to me and each of you holds a special piece of my heart. Most of all, I would like to thank God, because without Him, I would never have made it to MIT, never have learned to hope, and never have learned what the real meaning in life is. Thank you.

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1.0 Introduction

The creation of a nationwide Internet2 infrastructure in Brazil has the potential to produce rapid growth in many sectors of Brazilian society. Just as the industrial revolution vaulted some nations to the forefront of world dominance, successful deployment of new information technologies will enable some developing countries to advance to the category of developed nations.

The availability of a national digital communications infrastructure is a key component in the modern information age. While discussing the advantages of connecting Brazil's enterprises and individuals with each other and with other nations through high capacity links, the cost implications of creating such a network must also be simultaneously considered. In addition, significant computational infrastructure will be needed in order to create and benefit from a practical Internet2 system. The overall strategy for the deployment of the Internet2 will require intimate involvement of the Brazilian government for direction, regulation and support; in addition, industrial organizations and academic institutions will need to participate in many aspects of the endeavor.

This thesis paper will discuss both the need for strategic planning in many sectors of Brazilian society to assist in the development of Internet2, as well as the technological innovations necessary to make Internet2 a reality given Brazil's existing technology base. The six sections at the start of this thesis paper will detail existing organizational structure, policy and development strategies in various countries, as well as empirical research in large scale networking. The seventh and eighth sections of this thesis paper will examine relevant technologies that could be developed and leveraged. The remaining sections will discuss possible implementation plans, and evaluate the costs and benefits, leading to a final conclusion.

2.0 Benefits of Internet2

Internet2 can offer significant economic, social, and other benefits to Brazil, just as the Industrial Revolution did to non-industrialized countries in previous centuries. From a historical perspective, the industrial revolution created a great disparity between those nations who embraced the concept and those who did not. Today, the information revolution allows a similar potential for paradigm shift, giving opportunities for countries to gain another major competitive advantage in world markets. A nationwide network would allow faster communication channels for transmitting information in an electronic format.

The development of Internet2 can enable Brazilian products to acquire broader exposure on world markets. Agriculture stands to benefit from information sharing and improved crop controls. Tele-Education will become feasible as classrooms gain the capability to interact in real time (that is, without delay) with other learning centers. Medical information and expertise could also be made more widely available in Brazil through Internet2. The strengthening of the technology base in Brazil would help to reduce the gap between Brazil and more industrialized nations. For the average Brazilian citizen, information will become more readily available, in essence by creating a reference library in every home.

The urgency of developing a superior version of Internet is fueled by the explosive growth in Internet traffic: in the US, Internet traffic is increasing by 3-5 billion bits per year, while voice traffic is now at a stagnant stage (between 100-200 billion bits per year)[1]. Similar growth patterns are being observed in other countries. Most observers agree that this fast growth in Internet usage and traffic cannot be sustained indefinitely without major restructuring and enhancement to the current Internet framework.

2.1 Advantages of Internet2 over Internet

Internet2, a collaborative effort with the US Government's "Next Generation Internet" initiative, is envisaged to offer superior capabilities to the current version of Internet, in the following areas:

- Allow increasingly powerful real-time, multimedia applications such as video-conferencing and transmission of "streams" of audio and video; the latter application is very important for telemedicine and distance education. The current version of Internet does not provide any guarantees about the rate of data delivery, impeding the deployment of many real-time applications.

- Provide sufficient bandwidth to transfer and manipulate huge volumes of data. Satellites and scientific instruments will soon generate a terabyte (a trillion bytes) of information in a single day. As a point of reference, the entire printed collection of the US Library of Congress is equivalent to 10 terabytes.[2]

- Enable remote use of computing facilities, including the construction of a "virtual" supercomputer from multiple networked workstations, which would allow real-time simulations of tornadoes, ecosystems, new drugs, etc.

- Permit scientists and engineers to collaborate in shared, virtual environments, and enable reliable and secure remote use of scientific facilities.

As seen from the above set of goals, the current focus of Internet2 in the US is primarily on scientific and educational applications.

2.2 Implementing Internet2 in Brazil

The current implementation of Internet is perceived by most experts to be increasingly inadequate to handle the growing demands of education, research, electronic commerce, and allied fast changing facets of national and international endeavors. Over time, countries with superior Internet capabilities will command a major strategic advantage over others, based on the power to transfer large amount of information quickly and accurately for both civilian and defense needs.

In the US, the pattern for the development of Internet2 has interesting differences from the earlier experiences with Internet. The latter concept can be traced back to ARPANet, which was spearheaded by the Advanced Research Projects Agency (ARPA) of the US Department of Defense. ARPANet was envisioned in the sixties as a decentralized network, with multiple paths between all nodes, to serve as a communications backbone in the event of a nuclear war. Accordingly, the needs of the US Department of Defense took higher priority over other needs. Over time, the National Science Foundation of the US Government became the coordination agency, followed by concerted efforts to "privatize" various aspects of the Internet. The Internet industry is now a mature industry, with adequate number of private organizations to permit healthy competition and growth. This broad coalition is being utilized by the US Government to nucleate the design, development, and wide deployment of Internet2 across the US. In October 1997, ARPA (now renamed again as DARPA, for Defense Advanced Research Projects Agency) issued a solicitation seeking ideas for research related to Internet2; however DARPA's role in Internet2 is much smaller than the model role it played thirty years ago with ARPANet[3].

The implementation of Internet2 capabilities in Brazil is motivated by the same consideration that has fueled the conception and the preliminary design of these capabilities in US and Europe. In Brazil, civilian agencies of the federal government have played a pivotal role in the implementation of Internet capabilities; the same model can be utilized with respect to Internet2. A significant portion of the amounts spent in this sector accrues to foreign companies who provide products and services either directly or via a local partner in Brazil. The need for growing indigenization of this sector is a major objective, both with respect to Internet and Internet2.

2.3 Technical Issues Specific to Brazil

The establishment of an Internet2 infrastructure in Brazil can potentially boost the pace of scientific development, industrial development and overall productivity of the whole country. However, given the vast geographic size and high diversity that characterizes Brazil, upgrading the current information infrastructure, from Internet to Internet2, is a major endeavor that involves a number of technical challenges. Some of these challenges will also occur in other countries, whereas others are specific to Brazil.

The technical issues that relate to the creation of an Internet2 in Brazil can be grouped into the following categories:

- *Creation of GigaBit Research Testbeds*
- *Upgrading of Present Internet Infrastructure*
    - *Transmission medium*
    - *Switching hardware*
    - *Internet protocols*
    - *Training and Maintenance*

More specific details and suggested resolution to these issues can be found in Section 8.0 Current and Evolving Internet Infrastructure.

3.0 US White House Internet2 Strategy

On Oct 10, 1996, the US White House announced its intention to commit $300 million over three years towards the development of the Next Generation Internet (NGI) Initiative. Much of the leadership role for this program was provided by the Presidential Advisory Committee on High Performance Computing and Communications[4].

The official announcement for the US Internet2 Initiative specified three goals, as follows[5]:

- **Connect universities and national labs with high-speed networks that are 100-1000 times faster than today's Internet**: These networks (collectively referred to as Internet2) will connect at least 100 universities and national labs at speeds that are 100 times faster than today's Internet, and a smaller number of institutions at speeds that are 1,000 times faster. These networks will eventually be able to transmit the contents of the entire Encyclopedia Britannica in under a second.

- **Promote experimentation with the next generation of networking technologies:** Technologies are emerging that could dramatically increase the capabilities of the Internet to handle specialized services such as high quality video-conferencing on a real-time basis. These technologies, aimed at enhancing the capability and the speed for the interconnection network, need careful experimentation. By serving as "testbeds," research networks can help accelerate the introduction of new commercial services.

- **Demonstrate new applications that meet important national goals and missions**: Higher-speed, more advanced networks will spawn a new generation of applications related to scientific research, national security, distance education, environmental monitoring, health care, and other areas of broad appeal.

3.1 Major US Internet Initiatives

The three largest US development initiatives aimed at developing successor frameworks to the present Internet infrastructure are as follows:

- Next Generation Internet Initiative (NGI)
- Internet2 (I2)
- Very High Speed Backbone Network Service (vBNS)

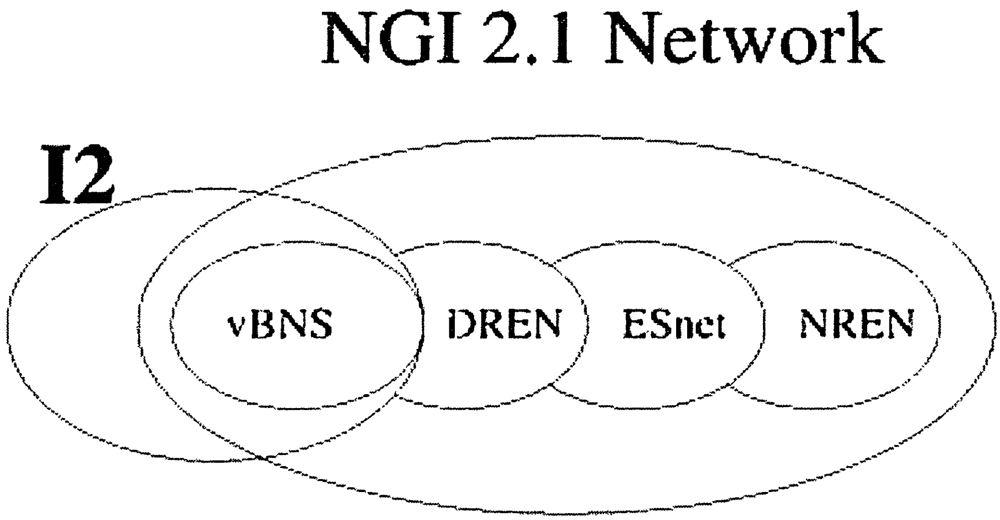
The Internet2 effort and the NGI initiative are overlapping programs with many common elements. The scope of both these initiatives includes implementation issues related to Quality of Service, and development and utilization issues concerning similar networking hardware and fiber-optic backbones. In particular, Internet2 is intended to assist in achieving the NGI goal of establishing a high-performance academic network that operates at speeds 100-1000 times greater than today. Internet2 and NGI, in cooperation, are envisaged to make available advanced network services over backbone networks provided by competing vendors in order to ensure minimal cost.

The vBNS (very High Speed Backbone Network Services) involves five major US supercomputing centers that are being interconnected with high speed links. The US National Science Foundation (NSF) has already implemented this large scale network as part of its High Performance Connections program via a contract awarded to MCI. The vBNS presently runs at 622 Mbps[6] and is expected to serve as an integral component of both the Internet2 and NGI initiatives.

The relationship between the three initiatives is depicted in Figure 1. NGI is the largest program based on its receiving large amounts of funding from the government. NGI and I2 overlap to a substantial extent and a cooperative arrangement is being pursued to jointly develop and deploy the next generation of Internet2 technologies. Integral in this plan is the vBNS network, which provides the communications backbone that already provides high speed end-to-end connectivity to several large research sites. DREN, ESNet, and NREN are examples of agency-specific initiatives that will be ultimately encompassed within the overarching I2-NGI framework.

3.2 Next Generation Internet Initiative (NGI)

The focus of NGI is on the needs of the US Government, with ultimate benefits to accrue to many sectors of the economy. While there is no broad agreement on which agency will specifically benefit or even which is in charge, the Presidential Advisory Committee on



DREN -Defense Research and Engineering Network (Department of Defense)

-Links several high speed defense computing centers (private and secure)

ESnet -Energy Sciences Network (Department of Energy Office of Energy Research)

-Serves as internal research network for Department of Energy

NREN -National Research and Education Network (National Science Foundation)

-Studies the networking needs of research institutions

Figure 1: Relationship between I2, VBNS, NGI and others (http://www.hpcc.gov)

High Performance Computing and Communications serves as the primary organizer behind the Next Generation Internet Initiative. The funding of $100 million per year is planned to come from defense and domestic technology budgets. The US administration has requested the US Congress to allocate $288 million in 1998 for Large Scale Networking area (which is the blanket umbrella over NGI), up from $252 million last year; this includes funding for many different fields (for further information on budgeting, see *http://www.hpcc.gov/pubs/bro98/budget.html*), and the final figure for the NGI component is expected to be close to $100 million for 1998[7]. As with previous networking initiatives, the US Administration expects to use this federal investment as a catalyst for additional investments by universities and the private sector. Final reports indicate an approved budget of $105 million for 1998.

Similar to Internet2, the slated goal of NGI is to deliver a minimum of 100 times or greater improvement over the current Internet performance on an end-to-end basis to at least 100 interconnected NGI-participating universities, national laboratories, and Federal research sites demonstrating research and other important applications that require such an infrastructure. This network fabric will be large enough to provide a full-system, proof-of-concept testbed for hardware, software, protocols, security, and network management that will be required in the commercial versions of the Next Generation Internet. Since the goals of I2 and NGI are very close, cooperation between the two initiatives is likely to increase over time.

3.3 Internet2 (I2)

Internet2 is the terminology used in the White House directive to connect the universities of the US with unprecedented high speed connections. Even though the concept is less than a year old, I2 has gained widespread support. As of July 1997, the set of I2 member organizations included over 100 universities, and had attained a funding level of $50 million a year from the government for developmental activities[8].

One of the interim goals of Internet2 is to create a backbone that offers transmission capacity of 600Mbps to 1.2 Gbps (OC-12 to OC-48) range in 1997/1998[9]. Educational campuses involved in the Internet2 endeavor are expected to provide significantly higher capacities to dedicated Internet2 client systems on the campus during the short term. Such implementation of Internet2 capabilities within educational campuses will offer the added advantage of supporting a large number of test areas where skeletal frameworks of high speed networking already exist, and a large group of users (students) is available to test the evolving concepts. Just as the university community contributed significantly to the implementation and the acceptance of the original Internet paradigm, a similar situation is beginning to take place with respect to the Internet2.

Significant research on Internet2 remains to be done, not just in the hardware arena, but also in the software realm. Hardware solutions for routing and aggregation are very expensive and sometimes difficult to obtain or maintain; as such many applied research and development tasks remain to be performed. Cabling is still quite expensive; in fact, one tries to find new ways to leverage existing copper cabling than to rewire an entire geographical area. Software has to be developed to work in conjunction with these new components. In addition, new Internet2 services need to be progressed from the drawing board to full scale implementation.

3.4 Very High Speed Backbone Network System (vBNS)

Very high speed Backbone Network System (vBNS) is a new advanced switching and fiber transmission network that enables very high-speed, high capacity voice, data and video signals to be combined and transmitted "on demand." Created under a five year cooperative agreement (beginning 1994) between MCI and the National Science Foundation (NSF), the vBNS is envisaged to use the capabilities of MCI's nationwide network of advanced switching and fiber optic transmission technologies, known as Asynchronous Transfer Mode (ATM- explained in Section 7.3 Asynchronous Transfer Mode) and Synchronous Optical Network (SONET- explained in Section 7.4 Synchronous Optical Network). The vBNS initially operated at speeds of 155 Mbps (million bits of data per second) and is presently operating at 622 Mbps. The goal is to attain a speed of 2 Gbps before the end of the program in 1999[10].

The vBNS connects five major supercomputing centers and a number of universities as shown in Figure 2. Unlike most other high speed initiatives which are confined to a single state or two, the vBNS spans the whole of the US. Incidentally, the predecessor of vBNS, NSFNET, served as the base backbone for the development of the Internet.

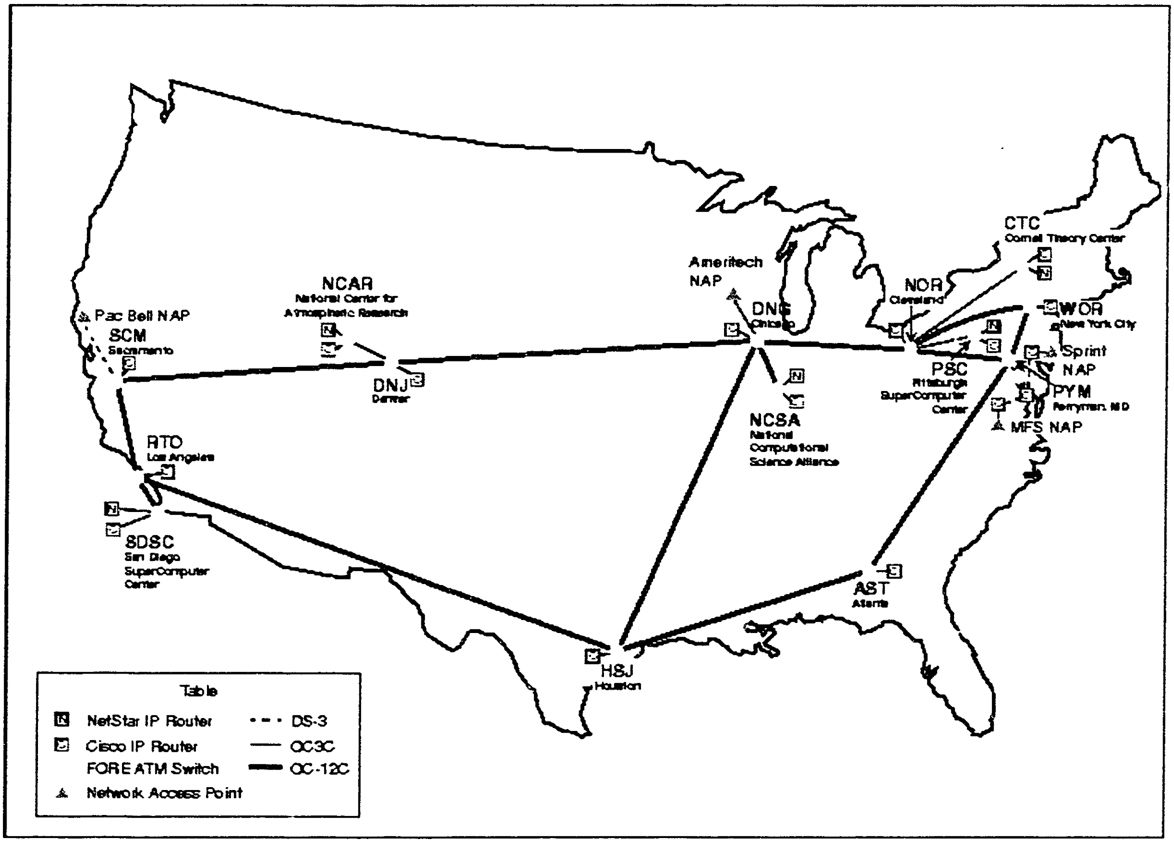


Figure 2: VBNS Logical Map (http://www.vbns.net/logical_map.html)

3.5 Lessons Learned from US Internet Initiatives

In partial conflict with the popular myth that the development of Internet has occurred entirely on a grassroots basis, the US Government has played a very significant role in the original development of ARPANet, which let to Internet, and is currently playing a similar role with respect to Internet2. These are both major endeavors that need close involvement of government agencies as well as resources of industrial and academic organizations to ensure balanced growth.

The development of Internet and Internet2 can be characterized in terms of four distinct stages: (i) Research and Development; (ii) Formulation of Partnerships; (iii) Privatization; and (iv) Commercialization. These four stages are depicted in Figure 3. Note that once commercialization occurs, funds are generated for supporting research and development of new technologies, and superior versions of existing technologies. This in turn fuels a new four-stage development cycle. Over time, a technology spiral is created with an increasing number of products and services, ultimately leading to a mature industry.

Let us trace the developments related to Internet[11]. ARPANet, the original US Department of Defense concept, was gradually extended to many universities, which sought funding from the government. In 1987, the National Science Foundation decided to support this endeavor and created the NSFNET. Networking became increasingly popular and Agency Networks were created. A little later, the concept of Advanced

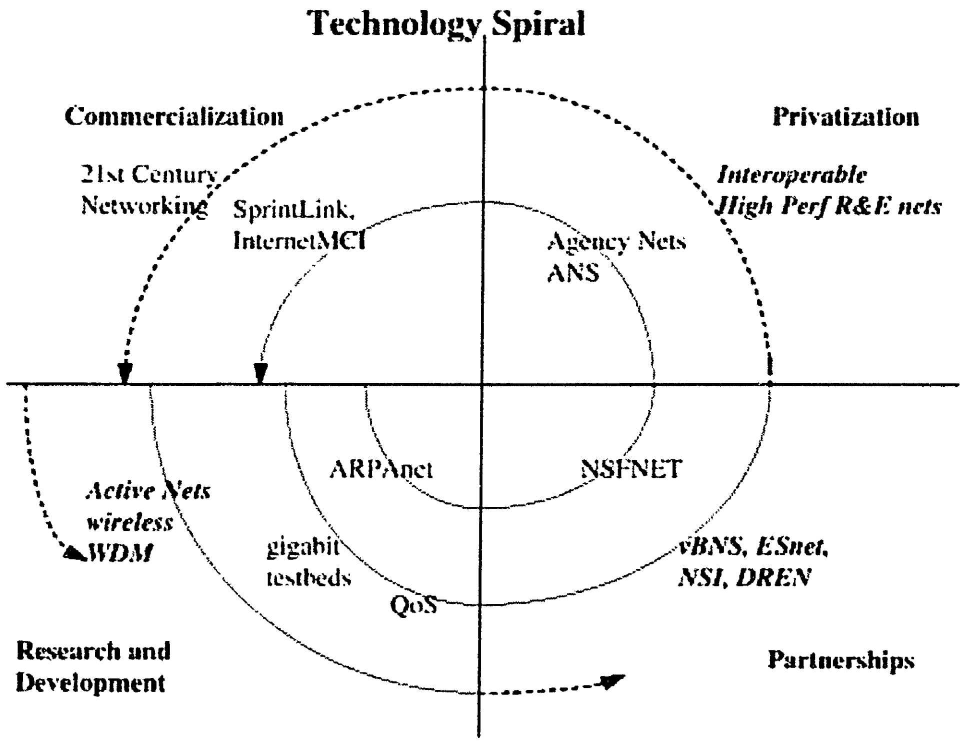


Figure 3: Outline of Technology Development (http://www.hpcc.gov/talks/)

Network Services was born to link the various networks together. Subsequently, commercialization took hold as companies such as MCI and Sprint began to offer their extensive communications networks for contract to the NSF and other companies. More recently, MCI was awarded the contract to construct the vBNS (very High Speed Backbone Network Services) in 1993, which is now one of the most technologically advanced networks of its scope. Considering the above facts, one can identify a number of lessons that are very careful in formulating plans for Internet2 in other countries.

Provide Leadership and Coordinate Multi-agency Efforts

Multiple initiatives, sometimes overlapping with each other, have been undertaken to fulfill the White House's mandate to link the country with high speed connections. Each initiative involves several government agencies, private industry, as well as the university community, to leverage national resources to the maximum extent possible. Though the balance of relative importance of the president's office, the set of participating governmental agencies, and the set of non-governmental organizations will differ from country to country, Internet2 needs continuing support of the highest levels of the government in order to deploy it quickly in a cost-effective manner.

Encourage Discussions in Research Community

A number of conferences have already occurred on NGI, I2 and vBNS. As one proceeds forward with the vision to implement I2 in any country, one needs to initiate workshops and information exchange sessions to educate individuals from government, corporate and university environments about current capabilities, future requirements, and unique opportunities with respect to Internet2.

Provide Seed Funding in Core Areas

"The last time we tried something like this, we spawned a multi-billion dollar industry," observes Dr. David Farber, holder of the Alfred Moore Chair of Telecommunications Systems at the University of Pennsylvania[12]. The government agencies can significantly accelerate the pace of development by providing funding for launching new products and for training adults, youths and children about the new technology.

3.6 Privatization Issues

In the US, the Internet has become increasingly privatized over time. MCI has taken over operations of the NSF's very High Speed Backbone Network Service (vBNS). Internet Service Providers, such as America Online and Compuserve each now provides facilities to several millions of customers. Shifting responsibility over to for-profit requires the formulation of an adequate regulatory framework to ensure fairness to all sections of the society. In the US, this framework has evolved through a series of Telecommunications Acts, which only recently opened the door to private cable and telecommunications companies. Based on initial observations, the deregulation has been a success, with expansive growth of the Internet in business and in previously unconnected areas.

Brazil's privatization of Telebras may spark similar corporate development and investment in the Internet. Many new start-up companies serving Internet needs are likely to appear, and will need some degree of protection.

3.7 Security Issues

At present, Worldwide Web Browsers contain measures that facilitate the transmission of confidential messages between two parties. While the exchange of such messages could potentially be for military needs, this secure method of communication is being increasingly utilized for purposes of electronic commerce.

At present, the superior types of secure encryption algorithms are restricted for use within the US and Canada only. Less secure versions are available for export from the US. However, a number of such less secure algorithms have been broken by computer hackers. In order to ensure high Internet security, countries like Brazil either will need to negotiate with the US Government to permit export of secure encryption algorithms or will need to facilitate the development of better algorithms that could be utilized in international trade to be conducted via Internet2.

For Brazil, access to such security mechanisms will be especially relevant for conducting electronic commerce and other types of exchanges, both on domestic and international basis, in particular with the US and countries in Europe. In addition, organizations in Brazil concerned about the dangers of unwanted computer intruders must begin to invest in firewalls and other devices capable of securing a network. Indigenous development of firewall hardware and software could potentially be a lucrative industry for interested Brazilian companies.

4.0 US National Information Infrastructure

In order for Brazil to make the smooth transition to become a pre-eminent information-technology based society in South America and in the whole world, one needs to see how National Information Infrastructure (NII) issues are being handled from an organizational perspective in the United States. This requires discussion of the following issues:

- What was the sequence of important events in the US?
- What institutions contributed to the success of US information society projects?
- What are the roles of government, industry and universities in leveraging and supporting IT development?
- What is the structure in Brazil and how it can handle the proposed tasks?

The focus is primarily on the situation in the US. The efforts on TEN-34 in Europe have involved a number of countries and are therefore less relevant to the situation in Brazil.

The evolving of Internet and Internet2 has involved close and continuing cooperation between the government sector, the commercial sector, and the academic sector. Although some activities commenced on a monopolistic basis, healthy competition has been encouraged as part of the overall framework.

4.1 Government Sector

Historically, the United States Government has set the national agenda with respect to science and technology development activities. The US Government, via its main science and technology research agencies, Defense Advanced Research Projects Agency (DARPA), National Science Foundation (NSF), and the National Institute of Standards and Technology (NIST) is the major sponsor of research in the information technology arena. This role is reflected in the following sequence of events:

1969 Defense Department commissions ARPANET to promote networking research.

1981 National Science Foundation provides seed money for CSNET (Computer Science Network)

1982 Defense Department establishes TCP/IP (Transmission Control Protocol/Internet Protocol) as standard.

1986 NSF creates NSFNET and five NSF-funded supercomputer centers. NSFNET backbone operates at a speed of 56 Kbps.

1989 National Science Foundation lifts restrictions on commercial use of the Internet. The High Performance Computing Act, authored by then-Senator Gore, is signed into law. World Wide Web software released by CERN, the European Laboratory for Particle Physics.

1995 US Internet traffic carried by commercial Internet service providers. .

1996 Number of Internet hosts reaches 12.8 million. President Clinton and Vice President Gore announce "Next Generation Internet" initiative.

(Based on: Hobbes' Internet Timeline, v. 2.5)

Figure 4 highlights how the US Government influences the science and technology arena, and the pivotal role it plays in technology development from the beginning experimental stages to the final implementation stages.

In the case of networking, the US Government provided valuable venture capital for networking research and for merging the traditionally separate fields of computing and communications. Next, the relevant government institutions found viable application niches for the networking research results found in the first quadrant. These government agencies also created partnerships with government affiliated groups and non-government related research institutions.

The last two quadrants of Figure 4 emphasize the US Government's commitment to strengthen the US economy by focusing on privatization and commercialization of all technology development activities. In fact, many science and technology developments in the United States would not have succeeded if the research had not received such heavy government support at the early stages.

The US Government has supported and continues to nurture the Internet2 field by providing initial research funds for prototype development, follow-on funds for testing and validation, and finally overlooking the entire commercialization process. In this sense, the United States is unique in that, for lack of a better phrase, it laid the necessary framework for networking and networking research. This framework, established by DARPA and

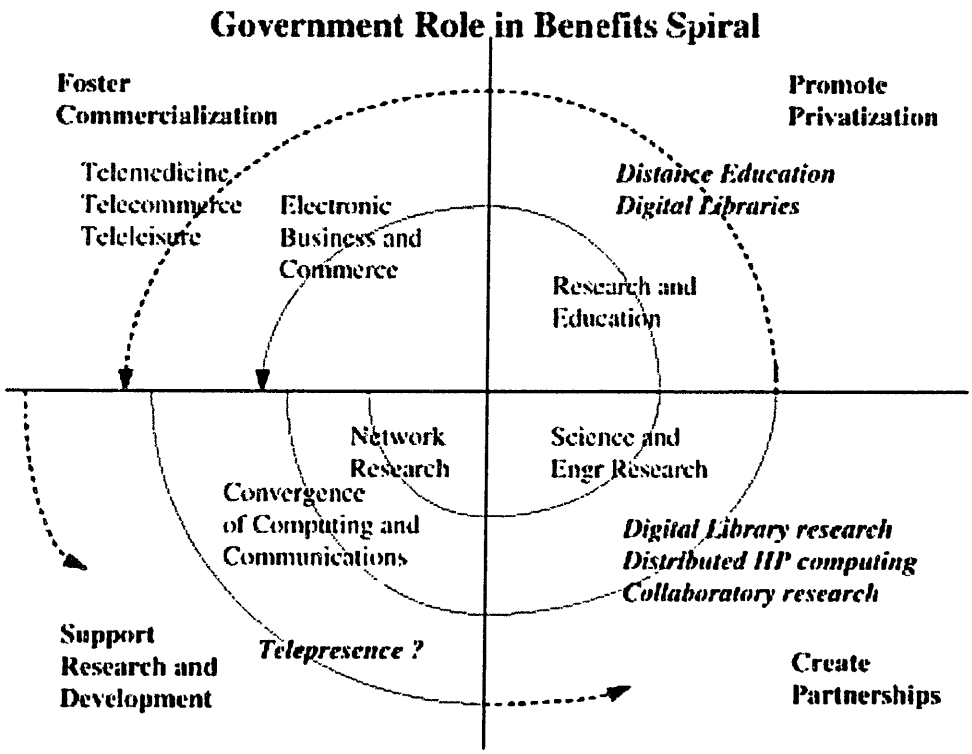


Figure 4: Government Role in Information Technology

(http://www.hpcc.gov/talks/strawn-13Jun97/slide10.html)

other federal research agencies has been the catalyst for most network-related developments in the United States.

As illustrated in Figure 5, a number of governmental organizations are involved in advising the White House. In particular, the National Science and Technology Council (NSTC) and the Office of Science and Technology Policy work in cooperation with the National Economic Council for setting the science and technology agenda in the US.

The Office of Science and Technology Policy (OSTP) provides expert advice to the President in all areas of science and technology. Through the National Science and Technology Council (NSTC), OSTP helps the US President to coordinate science, space, and technology policy and programs across the federal government. The President's Committee of Advisors on Science and Technology (PCAST) ensures public sector involvement in the work of OSTP and the NSTC.

The responsibilities of OSTP include the following:

- Advise the President and the Executive Branch in policy and budget development on all questions related to science and technology (S&T).
- Lead an interagency effort to develop and implement S&T policies and budgets across Federal agencies.
- Coordinate the Federal government's research and development efforts to maximize the return on the public's investment in S&T.

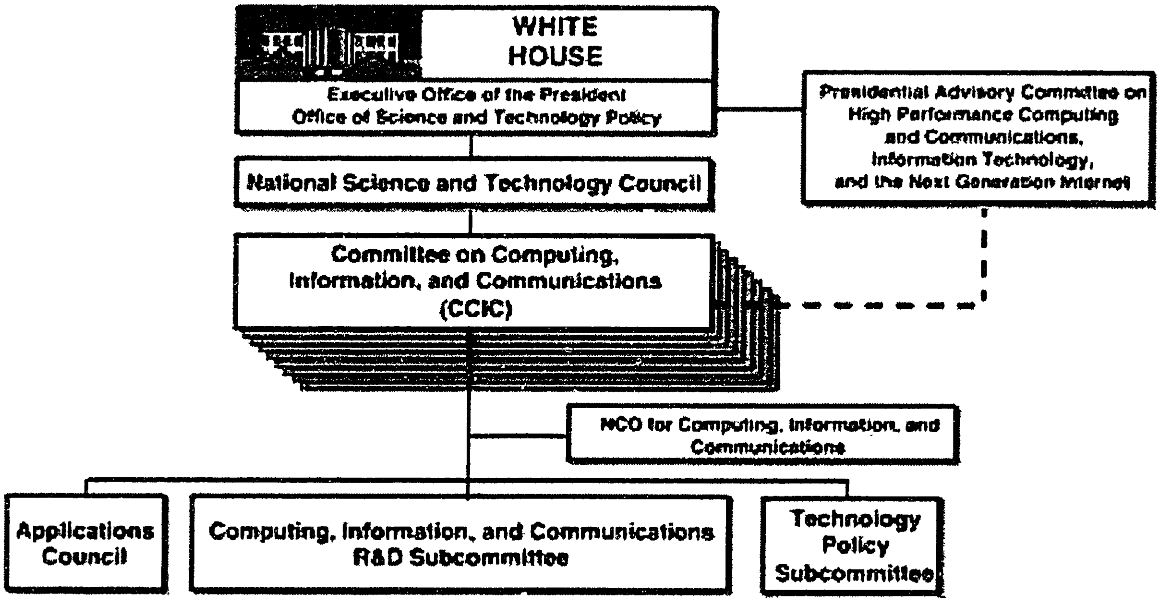


Figure 5: US Technology Organizational Bodies in the White House

(http://www.hpcc.gov/ccic/#organization)

- Foster strong partnerships among Federal, State, and local governments, and the scientific community in industry and academia.
- Communicate the President's S&T policies and programs to Congress and addressing the need for appropriate resources.
- Advance international cooperation in S&T.

In terms of ongoing initiatives, the organizational relationships are as follows (see also Section 3.1 Major US Internet Initiatives):

- I2 is a university led initiative based on the White House directive to connect US universities at previously unachievable speeds. It is not directly under any government agency.
- NGI is directly funded by the HPCC (see Figure 5).
- NSFNET(vBNS) is under the direction of NSF, which reports to HPCC. vBNS is presently being contracted out to MCI, as part of the Internet commercialization.

4.2 Commercial Sector

Realizing the amazing potential of large scale networking, the US Government lifted the commercial ban in 1989. Shortly thereafter, MCI was commissioned to take the lead in further research and development. The Internet and networking moved from a private research domain, only used by government officials and contractors for government sponsored research, to a profitable information commodity where the government is only one entity within a broad series of users.

MCI also received a contract from NSF to develop the vBNS (very High Speed Backbone Network Services) in 1995. Since then, MCI has developed a US spanning backbone network that operates at 622 MBps.

In addition, commercial organizations are involved in university testbeds such as the one in North Carolina's GigaNet. (see Section 5.0 GigaBit Research Testbeds)

4.3 University Sector

The university sector is taking the lead in the following areas:

- Demonstrate expertise in network management
- Provide standards for campus wide interconnection
- Explore other R&D applications of I2
- Train next generation of I2 professionals
- Develop models and simulations

Since the entire applications focus of Internet2 is on research and education, it is logical that US research universities are taking a lead role in the Internet 2 consortium. The universities that have joined the Internet2 initiative to date have faculty and researchers with leading-edge needs for early access to Internet2 functionality, as well as the institutional ability to fund the necessary network upgrades and applications development. Thus it is a self-selecting group of universities with pressing demands for advanced networked applications who will benefit from I2.

Colleges and universities and other organizations with less immediate needs for I2 applications and services, who are not participating in the early investment, will also benefit over time. A key objective of I2 is to accelerate the pace of transfer of new technologies into the commercial marketplace, thus creating the basis for making next-generation information services available to all sectors of society. However, it is not necessary to wait for integration of Internet2 services into the commodity Internet for all institutions to benefit. The Internet2 Project will also share its experiences and expertise on an ongoing basis with others in the education community and beyond. Through publications, presentations (at CAUSE conferences, for example), and workshops and focus groups open to non-members, the Internet2 community intends to provide updates and interaction with a wide community of interest.

5.0 GigaBit Research Testbeds

A major component of advanced research and development activities related to Internet2 in the US is done via the mechanism of university "testbeds." These testbeds are frequently developed and maintained in conjunction with one or more commercial organizations. This close working relationship between the corporate and the academic world provides benefits for both groups, and is recommended for similar endeavors in other countries.

Many of the current testbeds support transmissions at around 1 GigaBit per second (Gbps), using existing technologies. Such testbeds are designed to study efficient protocols and algorithms for switching at increasingly high speeds, as well as development of the Quality of Service protocols (see Section 8.9 Quality of Service software (QoS)) and other features to be implemented in evolving protocols such as Internet Protocol version 6 (IPv6). Enhancing the efficiency of routing software and hardware is another objective of such testbeds.

Because of their experimental thrust, virtually all the research testbeds cover only a small geographic area, typically within one state of the US. For example, the NC GigaNet includes four major nodes, all located within the state of North Carolina[13]. Over time, these experimental testbeds will be interconnected with each other, and will form part of the evolving Internet2 infrastructure. (see Figure 6 for details)

One major exception to the "intrastate only" concept is the very high speed Backbone Network Service (vBNS). Operated by MCI since 1994, under an award from NSF to replace the older NSFNET, the framework of vBNS runs at 622 Mbps; this speed will increase once additional funding is approved for upgrading this service[14]. As such, a 1 Gbps US-wide network could be implemented in the not too distant future.

As an example of a Gigabit testbed, North Carolina implemented in 1994 the first US statewide implementation of a high performance network, called the North Carolina Information Highway. In 1996, MCNC established VITALnet, a OC-48 2 Gbps network backbone, with OC-3 links to Cisco7507 switches interconnecting Duke, North Carolina State University, UNC-Chapel Hill, and MCNC for networking testing and networking research. See Figure 7 for more details.

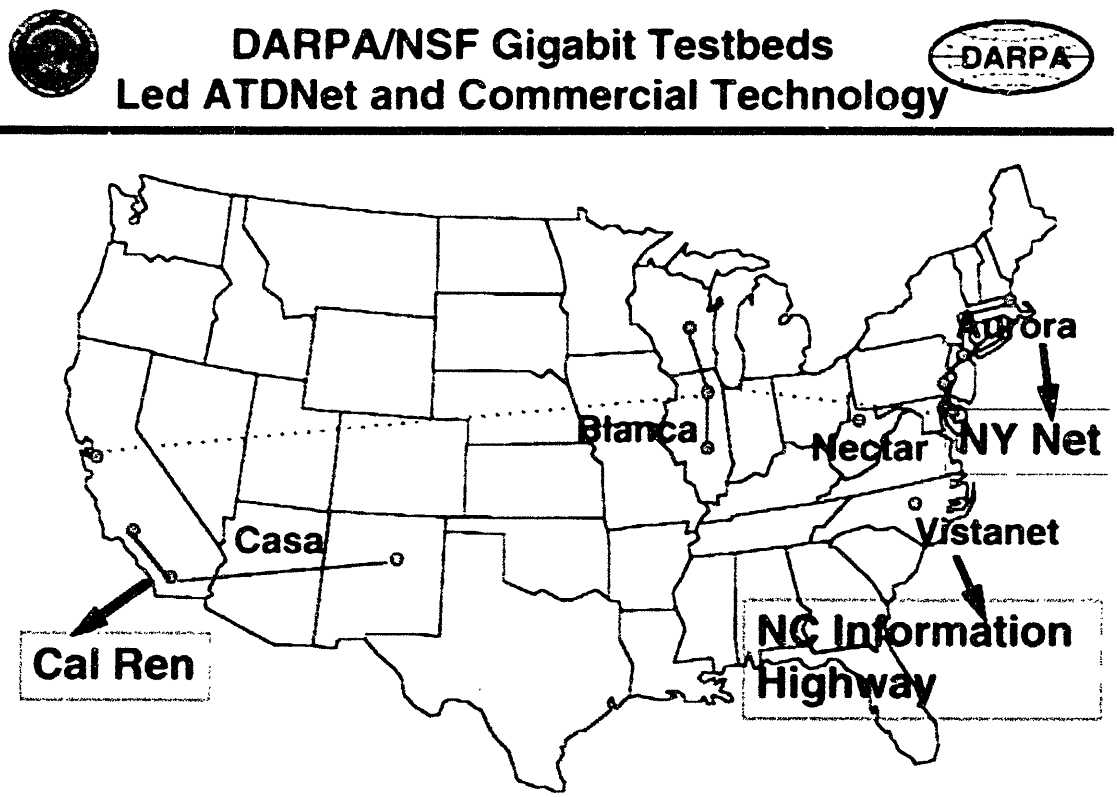


Figure 6: Selected US GigaBit Testbeds (http://www.arpa.mil)

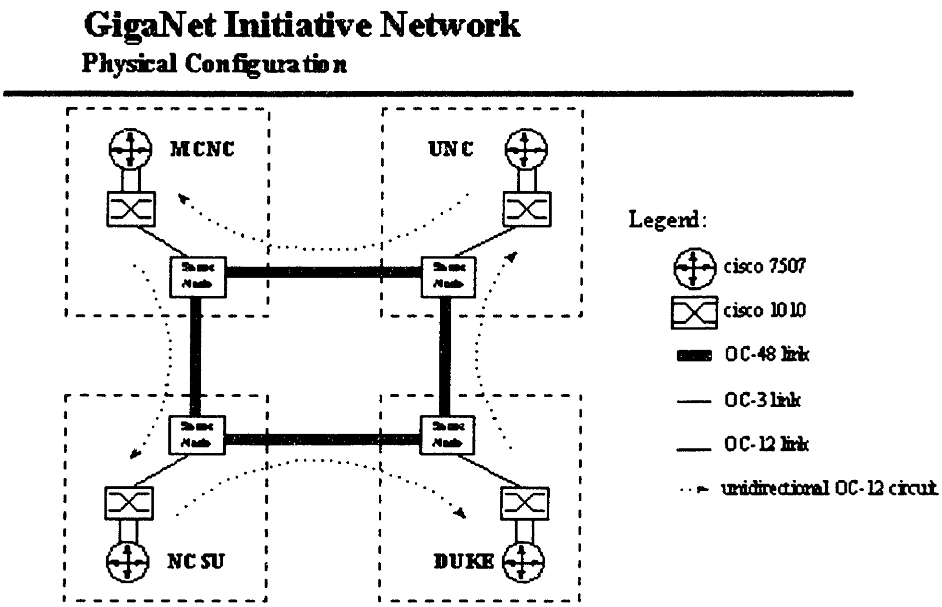


Figure 7: North Carolina GigaNet Topology (http://data.ncgni.org/topology.html)

A different example of a networking initiative is Cal REN, which stands for California Research Education Network by Pacific Bell. Cal REN's mission statement is: to realize the promise of the superhighway sooner rather than later. Cal REN is a $25 million grant program, established in 1993, which funds advanced technology for innovators in communications technology. CalREN's aim: to accelerate development of superhighway applications that will eventually touch every Californian[15]. CalREN funds many projects including:

- Studio of the Future: University of Southern California
- Cal Tech Earthquake Monitoring
- ATM NET for Medical Emergencies: University of Southern California
- BayLink: Monterey Bay Aquarium Research Institute
- Telemedical Emergency Neurosurgical Network (TENN)
- Science, Mathematics and Real Technology Network
- High-Speed Medical Network: University of California-San Francisco
- ATM Research Consortium
- Asian-Pacific Network, Los Angeles
- Medical Image Management System (MIMS), Los Angeles
- Bay Area Community Health and Education Network (BACHEN)
- School Networking Action Project, Beverly Hills
- Statewide Distance Education using Multimedia, San Jose State University
- TRW Satellite Data Archive
- CommerceNet

6.0 European TEN-34 High Speed Networking Initiative

Apart from the US, a number of other countries are currently examining the issue of follow-on interconnection frameworks to Internet. Probably the most significant of the non-US initiatives is the one being established in Europe by a number of organizations from different countries under the aegis of the European Commission.

TEN-34 (Trans European Network interconnect at 34 Mbps) was launched on May 20, 1997 to interconnect several of Europe's National Research Networks (NRNs) with a 34 Mbps connection[16]. While many existing research centers can exchange information at high speeds within the respective national boundaries, a high speed connection between these national 'Information Superhighways' was previously missing, which hampered collaboration between European researchers in different countries.

The TEN-34 network has been organized and is being implemented by a consortium of European Universities, with DANTE as the coordinator. DANTE is a not-for-profit company with Research Association status, based in Cambridge (UK), owned and established by a number of European National Research Networks to organize and manage the interconnections across continental Europe. The network is composed of an array of heterogeneous networks attached by parts from various suppliers. As each country has its own network, these countries each need have their connection problems addressed.

The TEN-34 project is co-funded under a joint initiative by DG-XIII (Telematics for Research) and DG-III (Esprit) of the European Commission[17].

UK	DANTE (Coordinating Partner)
Austria	ACOnet
Belgium	BELNET
The Czech Republic	CESNET
France	RENATER
Germany	DFN
Greece	GSRT
Hungary	HUNGARNET
Italy	INFN
Luxembourg	RESTENA
Netherlands	SURFnet
Denmark Finland Sweden	NORDUnet
Portugal	FCCN
Slovenia	ARNES
Spain	RedIRIS
Switzerland	SWITCH
UK	UKERNA

Table 1: Members of the TEN-34 Project

6.1 The Next Step for TEN-34

The TEN-34 contracts between the National Research Networks and telecommunications service suppliers extend until July 1998. From a researcher's point of view, the next step is an upgrade to a 155 Mbps European interconnect facility. Several nations already have this capacity, but only within their own geographic boundaries. In 1998, the European telecommunications market will be liberalized allowing additional "next generation network services" to be put in place.

6.2 Strategic and Organizational Lessons Learned from TEN-34

TEN-34 overcomes the idiosyncrasies of the many different types of network linkages used in the participating countries with the objective of unifying the research community in

Europe. Brazil too will need to address the issue of establishing high speed links with neighboring countries. Further, the European model of creating a new organization to oversee the connectivity (Dante) appears to be working well, and this may inspire the establishment of a similar organization in Latin America.

With its 30+ contracting partners, TEN-34 has evolved a pan-European approach for network provision which may be appropriate for the European scenario. In Brazil, a joint effort with state government officials would be an appropriate analogue in order to ensure due weighting to regional and provincial needs. (In terms of geographic area, Brazil probably exceeds the area of all the countries that are participating in the TEN-34 initiative).

In addition, securing funding for TEN-34 was difficult, as it was a pan-European effort without a central leader. This problem was aggravated by the fact that the involvement of large corporations, especially multinationals, is minimal in TEN-34. This again reinforces the fact that initiatives of this type need close cooperation between government agencies, private organizations, and academia; the absence of any of these three key constituencies will significantly reduce the probability for success.

6.3 European TEN-34 High Speed Network

The TEN-34 is functionally similar to the US vBNS, in linking several academic sites separated by great distances, but differs significantly in the scope of the project. Instead of looking at intra-country needs, TEN-34 attempts to serve as a bridge to several

European nations. TEN-34 offers a high speed pan-European backbone to complement an increasing number of high speed national backbones.

Structurally, the TEN-34 network is composed of two subnetworks[18]. One subnetwork utilizes ATM technology over leased lines and the other is a managed IP network, provided by Unisource. These two subnetworks are connected at three points in Europe: London, Geneva and Frankfurt. The national research networks allow Internet traffic over connections provided by the national telecommunications operators. TEN-34 became operational on April 1997.

There are two versions of Quality of Service being offered by telecommunications operators: Constant Bit Rate (CBR) and Variable Bit Rate (VBR). The former is aimed at supporting application services in which timing is important, such as video-conferencing, while the latter is geared to less time sensitive, "bursty" applications such as data transfer. CBR is more difficult to provide because of the "reserved connection" that must be established. As such, the pricing of CBR is higher than a VBR service of the same average capacity. TEN-34 uses VBR with Peak Cell Rate (PCR) = Sustainable Cell Rate (SCR) wherever it is offered, and CBR for the remaining links. Such a system provides a cost effective solution for the interconnection of the national research networks, whose international traffic is not bursty since such traffic is comprised of the aggregated data of thousands of lab users.

The IP Service is implemented using Cisco 7500 (American company) series routers connected to the telecommunications operators' ATM switches or leased lines. These routers control the flow of data into the ATM network according to parameters, so there is little loss of ATM cells due to the national research networks exceeding their respective agreed ATM bandwidths, as specified in their respective contracts with the telecom operators.

The managed IP subnetwork

The service delivered by Unisource is an IP network service with advanced features such as native IP multicast. The Unisource routers are on Unisource PoPs (Points of Presence), from where local loops would extend the network to the National Research Network sites. This is the normal network set-up as used in most backbones today.

The Unisource subnetwork connects the following national research networks or organizations:

NORDUnet	(Nordic countries)
SURFnet	(Netherlands)
SWITCH	(Switzerland)
RedIRIS	(Spain)

In order to provide sufficient service, Unisource's trunk connections will be re-implemented using STM-1 (the European Equivalent of OC-3, approx. 155 Mbps) circuits. The hope is that this transition between networks will be transparent to the connected networks. To ensure highest speed, the setup between the trunk router and the ATM switch installed in the Unisource Point of Presence was implemented using STM-1/ATM. (see Figure 8)

To maintain the hardware, UKERNA has been awarded the contract for the Network Management Service, which covers the entire TEN-34 community.

6.4 Technical Lessons Learned from TEN-34

The TEN-34 implementation of Quality of Service, using a blend of Constant Bit Rate and Variable Bit Rate is efficient. In addition, the ATM model and the use of frame relays to minimize traffic across international borders (where it is most expensive to send) could be used in Brazil, where international or interstate traffic may have a premium cost attached to it.

Where necessary, TEN-34 utilized foreign technology, but with a native implementation. Such a model exemplifies how one can quickly implement a sustainable large-scale network. TEN-34 also had the privilege of simply connecting various existing information infrastructures, whereas an entirely new networking infrastructure may need to be implemented in many areas of Brazil. As such, predictions made for TEN-34 based on existing traffic and needs in Europe will need to be analyzed carefully before one can extrapolate the numbers with reference to Brazil.

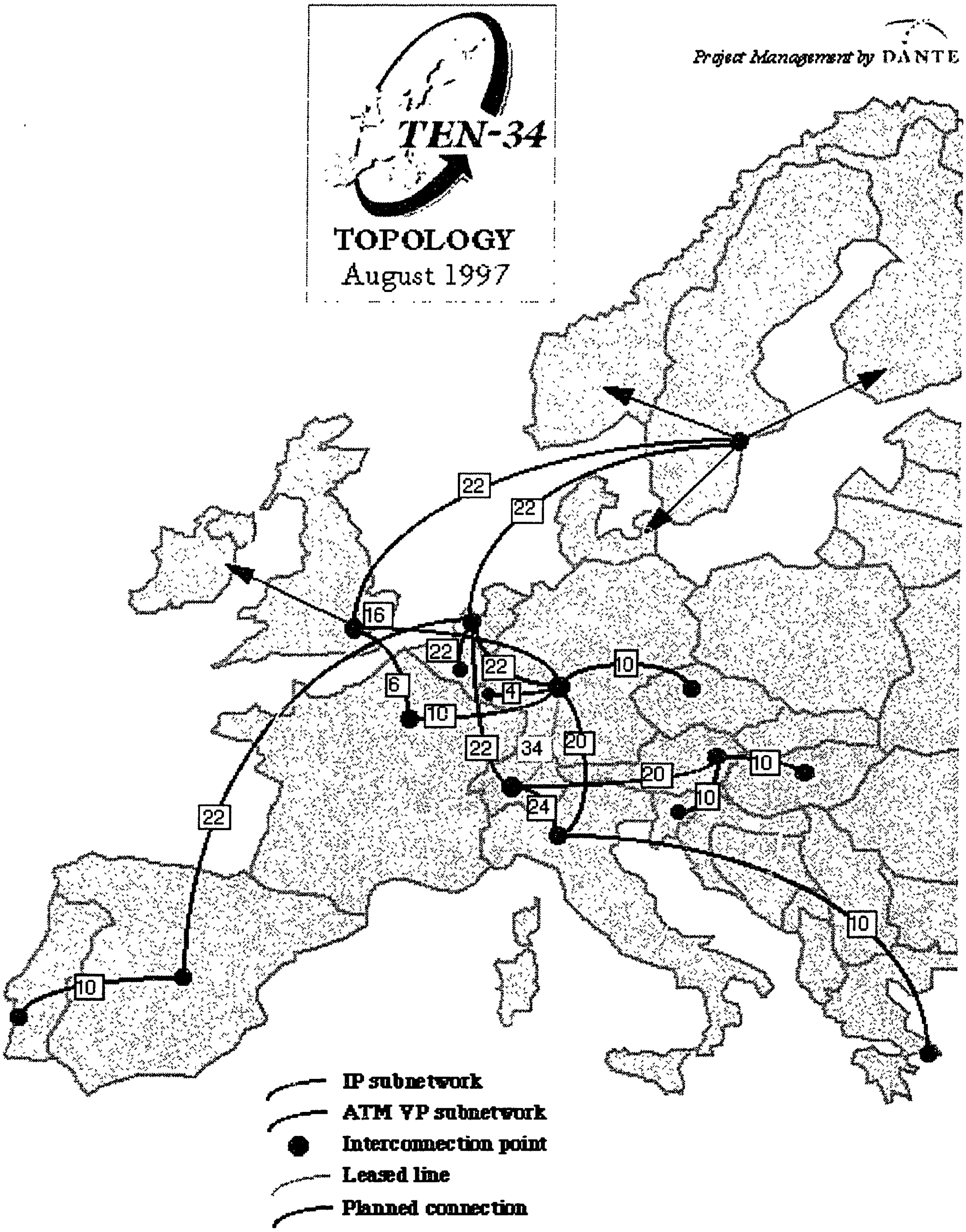


Figure 8: TEN-34 Topology (http://www.dante.net/ten-34/ten34net.GIF)

The TEN-34 implementation team noted severe difficulties in linking to countries because of the heterogeneous systems and multiple suppliers, and the lack of available 34 Mbps lines; in fact, the latter did not turn out to be more cost effective than 2 Mbps lines. Since, the funding was provided only by government agencies, a number of bureaucratic hurdles had to be overcome. Also, many "country specific" compromises were made, resulting in a bottom up design, instead of an optimized top-down design. Future implementations must attempt to prioritize re-engineering and redesign needs.

7.0 Technical Details of GigaPOPs (Gigabit Point of Presence)

At the heart of the US Internet2 design lies the GigaPOP, a new technology for providing advanced communications services. The term "GigaPOP" was coined by a politician when describing a gigabit of information POPping from one location to another. Hence the word GigaPOP[19].

GigaPOPs represent a new concept in networking because they will allow endusers to access the Internet2 in a more direct way, with more choices than ever before. At present, users must call their local Online Service Provider to gain Internet access, but GigaPOPs will allow people with modems to connect directly to the GigaPOP, from which the user would be able to select his or her choice of Online Service Provider (such as AOL). High speed GigaPOPs will improve connectivity and allow faster access.

One of the goals of the US Internet2 initiative is to create and deploy a large number of GigaPOPs in various high use areas. The initial deployment will include 20-30 GigaPOPs serving regional or state-based not-for-profit consortia such as the Virginia Educational Network, the Washington State K-20 network, or the combined University of California and California State University system[20]. These GigaPOPs will be designed and managed collectively on behalf of the Internet2 project community. (see Figure 9 for details)

7.1 Specific GigaPOP Design Specifications

There are likely to be two types of GigaPOPs[21]:

- Type I gigapops are relatively simple, are intended to serve only I2 members, route their I2 traffic through either one or two connections to another gigapops, and therefore have little need for complex internal routing and firewalling;

- Type II gigapops are relatively complex, serve both I2 members and other networks to which I2 members need access, have a rich set of connections to other gigapops, and therefore must provide mechanisms to route traffic correctly and prevent unauthorized and improper use of I2 connectivity.

The engineering principles involved in designing the GigaPOPs are:

- Buy rather than build.
- Open rather than closed.
- Redundancy rather than reliance.
- Basics before complexity.
- Production not experimentation.
- Services to end users, not to commercial providers.

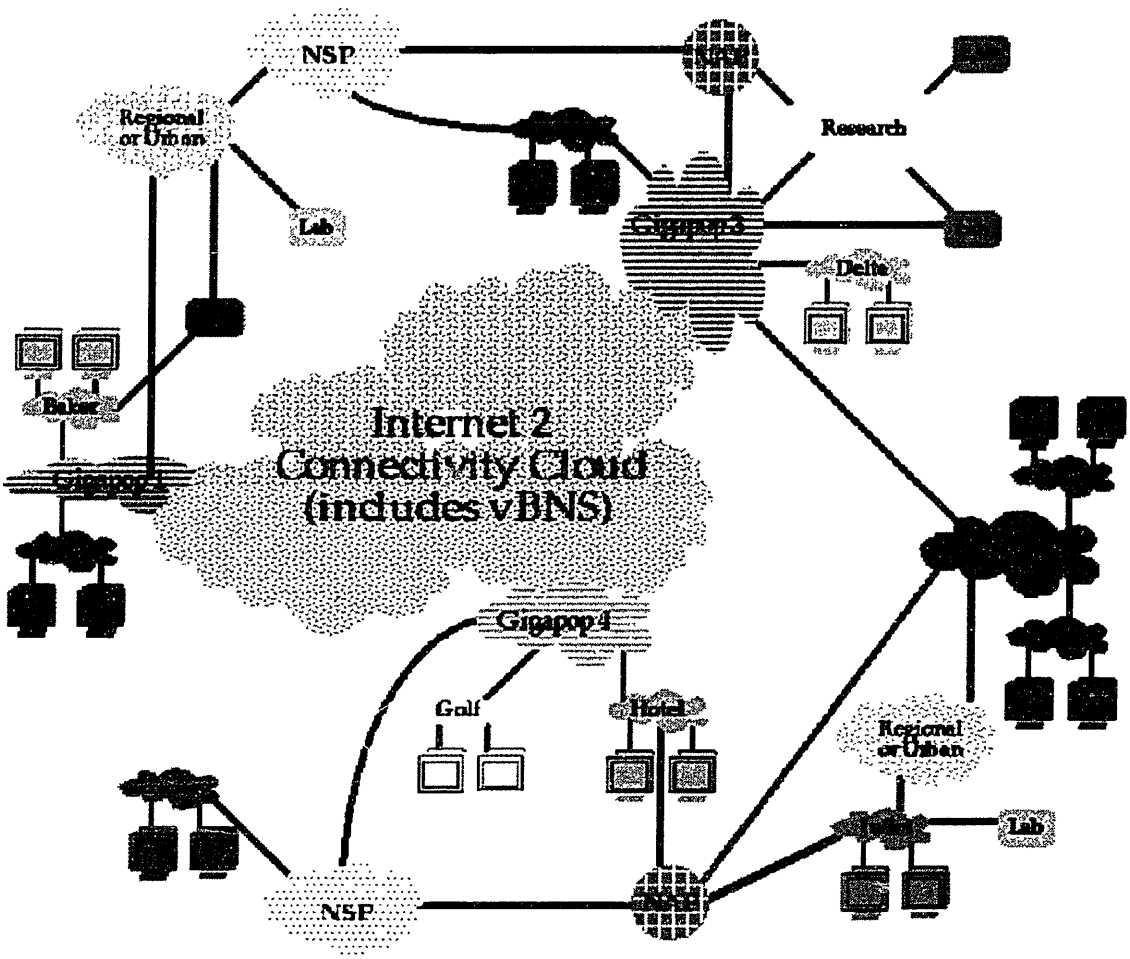


Figure 9: Role of GigaPOPs in Internet2 (http://www.internet2.edu)

Goals for Campus Networks

- Provide 10Mbps on an unshared basis available from desktop
- Offer >500Mbps backbone
- Support ATM in native mode
- Utilize NOC instrumentation, reporting, monitoring, trouble-ticket sharing capabilities
- Facilitate QoS management

Campus-to-GigaPOP Connections

- Offer bandwidth >150Mbps
- Provide NOC-NOC trust & communications
- Accept responsibility for on-campus services

7.2 GigaPOP Components

To achieve a throughput rate of 1 Gigabit per second, the GigaPOPs will need to be designed very carefully, using the latest technology and products, as follows:

High capacity advanced function packet data switch/routers

Companies such as Ascend and Cisco already provide switches that operate at the desired 1+ Gbps rate. At the minimum, the router must be able to handle OC-12 (622 Mbps) links and switched data streams as well as packet data routing.

High speed frame relays or concentrators will be required to compress the data before they are sent over the channels to other routers. Typically, the companies that offer routing hardware also offer a full range of Internet connectivity products.

Support for IPv4 and IPv6

Present implementations of GigaPOPs must support existing IPv4 packet switching protocol, but, in preparation for the imminent, but gradual transition, they must also support IPv6 switching; the latter is becoming the de facto standard for the near future (1-3 years).

Advanced Routing Protocols

While the hardware may be able to physically route packets at the 1 Gbps rate, the actual speed seen by the user will be significantly lesser. However, with new protocols that incorporate multiple priority levels, this difference can be reduced especially by giving higher priority to packets of higher importance. For additional details, please see Section 8.9 Quality of Service software (QoS).

SONET or ATM Multiplexers

GigaPOPs involve the use of the new SONET and ATM technologies to enable allocation of link capacity to different services such as highly reliable IP packet delivery, experimental testbeds for emerging protocols, and for special requirements determined by new initiatives among the Internet2 member institutions. Although direct SONET pathways might be most effective in providing the inter-GigaPOP pathways, it seems most likely that ATM-over-SONET will be the most commonly available commercial service. Thus, a test network can be implemented using ATM over SONET, and a parallel production network can be implemented too without requiring having to duplicate communications facilities. In addition, traffic measurement and related data gathering instrumentation will need to be installed to enable monitoring of flow characteristics of the GigaPOPs.

7.3 Asynchronous Transfer Mode

Asynchronous Transfer Mode (ATM) is a switching technology that organizes digital data into byte-size cells and transmits 53 cells at a time over a digital medium[22]. The term "asynchronous" implies that the communication can occur at any time and the receiver will be able to handle multiple requests at the same time and to keep track of the different requests being handled. Individually, a cell is processed asynchronously relative to its related cells and is queued before being transferred over the communications line.

Because ATM is designed to be easily implemented by hardware (rather than software), faster processing speeds are possible. IEEE Spectrum (1/96) reports that speeds on ATM networks are expected to reach 10 Gbps.

7.4 Synchronous Optical Network

Synchronous Optical Network (SONET) is a robust US technical standard for synchronous data transmission on optical media[23]. The international equivalent of SONET is synchronous digital hierarchy (SDH). Together, they provide the framework for digital networks to interconnect internationally and also for existing conventional transmission systems to take advantage of optical media through tributary attachments.

SONET is essentially a modulation standard. Once the cabling has been laid, SONET is the method used to transfer the data. SONET provides standards for a number of line rates up to the maximum line rate of 9.953 gigabits per second (Gbps). Actual line rates approaching 20 gigabits per second are possible. ATM runs as a layer on top of SONET as well as on top of other technologies.

SONET offers the potential to provide:

- Lower operating cost because of enhanced interfaces to operating systems that provide more detailed status report and remote provisioning capabilities;
- Lower capital requirements because of increased vendor competition; and
- Improved service quality because of pro-active performance monitoring and thresholding reports

7.5 GigaPOPs in Brazil

Hardware components of a GigaPOP of the type described in Section 7.2 GigaPOP Components will be needed to implement Internet2 in Brazil. Based on current estimates of communications needs, Brazil will need to implement relatively small numbers of strategically located GigaPOPs to provide good connectivity to the general public.

In terms of deployment strategies, the initial focus should be on 2-3 experimental sites, based at either universities or in large populated centers (see Section 10.0 Strategic Options and Recommendations for Brazil). The GigaPOPs will need to be deployed in a gradual fashion, in order to learn from each successive implementation, and also to give due importance to Brazilian-specific traffic preferences and hardware/software requirements.

In terms of different technical options, centralizing GigaPOPs and creating a "GigaPOP cloud" of connectivity over a small, already developed area appears to be the best solution. Once a Gigabit backbone has been implemented in large cities, the less urbanized areas can be phased in gradually.

8.0 Current and Evolving Internet Infrastructure

The extensive man-machine framework that supports Internet and Internet2 can be studied in terms of its four major components:

- *Transmission Medium* includes how the data are transported from one area to another.
- *Switching Hardware* deals with how the data are sorted, compressed and directed to their final destinations.
- *Software* development needs to be done on a continuing basis to accommodate advances in hardware. The current focus is on Internet Protocol version 6 which includes Quality of Service capabilities.

- *Personnel* that help to develop and maintain the Internet2 framework on a continuous basis. The personnel possess skills in a number of areas, including network topology and planning, as well as on practical implementation issues, such as hardware connections and maintenance.

In order to study the technical issues involved with respect to Internet2 in Brazil, each of these four component areas is analyzed in detail.

8.1 Transmission Medium

The extensive fiber optic base in the US is owned by companies like MCI and Sprint. These companies then lease the use of the communications lines to Internet companies and institutions (called Internet Service Providers, or ISPs), who in turn make the Internet services available to the general public.

However, cabling alone does not determine the speed of the Internet. Rather the technology utilized at each end (the transmitters/receivers and encoding of information) is usually the major factor determining the ultimate speed seen by the end-user. With traditional copper wiring, signals degrade over distance and do not carry as much data per fiber. Fiber-optic cables carry data with higher fidelity than traditional copper cabling. With the large number of companies involved in fiber optic cabling now[24], the cost of large scale cabling endeavors has become fairly competitive. In addition, new DSL (Digital Subscriber Line) technology has been developed which can leverage existing copper wire, such as phone lines, with much greater efficiency than previous systems (see Section 8.3 Digital Subscriber Lines (DSLs) for more information.

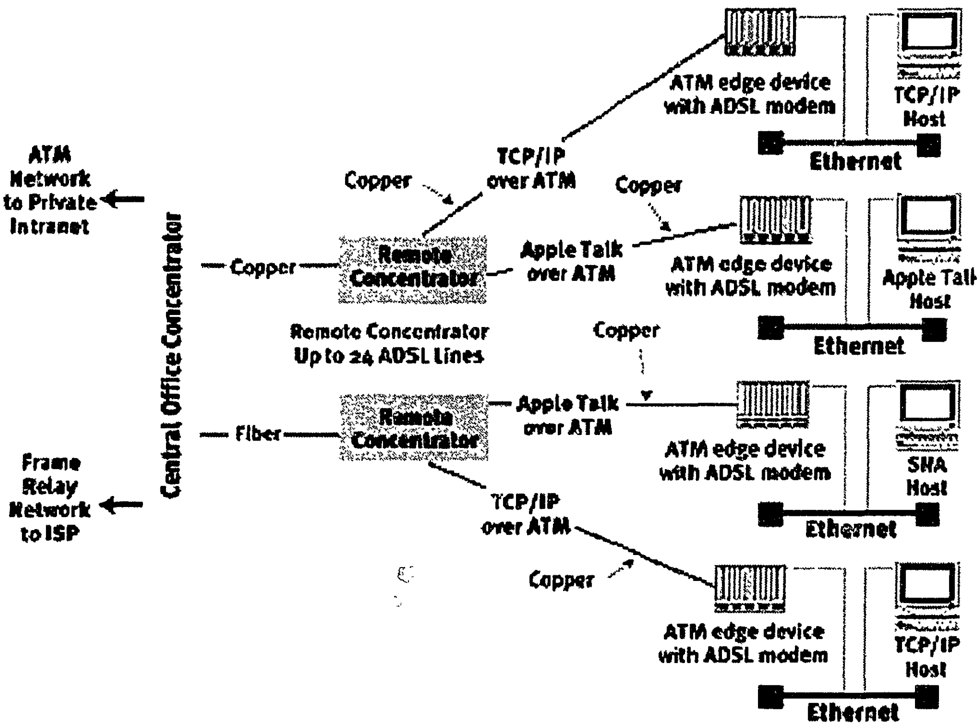
8.2 The OC-x Standard

OC-x means Optical Carrier level x. It is a SONET term (see 7.4 Synchronous Optical Network) for an optically transmitted SONET signal at a particular speed. The base rate is 51.84Mbps. OC-1 runs at the base rate, OC-3 runs at 3 times the base rate, etc. Commonly planned rates are OC-1, OC-3 (155.52Mbps), OC-12 (622.08Mbps), and OC-48 (2.488Gbps). The most advanced networks today utilize the OC-48 standard[25].

8.3 Digital Subscriber Lines (DSLs)

Digital Subscriber Lines (DSLs) is a new technology that offers extremely high speed communications bandwidth (6Mbps, as compared to present ISDN at 128kbps) over copper wires, directly into end-user homes. In addition to performance, the cost of operating DSLs is estimated (in the Jan/Feb 1997 issue of IEEE Network magazine) at 15 cents per Kbps bandwidth, as opposed to $7+ per Kbps for present T1 lines.

The leader in this area, DAGAZ Technologies, a recent spin-off from Integrated Networks, of Bridgewater, NJ, has been acquired by Cisco, who plans to continue work on xDSL, a high speed version of DSL. Before being acquired, DAGAZ helped China, South Korea, and other Asian countries build telephone and cable television infrastructures where none existed before[26].



DSL concentrates several copper lines into a single digital line

Figure 10: How DSL works (http://www8.zdnet.com/zdimag/webconnections/adsl/)

Cisco and Dagaz's newly released Jera 2000 product line includes the ATM edge devices (with ADSL modems) installed at each customer site, as well as a multiplexing gear that consolidates many digital subscriber lines into the 45Mbps or 155Mbps high speed trunks, feeding into the telephone networks. Jera 2000 is designed to offer three types of connectivity to DSL subscribers: direct access to an ISP, secure access for remote LAN users to a corporate intranet, and a low-cost, high-speed alternative for conventional leased lines; the last one is most important for large scale development. (see Figure 10 for details)

DAGAZ claims its architecture can achieve the 15-cents-per-1Kbps operating cost by multiplexing as many as 480 ADSL lines (with as many as 1,000 ATM virtual circuits per line) onto a single high-speed port in the telephone or ISP network.

8.4 Brazil's Transmission Medium

Brazil presently utilizes satellite based relaying for many of her communication needs. Due to terrain difficulties and large distances between urbanized centers, deploying fiber-optic cables on a nationwide basis is a challenging proposition. In addition, the fiber optic cable industry in Brazil is still at an evolving stage with respect to contending with the needs of a nationwide inter-connection program.

While Brazil's satellite broadcasting capabilities are currently for commercial purposes, one needs to look into long-term issues relating to the use of satellite technology for purposes on Internet2. In the case of a satellite, the data must travel the distance to orbit and back. Further, existing satellites could be increasingly clogged with data when Internet2 becomes widely utilized. As such, the installation of ground based communications infrastructure needs to be encouraged wherever feasible. For example, for urbanized areas, installation of fiber-optic cables may be a good option. However, in less urbanized areas, satellite communications may be more appropriate, especially until cheap and effective means are developed to interconnect such areas with ground based transmission technologies.

Irrespective of the physical medium used to transfer the messages, the digital communications infrastructure could be vastly improved with the aforementioned DSL technology. Implementing DSL would involve a high initial cost to install the connection hardware at both ends of the system; however the overall performance and lower long-term maintenance costs make DSL an attractive possibility.

8.5 Switching Hardware

At the national and regional levels, Internet can be modeled as a large collection of "smaller" networks, such as corporate, educational and government agency networks. Routers connect these various networks, and are used to sort and direct packets along the proper networks. Routers are present at all network junctions and are also utilized to connect various Internet structures, such as ones from BBN and UUNet to each other. Frame relays and "compressors" help reduce packet traffic and increase overall speed on the networks.

Ascend, Cisco, 3Com are among the set of companies that provide high speed routers. Each company typically focuses on a specific target market, such as educational institutions or small corporations. For large scale, nationwide public networking, Ascend is the leading provider of routers, although other companies are gradually gaining market share. 3Com deals almost exclusively in commodities (private smaller networks), while Cisco also deals in private networks, but features a more complete product line. These companies also provide frame relays and other associated networking equipment.

The various types of routers are designed to meet a broad variety of switching needs, which depends on load, type of traffic, cabling used and networks being connected. In general, broadcasting data on a wire at high speeds is fairly easy, but routing at high speeds is very expensive.

8.6 Brazil's Switching Hardware

The existing communications networks in Brazil could be potentially utilized in the proposed national infrastructure. This would require Brazilian communications and networking companies to invest in the development of high speed routers, so that these networks can be connected at high speeds. The number, location and characteristics of routers will depend on the location of existing networks and the volume of traffic generated by corporations, institutions, government agencies, and other major users.

However, in the interim period, high speed routing devices can be purchased from abroad to connect the major existing Brazilian networks. OC-48 routing should be sufficient to create the high speed backbone for near term needs.

8.7 Software

As hardware technology improves, software technology and standards used for routing and packet transfers also need to evolve. The existing Internet protocol was not designed for the volume or demand of users that are now accessing the Internet. As a result, new standards are being developed to control access to ensure better quality of services. The two major new initiatives are a replacement Internet Protocol (IPv6) and its "piggybacked" concept, Quality of Service.

8.8 Internet Protocol, version 6 (IPv6)

Though most lay-people have been told that IPv6 is primarily a fix to solve the problem of running out of IP addresses by 2010, there are other, equally important motivations for the development of IPv6. When it was realized that the needs of a new Internet could not be met with the exiting Internet Protocol and its outdated labeling system, a consortium of experts in Internet communications was gathered to prepare a solution. They met under the umbrella of the Internet Engineering Task Force (IETF), and drafted a new Internet Protocol, IPv6, along with detailed implementation and transition plans. IPv6 is not just a US standard, it is intended to replace the IPv4 worldwide. IPv6 will offer Quality of Service, security packages, improved routing support, more efficient packet labeling and, of course, more addresses[27].

The existing protocol, IPv4, will be phased out slowly, through unintrusive procedures, beginning in late 1997, with IPv6, not IPv5. IPv5 was the name given to a protocol (also known as ST2) designed as a supplement to an existing protocol that utilized connection based features; unfortunately, it never gained broad acceptance.

IPv6 is relevant to Internet2 because all switching software for Internet2 will need to support IPv6. In short, IPv6 serves as the foundation for Internet2 from a software viewpoint.

8.9 Quality of Service software (QoS)

As Internet speeds rise, so will the application bandwidth requirements. While advances in hardware will certainly improve the number of users that are able to access a higher speed line, the number of users demanding higher bandwidth increases at a much greater rate. Regulations must be put in place to determine who is permitted to use the higher bandwidth and what is the appropriate price for priority usage of the bandwidth.

The definition of Quality of Service varies greatly from user to user. The ideal Quality of Service mechanism must balance the user's desire to specify total elapsed transfer time, and also handle different transfer sizes of different applications, 1 byte or 10 million bytes, and the different target transfer times, which may range from tenths of a second to minutes or even hours.

A number of possible approaches for supporting Quality of Service are described in the following paragraphs[28].

- **Guaranteed Minimum Capacity Service:** As the name implies, a user pays for a group of packets to have a guaranteed minimum speed to its destination. The difficulty lies in providing the guarantee for such service during high peak usage. In addition, each object sent by the user represents a separate short-term load on the network, which the user wants serviced as quickly as possible, not at a steady rate.

- **Connection-based Reservation:** Some implementations of RSVP (Reservation protocol) allow a user to reserve a fixed amount of bandwidth to send/receive data. This creates a system very much like the "Guaranteed minimum capacity service" noted above, with the guaranteed service of the "pipe" that has been reserved. However, since most data sent are "bursty," much of the reserved bandwidth will be wasted; also, larger bursts of information cannot be handled properly by this methodology.

- **Payment by Sender and Receiver:** In addition, the question of who pays for the information transfer is significant in the development of an appropriate Quality of Service system. For example, if only the sender pays for the data sent, then there would be a very strong discouragement to anyone willing to provide free information services. At the same time, it seems appropriate that commercial services, like advertising, should pay for the transfer of their product or product information over the Internet. A balance of sender and receiver payments seems like the most intuitive and natural arrangement, because it will ensure that money can flow in the appropriate proportions to the proper organizations.

8.10 Relevance of Software to Brazil

IPv6, as described above, will be implemented soon, and all routers will need to upgrade to the new standard or become obsolete. Fortunately, the change is only at the software level. Unfortunately, the IP addressing system has very widespread usage. In fact, almost every networked computer in the world utilizes IPv4. Thus, Brazil will have to undertake an information campaign to upgrade all users nationwide, and until then, will be forced to run routers serving both IPv4, to remain backwards compatible, and IPv6, to ensure Brazil is not assigned to the backwaters of the Internet.

Quality of Service software is an area that should be of interest to businesses in Brazil. Quality of Service software will determine who makes money and how from the Internet. As Brazil moves towards a privatization of Internet services, the continued development and large scale development of the Internet2 may depend heavily on the cost/payment structure. The mechanisms of Quality of Service are still in development, but a strong push will be needed to formalize the structure in Brazil.

8.11 Personnel

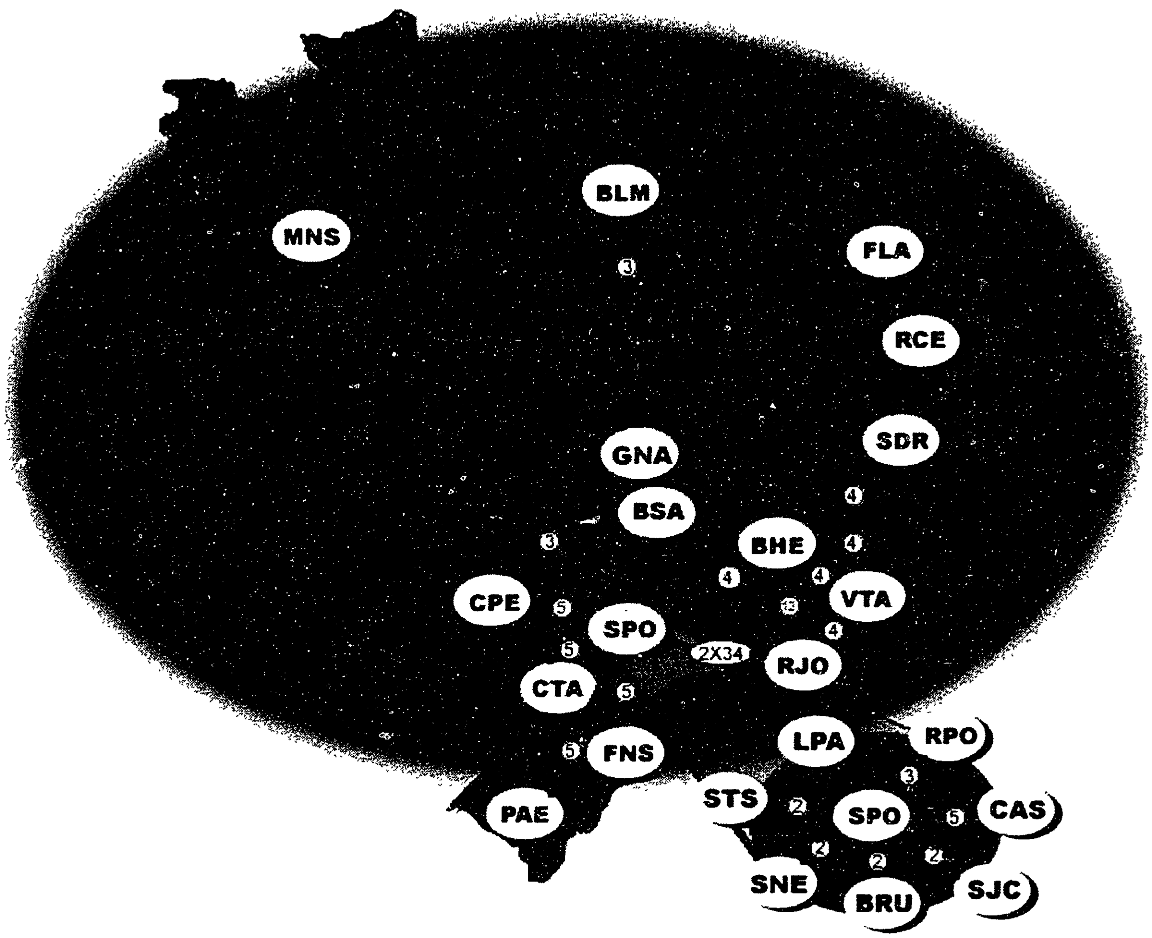
Trained personnel are necessary two main areas in Internet development: research and planning, and implementation and maintenance. In North America, corporations and the government generally provide research funding, while the academic communities generally provide most of the research personnel and expertise. Brazil will need to actively pursue focused research and training programs in universities to develop intellectual skills related to Internet2.

Education costs to the government can be reduced by partnerships with corporations to promote back-to-school or higher educational studies, through scholarships, subsidies, and legislative protection.

Having laid out the structure of the Internet2, engineers and other full time staff will need to be hired and trained to implement and maintain the centers, observing network traffic, maintaining equipment, updating software, and generally overseeing general operations. Most major networking centers in the US have automatic monitoring systems, and also a staff of 20-30 people to address difficulties.

9.0 Brazil's Communications Backbone

The federal government of Brazil has traditionally controlled the communications industry through regulation. Until recently, the Ministry of Communication (MC) had made Telebras as a national communications monopoly. Embratel is the division of Telebras concerned with international communications and Internet communications.



Speeds of links in Megabits/second are as marked (note the 2x34Mbps between São Paulo and Rio de Janeiro)

Figure 11: Existing Internet Connections in Brazil

(http://www.embratel.net.br/internet/tecnologia_g.html)

Recently, MCT has formed the Comite Gestor (Management committee) for Brazilian Internet network management. This Management Committee is now chartered to: encourage development of Internet services in Brazil; recommend standards for the technical operations for Internet in Brazil; coordinate assignment of Internet addresses, registry of domains, interconnections of backbones; and collect, organize and disseminate information about Internet services.

Of the 80 cities that currently have Internet connectivity, only 10 of them are connected to the Internet at speeds higher than 2 Mbps. Embratel's phase 2 goal, however, is to connect all 27 Brazilian states with minimum speed of 64kbps and make viable their connections to world Internet[29]. To aid in the development process, companies like Compaq, Equitel, IBM and Phillip have offered equipment and software and have funded research in the Brazilian Internet. Recent developments show that Telebras will become privatized, opening up the market more for such companies. (see Figure 11 for details)

In 1996, Embratel derived 60% of its revenues from voice services, while only 30% of the revenues were derived from data transmission (remaining 10% from other miscellaneous services)[30]. While the percentage revenue from data transmission will increase over time, costs may also increase as upgrades to technology are implemented. However, because Embratel can continue to be supported from its voice services, by virtue of its monopoly on long distance services, this is a company which can play a major role in the deployment of Internet2 in Brazil. (see Figure 12 for details)

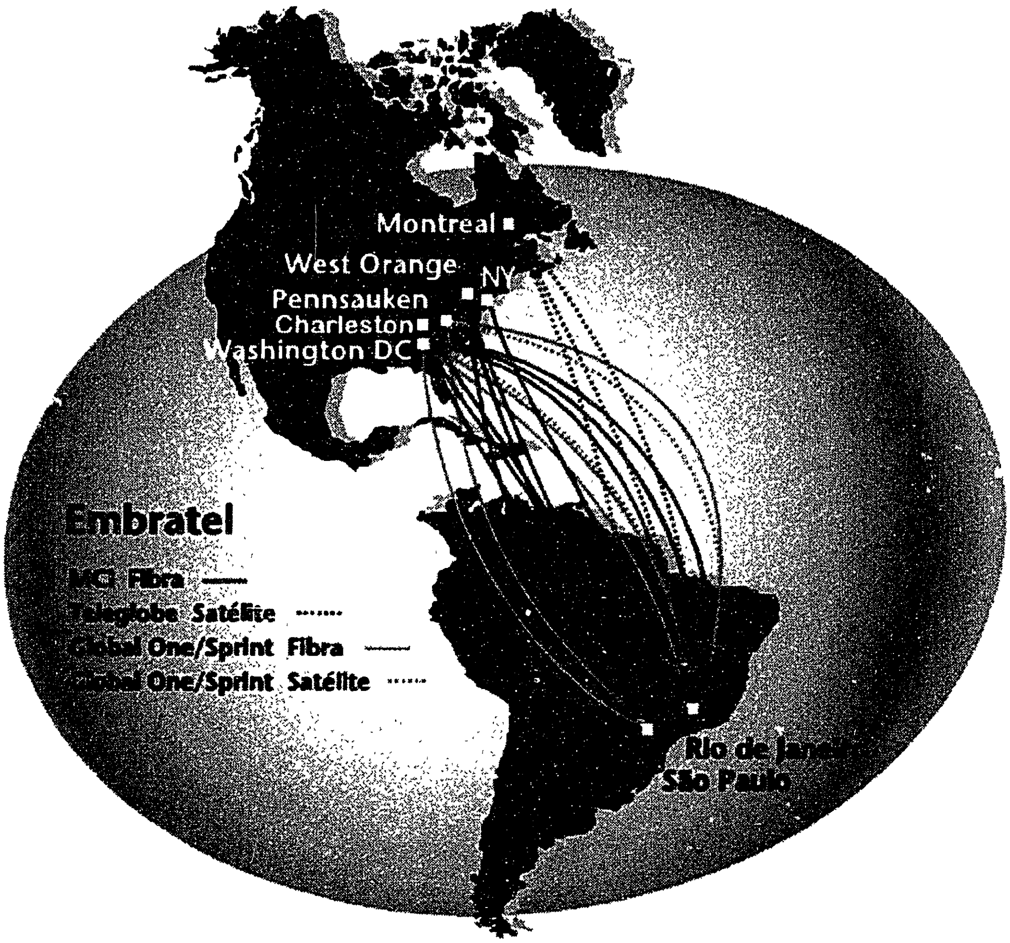


Figure 12: Brazil's International Internet Connections

(http://www.embratel.net.br/internet/backbone.html)

All the aforementioned players are now joined by RNP, the university arm of Internet development, formed in 1988 under the leadership of the MCT[31]. RNP's mission is to delineate a national initiative in networks at the university level, and to define a clear partnership model with the state initiatives. Internet2 is likely to emerge and grow from this environment in Brazil.

9.1 Brazil's Information Technology Organizational Structure

In Brazil, the Ministry of Science and Technology coordinates many aspects of Information Technology. In the case of development of Internet, this Ministry worked closely with the Ministry of Communications since all telecommunications related issues are handled by the latter ministry. Participation by academic institutions was largely driven by research funding provided by the Ministry of Science and Technology. Unlike the US model, the Ministry of Defense has not been a major player in this arena. Participation by the commercial sector has been varied, with most of the companies operating in the affluent parts of the country.

One must recognize that key industries in Brazil were traditionally operated as state monopolies. In 1991, the Executive Office initiated the Industrial Competitiveness Program which aimed at deregulating state monopolies. Particularly relevant was Decree 99.179, which included the decision to relax the laws concerning regarding private, foreign participation in telecommunications. The broad telecommunications agenda involves the installation of 25 million telephone lines by 2000. The major telecommunications provider in Brazil, Telebras, has secured $3.5 billion to install 4.2

million new terminals. In 1995 barriers to trade in computer software and hardware were lowered. Although Brazil has significantly liberalized some of its telecommunications infrastructure, it is still going through important stages in the privatization endeavor.

Within the Ministry of Science and Technology, the organization has been as depicted in the top part of Figure 13. RNP has been focused on networking issues, including Internet. SOFTEX has concentrated on software development aspects.

The organizational model has recently shifted to be one depicted in the bottom half of Figure 13. This change deserves praise, as issues related to information technology are now being coordinated through the Office of the President, as in the case of the US. Further, the change recognizes the fact that evolving information technology will impact many sectors of the Brazilian sector. In particular, the academic aspects need to be strengthened at an early stage.

Fortunately, the Ministry of Education has embarked upon an ambitious program to provide computers to all public schools in the country. The emphasis is primarily on computer hardware and the basic computer software at this stage. The Ministry of Education and the Ministry of Science and Technology need to work together to create a program that will develop software, especially educational material in Portuguese, to make better use of the computer equipment being acquired for Brazilian schools.

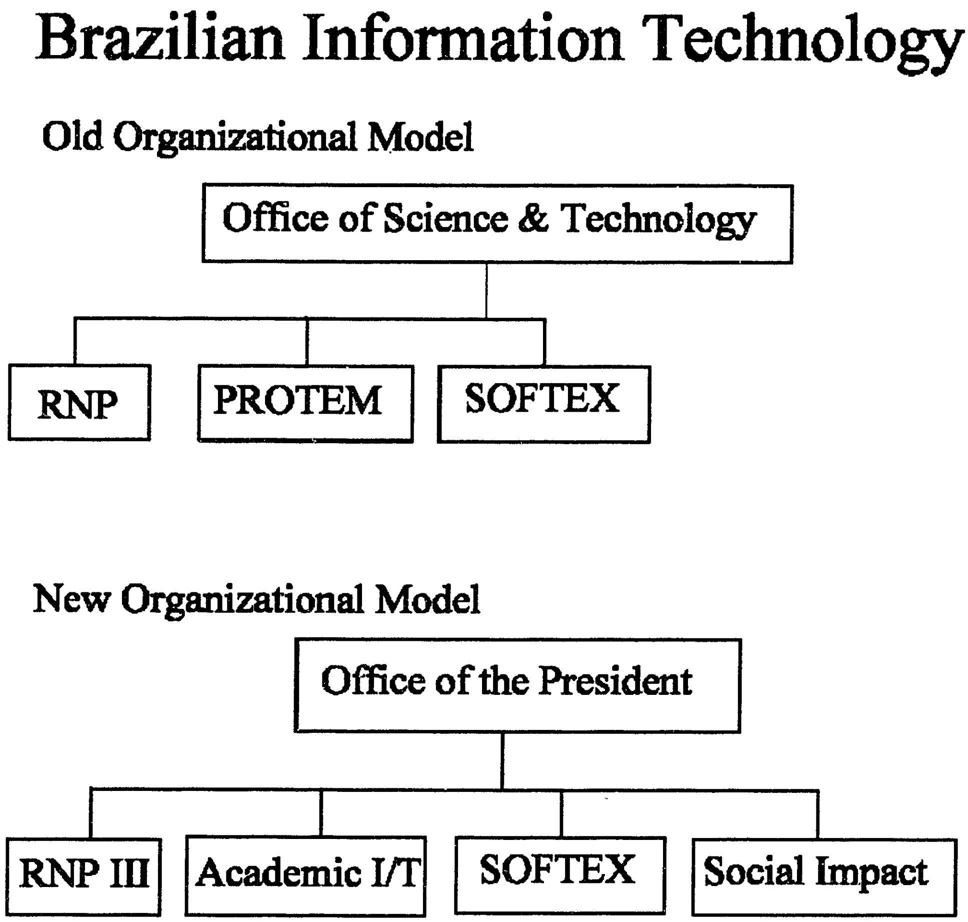


Figure 13: Brazil's Information Technology Organizational Structure

Similarly, closer ties need to be established with the Ministry of Communications so that Internet2 related issues receive due emphasis in the current thrust towards privatization of the telecommunications sector. Incentives and regulations need to be introduced to encourage balanced growth of networking capabilities across the country.

The relevant research organizations of state governments need to be more involved with respect to changes related to Internet2. The same applies to universities that are operated by state governments.

10.0 Strategic Options and Recommendations for Brazil

Brazil is characterized by large geographic size (which implies huge costs for any nationwide endeavor) and high diversity. At one end, there are provinces with thousands of websites. On the other, some provincial governments are only now in the process of establishing their own websites. Installing Internet2 capabilities throughout the country will involve capital expenditures running into billions of dollars. As such, one needs to plan a multi-staged endeavor that is consistent with the available infrastructure and the likely level of funding. Such a program will spread the deployment activities over a period of 5-10 years.

In order to proceed in a phased manner with acceptable levels of annual capital expenditure, one can identify different operational scenarios. Two such scenarios are as follows:

- Identify the geographic areas with the best Internet infrastructure and the most experienced users (possibly S‹o Paulo, Campinas, Rio de Janeiro, etc.), and upgrade this foundation to create computerized hubs that are comparable to the ones at the leading edge in the US and Europe. These hubs will be enlarged over time, eventually leading to a nationwide I2 system.

- Concentrate first on the less computerized areas of Brazil, so that the existing disparity in the availability of information technology resources and expertise is minimized, and the entire population of Brazil would be able to have better access to worldwide information resources.

Each of these two alternatives is discussed in detail in the following subsections.

10.1 Develop and Deploy Internet2 in Advanced Areas First

As in the US, the academic and research community was the first to embrace the concept of Internet in Brazil. Even today, this community plays a major role in terms of using the Internet, training people on the Internet, and developing new applications. The other major constituency in the Internet arena is the Internet Service Providers and the telecommunications operator(s) who owns the actual communications lines; this operator has traditionally been a monopoly, but one will see a growing number of operators, especially in the state of São Paulo and other affluent provinces of Brazil.

In the situation described above, most of the Internet users, the researchers involved in Internet-oriented endeavors, the set of Internet Service Providers, and the private telecommunications companies are heavily concentrated in São Paulo and other richer urban areas of Brazil. The prosperous areas are also the ones that are most advanced from technology infrastructure and technology adaptation points of view. Because of this strong technical foundation, one will find it easier to introduce Internet2 concepts in these technologically advanced areas of Brazil as compared to ones that are only now beginning to work with Internet. The ease will be both in terms of acquiring only incremental amounts of new hardware and software, as well as the total amount of funding needed to deploy Internet2 in a geographic area of a particular size. Further, since these technologically advanced areas are also more affluent from a financial viewpoint, provincial governments, local governments, and local businesses will be more willing to contribute significant funds towards the creation of Internet2 infrastructure in the respective province or town.

By providing incremental upgrades to the existing information infrastructure in technologically advanced areas, one could create one or more zone(s) of excellence that can compete with the best in the developed countries. This process can be done within a three-year framework and at relatively low costs by leveraging upon the growth of the existing infrastructure. The establishment of such zones would serve to attract new business enterprises leading to a new cycle of economic development. The zone would nucleate national and international trade and business development, leading to increased revenues and alleviation of poverty. The concept of information technology serving as the central theme of a new economic zone is being attempted on a large scale by Malaysia and Singapore.

This plan would require minimal redeployment of personnel. Further, funding could be channeled through the academic community. On the negative side, this approach increases the prevailing difference between the advanced parts and the less advanced parts of the country. In theory, the revenues from the new zones of excellence could be ploughed back to fund Internet2 development in less prosperous parts of the country. But this approach has several problems. First, the prosperous provinces must be willing to let income from the new zones be used by other provinces. Second, the new revenue stream may take as long as five years to commence, and the less prosperous provinces will need to wait for a long time to see the beginning phase of Internet2 activities. Third, the evolution of Internet is a continuing phenomenon, and the prosperous provinces will need financial resources to retain the momentum of activities within their respective provinces. As such, the concept of technology and funds "rippling through" from affluent areas to less affluent areas must be viewed with caution in the context of Internet2 in Brazil.

10.2 Expand Breadth of Internet Accessibility

The issue of providing an equitable strategy between richer urban areas and poorer areas has come up in a number of countries with respect to Internet and Internet2. For example, in the US, funding for the development of Internet2 was placed on hold while a plan was developed to deal more equitably with the rural areas of the US.

In a number of geographic areas of Brazil, access to even basic Internet services is not available. At some places, this is due to the lack of availability of telephone facilities; this is especially true of the mountainous parts of the country. The availability of modern telecommunications and information technology techniques could potentially spur growth in these areas. In particular, such technology could enhance the quality of education that is currently imparted in schools and colleges in the remote areas. Also new information technology facilities can help to provide remote medical consultation, diagnosis, and monitoring of patients. Apart from education and health, which are two measures of social prosperity (and inequality in the context of differences across provinces), one can improve commerce, manufacturing potential, and other aspects of the economy by providing technologically superior infrastructure capabilities.

At the same time, one should be conscious of the fact that the cost for deployment of Internet2 in a number of these areas may be quite high, and it may still offer minimal return: This is because mountains and other natural barriers make it difficult to bring high speed networking technologies into such areas. The good news is that the combination of satellite and ground based communications could help to overcome this hurdle within the next 5-10 years, and provide solutions at more reasonable prices. As such, the prudent approach may be to await the availability of such lower cost options in some cases.

In conjunction with the issue of timing with respect to evolving technologies, one needs to evaluate potential applications in less affluent areas that can utilize the connectivity and the high data rates that characterize Internet2. This is not a problem, per se, but rather a consideration that perhaps the particular technology being considered may vastly outscale the needs of the area. For example, if no Internet capability is available today, should one try to install basic Internet capabilities now or go (directly) for higher bandwidth Internet2 capabilities directly? The answer depends on the characteristics of the particular situation. In areas where adequate telephone networks are available, the optimal scenario may be to offer basic Internet services now. However, if the particular area happens to be close to a planned site of an Internet2 testbed, one can see the merits of enlarging the geographic area of the Internet2 testbed over time to encompass neighboring areas who may move directly from no-support for the Internet to Internet2.

An additional consideration relates to the source of funds and the interest of the private sector. As in the case of the telecommunications sector, commercial organizations are interested primarily in prosperous urban areas, with several companies bidding to provide services in such areas. At the other end, not a single private company may express interest in providing telecommunications services to the poorer and rural parts of the country. Similarly, business corporations are likely to be less motivated to make investments in Internet2 in less affluent areas. As such, funding for the project will have to be borne almost entirely by the government. One option may be to offer subsidies to companies and local groups who are willing to develop the communications and information technology infrastructure in such places.

A similar dilemma occurs with respect to the level of interest from the academic sector. Most of the internationally renowned universities of Brazil are located in the affluent parts of the country, and one would find it harder to motivate personnel from these universities to physically work at sites located in the less affluent provinces of the country. In fact, many of these universities have strong ties with the respective provincial governments, and are likely to resist pressures to make their faculty members work in other provinces for varying amounts of time. Based on these facts, finding and retaining competent personnel to work at less developed locations will involve significant funding and motivation.

The issues mentioned above are relevant to many types of developmental activities, not ones relating to information technology alone. Rather than be guided simply by the population figures of each province, the federal government will need to allocate a larger share of resources to less affluent provinces in order for them to benefit from emerging information technologies and to alleviate the existing level of disparity in the use of such technologies.

10.3 Hybrid Model

Considering the problems associated with each of the two alternatives discussed above, we advocate a hybrid model that balances the needs of diverse areas and needs of population segments in Brazil. This hybrid model involves concurrent focus on four types of activities: (i) address voids in communications infrastructure and technology; (ii) use coalitions involving government, business, and academia to establish testbeds; (iii) develop infrastructure that would be needed to make meaningful use of I2 capabilities; and (iv) introduce new education programs. These four issues are discussed in the following paragraphs.

- *Address voids in communications infrastructure and technology*: At this stage, one needs to make significant investments in satellite and wireless technologies to develop low-cost products and services that utilize these technologies for providing Internet2 services in remote parts of the country. Support for Internet2 capabilities can be provided either via ground-based communications links or via satellite/wireless links. In some parts of Brazil, natural terrain makes it difficult to install ground-based communications links. As such, satellite/wireless links hold special significance for Brazil. CNPq has previously funded research on the use of ham frequency radios for Internet applications. Such efforts are in the right direction and need to be augmented. Continuing advances in wireless technology have reduced the costs where this technology has come close to the current costs of ground-based technologies. Research in this area will help to reduce the prevailing gap in the use of information technologies across different parts of the country.

- *Use coalitions involving government, business, academia to establish testbeds*: In both affluent and less affluent areas, one needs to develop and deploy technologies that are "appropriate" to the respective areas. Such efforts should include relevant government agencies (federal, provincial and local), commercial organizations, and local educational institutions. This model of government, business and academic consortia is being increasingly applied to large projects around the world. The responsibility of the government representatives is to provide overall vision and general coordination; the responsibility of the representatives from academia is to introduce leading edge techniques and technologies for experimental use in small settings; and the responsibility of the commercial sector is to take the idea from lab settings to full-scale configurations. Such joint endeavors need to be conducted, on a concurrent basis, at multiple locations each, both in affluent and less affluent parts of the country.

- *Develop infrastructures that would be needed to make meaningful use of Internet2 capabilities*: At this stage, one needs to commit resources and personnel to undertake tasks which are needed for the success of I2 and which will not occur based on market forces alone. One such area is the development of Portuguese language repositories. Today, when one conducts a search on the web, receives information which is almost entirely in the English language. Such information was compiled mostly by commercial organizations and educational institutions as part of their usual activities, and subsequently made accessible to others via the web. In a few cases, government agencies of developed countries have funded the collection of relevant information for public use. In other cases, the information sources may receive no revenue at all; receive revenue via advertising; or receive the revenue for the information itself. Such market-driven incentives are unlikely to be adequate to create specialized webpages in the Portuguese language for many types of applications. As such, the government needs to fund the creation of specialized knowledge bases (actually data collection and knowledge management) in critical application areas, which in turn will motivate individuals in Brazil to make greater use of Internet and Internet2 capabilities.

- *Introduce new education programs*: The government needs to initiate new education programs to ensure that students graduating from schools and colleges across the country would possess the skills to make immediate and good use of communication facilities. Discussions have been held with officers of the federal Ministry of Education on this subject, particularly on the computer and communications hardware and software that needs to be acquired at this stage. The Ministry of Education is proceeding ahead with the acquisition of computer hardware and basic computer software for all schools. In parallel, teachers are being trained at a number of places in the country. However, the program launched by the Ministry of Education still needs to be complemented with a parallel program that focuses on communications and applications software arena. The computers being installed in schools by the Ministry of Education need to be provided with web-based educational material in the Portuguese language. This involves the creation of specialized software for teaching different subjects, as well as national educational repositories that can be accessed by all students in the country. In addition, more specialized training programs need to be developed, possibly in collaboration with universities in the US and in European countries. Some of these activities need to be coordinated with the development of testbeds (discussed further in Section 5.0 GigaBit Research Testbeds).

We believe that the four-pronged strategy described above presents a rapid and cost-effective plan that adequately balances the diverse needs of a broad spectrum of the population of Brazil. While allowing the leading provinces to progress forward, it will enable other provinces to catch up over time.

10.4 Testbed Development

As highlighted previously, the deployment of Internet2 will require the formation of close alliances between government, industry and academia to undertake design, development, training, deployment, and other related tasks. The work will be initiated in the form of "islands of expertise" which will be enlarged and integrated over time to cover the entire country.

The effort should commence with the creation of 3-4 experimental testbeds of the following characteristics:

- Each testbed should initially cover a geographic area of a few square kilometers and be expanded over time;
- In the case of affluent areas, the selected locations should be characterized by a high density of users with heavy communications needs;
- Each testbed should be anchored to a national, provincial, or local research laboratory or an educational institution of high repute in the area of computers and/or communications;
- Each of the experimental sites should involve relevant federal government agencies, private sector companies, and local academic institutions(s). The roles and the responsibilities of each of these three constituencies should be clearly established in

advance of initiating the effort. For example, the government agency may provide most of the funds of the experimental endeavor, and hold exclusive intellectual property rights on results and products obtained from the endeavor; the participating private sector companies may provide technical personnel to work on the project at the cost of the respective company, who may in turn be provided with preferential licensing rights to new technologies that emerge from the project; and the academic institution(s) may provide for the use of their infrastructure to support the effort, and be able to organize training courses on various aspects of Internet2.

- Each testbed should be designed in a modular fashion to facilitate its expansion over time, and also to permit ultimate interconnection (of the expanded versions) of the different testbeds.
- Bilateral or multilateral alliances may be established with professional alliances and groups engaged in similar activities in the US and in European countries;
- As other developing countries follow the example of Brazil towards establishing Internet2 capabilities on a wide area basis, these experimental testbed alliances in Brazil could serve as "training ground" for professionals from other countries, as well as engage in collaborative activities with them on a continuing basis.

11.0 Recommendations and Conclusions

Analysis and evaluation of the aforementioned technical and strategic issues including current trends in Internet development in the US and other more developed nations serves as the basis for the following recommended courses of action for Brazil.

11.1 R&D and Technical Training Recommendations

The gradual deployment of Internet2 over the forthcoming years motivates that a number of technical issues be addressed at this stage. The objective here is to facilitate indigenous deployment, not the fabrication of high-tech products for global consumption.

- First, Brazilian universities and research organizations must be encouraged to initiate applied research into the protocols, standards and new technologies that will be used in the Brazilian Internet2. While Brazil could utilize many of the same standards developed in other countries, such as the US, there will be many other issues, such as those relating to transmission speeds, routing headers, and specific language markers, that may benefit from indigenous standards.
- Second, an assorted mix of land-based, satellite and wireless communications technologies will need to be employed to support Internet2. Focused research endeavors need to be established in these areas.
- Third, existing and evolving technical documentation on Internet2 need to be translated into Portuguese on an ongoing basis to encourage broad acceptance to facilitate native implementations and optimizations.
- Fourth, the conventional model for communications is to use analog circuits to make digital transmissions. This paradigm is now changing and needs to be carefully analyzed.

11.2 Active Areas for Research

As the various Next Generation Internet initiatives progress farther in the implementation phase, experts feel the need to seek revolutionary ideas, rather than ones that offer incremental improvements over existing technology. In fall 1997, the lead US government research agency (DARPA) solicited ideas falling into the following seven categories (Edited from: http://www.ito.arpa.mil/Solicitations/PIP_9802-NetEng.html):

- **Automated Analysis, Diagnosis, And Control**: Efficient and powerful tools must be developed to allow observation of the (NGI) network. The analysis is intimately tied to controlling of the network configuration for elements and protocols. More sophisticated algorithms and network problems may require real-time models and simulations for diagnosis. Furthermore, the automatic report and retrieval of diagnostic recommendations into a format that allows reconfiguration of network elements, through software and/or firmware, is important. One possibility for such a real-time solution lies in developing command compilers, self-organizing command generators, or configuration generators.

- **High-Fidelity Integrated Monitoring And Hardware:** New technologies must be developed for collecting information about all levels of network performance and service quality. Research must address methods for collecting and storing data, as well as distributing monitoring data to the sites that will analyze the data and issue the aforementioned control commands to network elements.

- **Modeling And Simulation For Real-Time Analysis, Diagnosis And Control:** Testable, highly accurate models for large-scale network behavior which are capable of validating or predicting network behavior in real-time are needed too. Models should also allow manipulation of network parameters for prediction, planning, and validation. In addition, methods for real-time simulation of very fast, large-scale networks with protocols and hardware are also important.

- **Protocol-Oriented Visualization Of Distributed Processing:** Methods to visualize large-scale network distributed processing patterns are also useful for network maintenance. Whenever application load is being distributed, all of the network communication streams must be viewed as a coherent pattern. The application's effect on the overall network (and the network's effect on it), can be displayed and used in designing new network additions or changing existing nodes.

- **Fine-Grained Management And Provisioning**: Research also much be done into software and hardware solutions to the collection of traffic with various speed and importance characteristics. Of particular interest are methods to manage widely varying service levels over ultrafast networks; service levels could range from best effort one Mbps lines to guaranteed latency 100 gigabit reserved channels.

- **Security For Ultrafast Networks**: Traditional methods of network security may not scale well to the new, larger scale networks, however commercial applications in this area remain critical. One needs approaches to fast authentication, and encryption methods, as well as secure management techniques for all-optical networks. Intrusion detection and other non-cryptographic protection methods may also be important development areas.

- **Architectural Frameworks**: Of course, an overall architectural network structure, integrating the above areas of development is extremely important. Frameworks which are inherently suited to very large networks and are self-configuring and automatically maintained would certainly be the optimal research area.

The above technical areas can be considered for joint exploration with organizations in the US and other countries.

11.3 Research on Communications Infrastructure Issues

In terms of implementing a large scale data communications infrastructure in countries with existing voice communications networks, one classifies ongoing development into three main areas as follows:

- **Wide Area Broadband Core**: This area addresses technologies and networking at the physical layer, such as cabling and switching. In Brazil, a potential target of one metropolitan network with links capable of at least 1 Gbps transmission rates could be the initial goal. Later, some of the metropolitan networks would be connected to form the national Internet2 infrastructure.

To achieve the highest speed, almost all the network elements would have to be all optical in nature (with little electronic conversion). In the US, network elements under consideration include wavelength add-drop multiplexers and wavelength cross-connects with and without wavelength conversion. For maximum flexibility, some network elements may be fully reconfigurable, that is, they provide the capability of switching signals from any input port to any output port.

- **High Speed Multiplexing And Switching**: In the US, DARPA is currently targeting 1 Terabyte/second packet network. In addition to scaling up existing technology, which could be subject to frequent and high volume failures, new switching methodologies are being explored. One example is to arrange for packet-based traffic to be deflected on to available space on switching system.

- **Broadband Local Trunking**: Due to the need of certain high-end users to have bursty service, and because of the need to provide selected Internet sites with "orders of magnitude above average" access to the network core, a system needs to developed to handle such demands in a cost-efficient manner. For example, commissioning of advanced research facilities is difficult when the high end users must share access with common users, resulting overall lower speeds. Research solutions should permit near transparent connectivity between high-end users and the all-optical backbone, discounting the required traversal through electronic components in the local network. Potential solutions include ultra fast fiber based access at 20-40 Gbps rates (subdivided for practical application) or Gbps satellite-based trunking. The latter may be particularly cost effective in accessing remote and/or rural locations of importance to Brazil.

11.4 Personnel Development and Training Plan

While the purchase of imported hardware will permit Brazil to begin the task of implementing islands of Internet2 in the short term, long term growth can only be achieved by creating an indigenous production and support infrastructure. University programs need to be established or redirected to produce personnel with the requisite technical skills.

Since most of the educational institutions of higher learning in Brazil are funded by the government, the appropriate government agencies need to lay greater emphasis on relevant courses, such as network construction, software and hardware engineering, testing and maintenance, advanced programming, and graphics.

As an incidental observation, MIT is entering into a major educational initiative with the state of São Paulo. This mechanism, as well as similar ones that could be instituted with other state governments in Brazil, could be utilized on a "Teach the Trainer" (TTT) basis to educate or re-educate large numbers of individuals within a period of 2-3 years.

11.5 Overall Technical Recommendations

The deployment of Internet2 in a phased manner in Brazil motivates action in the following areas at this stage:

- Establishment of several high speed networking centers in research universities
- Development of a "GigaPOP cloud" of high speed connections in the urbanized centers
- Deployment of a large ground based, high speed transmission network
- Creation of several routing centers, with appropriate software and staff
- Implementation of IPv6 and development of an effective Quality of Service protocol
- Establishment of network training and education programs
- Encouragement to research and development activities that address language needs and terrain issues

11.6 Conclusion

The Government of Brazil deserves praises for its vision in thinking about Internet2, almost simultaneously with the formulation of this notion in the US. The issue of embarking upon major national programs is especially difficult in the case of developing countries. First, one is dealing with technology that has been largely developed abroad, and for which the indigenous manufacturing capability is weak, especially at the beginning stages of the program. Second, the costs involved are large, and involve trade-offs with funding for other priority sectors of development. Third, the question of appropriate technology and appropriate timing needs cautious evaluation and continuous reevaluation, especially with respect to the less affluent parts of the country. Overall, Internet2 is a technology that offers great potential for broad-based benefits for Brazil.

The potential benefits outstrip the potential costs for a number of application areas that are considered in this thesis paper. The opportunity costs involved in not embracing Internet2 within the next 2-3 years are very high for any large developing country. Even though the costs involved are high, a country such as Brazil needs to implement the Internet2 infrastructure within the next 3-year period. The hybrid plan proposed in Section 10.3 Hybrid Model best balances the dissimilar needs of different parts of the country.

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