Chapter 6

Upgrading Information Infrastructure

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Obtaining and applying information lies at the heart of the innovation process. Thus, the availability of information is a key driver of firms' ability to create and absorb new ideas. The creation of ideas and dissemination of ideas between firms and countries are strongly influenced by the availability of information, the cost of obtaining it, and the ease of sharing it. Electronic communication systems are at the center of this information transfer process, so investment in information and communication technology (ICT) infrastructure is one way of stimulating growth in national innovation and economic productivity. International evidence shows a clear link between investment in ICT and productivity (Röller and Waverman 2001; Qiang and Pitt 2004). At the firm level, research shows that use of ICT can result in higher productivity and profitability. A recent World Bank study concluded that "enterprises that use ICT more intensively are more productive, grow faster, invest more, and are more profitable" (Qiang, Clarke, and Halewood 2006: 57).

India's ICT sector has progressed rapidly—but challenges remain if it is to continue to create and enable innovation. India's ICT sector has grown quickly over the past 20 years, but this growth must continue and reach all segments of the economy to fully support the development of an innovation economy. To achieve this, the government must address a number of policy and regulatory issues to ensure the sector's continued growth and its extension into underserved areas.

The availability and quality of ICT infrastructure accessible by research institutes will be increasingly important in fostering innovation. Collaboration between universities and research institutes—both within and outside India—requires investment in high-speed communications networks.

Improving Access to ICT Infrastructure

The use of basic ICT infrastructure and services is a key enabler of innovation in all types of firms. The availability of ICT services is an important determinant of businesses' ability to innovate and develop new ways of organizing. This applies across the entire range of businesses, from large enterprises investing in IT-based reorganization to micro and small enterprises using ICT to change how they do business. Studies of demand for telecommunications services in developing countries indicate that telephones are often used in basic economic activities, such as seeking information on input and output prices, employment opportunities, and so on.

ICT-based exports are becoming increasingly important in India. The ICT industry has grown quickly through innovations in products, services, and business practices. Over the past 15 years India's services sector has become an important contributor to economic growth. In 2004 India was ranked 30th in the world in total exports, but 9th in exports of services (excluding travel and transportation),[1] accounting for 3 percent of the global total. Communications and business services have made major contributions to this growth (table 6.1).

Over the past 10 years, growth in the IT services industry has been boosted by the global increase in offshoring IT- and IT-enabled services (ITES, such as business process outsourcing). By 2005 turnover of this industry had reached $22 billion in India (Purfield and Schiff 2006), with software and business process outsourcing accounting for about a third of service exports. India leads the world in the supply of business process services, with two-thirds of the global offshore IT industry and 46 percent of the global offshore business process industry (NASSCOM and McKinsey 2005: 56).

ICT and ITES have been a major source of innovation in the Indian economy. The IT industry was originally based on import substitution, then low-skill computer programming. However, since then, innovation in business practices and technology has stimulated the evolution of the industry. The model of sending

Table 6.1 Average Annual Growth of Value Added in Communications and Business Services in India, 1950s–2000s

(percent)

Sector	1950s–70s (share of 1980 GDP)	1980s (share of 1990 GDP)	1990s (share of 2000 GDP)	2000s (share of 2004 GDP)
Communications services[a]	6.7 (1.0)	6.1 (1.0)	14.9 (2.2)	24.4 (4.3)
Business services[b]	4.2 (0.2)	13.5 (0.3)	19.8 (1.1)	20.7 (1.8)

Source: Purfield and Schiff 2006.

a. Includes, among others, postal services, money orders, telegrams, telephones, and overseas communications services.
b. Software and business process outsourcing.

Table 6.2 IT-Enabled Services and Business Process Outsourcing Revenues and Employment in India, by Service Line, 2003–04

Service line	Employment	Revenues ($ millions)
Customer care	95,000	1,200
Finance	40,000	820
Human resources	3,000	70
Payment services	21,000	430
Administration	40,000	540
Content development	46,000	520
Total	245,000	3,580

Source: Athreye (2005) estimates based on data from the National Association of Software and Service Companies.

teams of software engineers to client sites to conduct projects originated in India, and the more recent shift toward exporting offshored office services are major innovations made possible by the development of India's ICT industry. The adoption of new ways of doing business and the use of new technologies to carry out functions previously done onshore have transformed India's export sector—and this process is continuing, resulting in the offshoring industry in India servicing a wide range of markets (table 6.2).

Innovation in IT and ITES continues—and is increasingly at the higher end of the value chain. The offshore revolution in India has not stopped with software maintenance and call centers. ICT services increasingly facilitate the location of high-end, innovative economic activity in the country. Not only are there huge untapped areas in services already offshored, further growth opportunities are opening up as high-risk and complex service lines are also offshored. For example, the John F. Welch Technology Center in Bangalore is conducting advanced research and development (R&D) in technologies such as advanced propulsion systems for aircraft engines and contributed significantly to the design of General Electric's latest jet engine. This is not all. The market can be further expanded by innovations in service delivery allowing the creation of "offshore-only" processes, for example, to stem the big "value slippages" facing industries. A leading U.S. bank has saved $100 million through offshore detection of fraud in low-value transactions. Offshoring has also allowed banks to create new services (for example, subprime lending for previously unviable customer segments) (NASSCOM and McKinsey 2005: 56). This type of innovation by large, export-oriented businesses depends on high-quality ICT infrastructure. As this sector grows, the availability, quality, and price of ICT infrastructure will become increasingly important for the Indian economy.

Basic ICT infrastructure and services also have a significant impact on innovation and productivity in households and small businesses. Households and small enterprises use ICT services to improve the organization and marketing of their economic activities. Thus, investment in ICT services (such as mobile handsets) is investment in productive assets that have the potential to raise household and firm incomes. Box 6.1 describes a study that quantified the economic impact of mobile phones in Kerala, India.

In rural areas there are few alternatives to ICT as a means of communicating. Those alternatives—such as sending a person, using mail, or calling from somewhere

Box 6.1 The Impact of ICT on Small-Scale Fishing Enterprises in Kerala

The fishing industry is an important part of life in the state of Kerala. More than 70 percent of adults eat fish at least once a day, and over 1 million people work in fisheries. Fishing is done primarily by small enterprises, working near home markets and traditionally selling their catches to a specific market. Fishermen have traditionally been unable to observe prices in other markets along the coast because of high transport costs and ineffective communications. There is little storage of fish because of costs and little transportation of fish over land and between markets because road quality is poor and refrigeration is not available. Thus, the quantity of fish sold in any market is determined by the local catch, which also determines the prices that fishermen receive for their catches and the prices that customers pay. This dislocation of markets results in significant differences in the price of fish on any given day between markets that are quite close to each other. It also results in wasted catches because there are occasions, when there are large catches, where there are not enough buyers.

Mobile phone services were introduced in Kerala in 1997. As in other parts of the world, mobile networks were initially concentrated in cities and towns. However, because many cities in Kerala are located along the coast, mobile network coverage extends 20–25 kilometers out to sea—the distance within which most fishing is done. Fishermen adopted mobile phones very quickly, reaching an equilibrium penetration rate of 60–75 percent (compared with an average rate of 5 percent across the region). Fishermen use the phones while still at sea to find out the prices in different markets and to decide where to land their catches. Fishermen typically call several markets and agree on a price before landing their fish, effectively conducting auctions by phone.

The effects have been dramatic. After mobile phones were introduced, 30–40 percent of fishermen began selling fish outside their home markets, compared with almost none beforehand. Within a few weeks this significantly reduced the dispersion in fish prices between markets. Prices on any given day now rarely differ by more than a few rupees per kilogram, compared with up to 10 rupees per kilogram before. Moreover, there are no cases of wastage. The use of mobile phones has also boosted incomes for fishermen. On average, daily revenues have risen by 205 rupees, while costs (including for mobile phones) have increased by 72 rupees. Thus, the profits of fishermen have jumped by 133 rupees a day—a 9 percent increase. The introduction of mobile phones has also had a modest benefit for customers, with the average price of sardines falling by 0.39 rupee per kilogram, or just under 4 percent.[a]

Source: Jensen forthcoming.

a. This is consistent with findings in other countries. See, for example, a recent study from Lao People's Democratic Republic indicating that calls to and from suppliers are the most common reason for use of ICT services by small enterprises, many of which are household-based. See Song and Bedi (2006: 265).

farther away—usually have high monetary or nonmonetary costs. The value of electronic communication networks and the cost of alternatives usually mean that uptake of these services is rapid when they become available. In Kerala, when mobile phones became available, the telecommunications penetration rate among fishermen went from zero to an equilibrium rate of 60–75 percent in just a few months. This effect is also seen at the national level, where the uptake of telecommunications services grew 24 percent a year between 1995 and 2005.

Much of India's population could benefit from ICT-driven innovation. The effect on fishermen incomes described in box 6.1 could apply to any small enterprise involved in producing and distributing perishable goods such as fish, fruit, vegetables, and livestock products. Nearly three-quarters of India's population is rural.[2] In 2005, agriculture (including fishing, logging, and forestry) accounted for 19 percent of GDP and employed 60 percent of the workforce, making it the biggest sector of the Indian economy. Agriculture is dominated by small-scale firms and household enterprises. Thus, innovation brought about through ICT could positively affect a huge portion of India's population.

The availability of ICT infrastructure and services has increased dramatically in recent years. High investment in ICT infrastructure and services, increased competition, and lower equipment prices have raised teledensity and driven down prices. As a result, Indian consumers now enjoy some of the world's lowest charges for mobile telecommunications. By September 2006 there were 41 million wireline subscribers, 130 million wireless subscribers, and more than 1.8 million broadband subscribers (Telecommunications Regulatory Authority of India 2006). The number of wireless subscribers is continuing to grow rapidly, increasing by 55 percent in 2006, with an average of 6.5 million subscribers added in each of the last three months of the year, for a total of roughly 150 million wireless subscribers by end 2006—making India the world's fastest-growing market for mobile phones (*Economist* 2007). This rapid growth in penetration rates has reduced the price of information for individuals and businesses, making it easier to obtain information on, for example, prices of inputs and products. It has also allowed companies to introduce innovations in how they run their businesses, making it easier to stay in touch with staff, customers, and the various components of the supply chain.

Still, despite the recent rapid increases in mobile and broadband subscribers, India continues to lag behind some countries, and there is a large and growing gap in teledensity between urban and rural areas (table 6.3). This gap is particularly stark in broadband access. For example, penetration in China, a country of comparable size, is 30 times that in India. Average penetration rates also hide major disparities in access between rural and urban areas. Teledensity in India is 40 percent in urban areas, but just 4 percent in rural areas (figure 6.1). Only 45 percent of India's population is covered by a mobile signal—compared with more than 90 percent in China and South Africa. Thus, a priority for India is to increase the availability of voice services in rural areas and ensure that broadband networks are developed as quickly as possible.

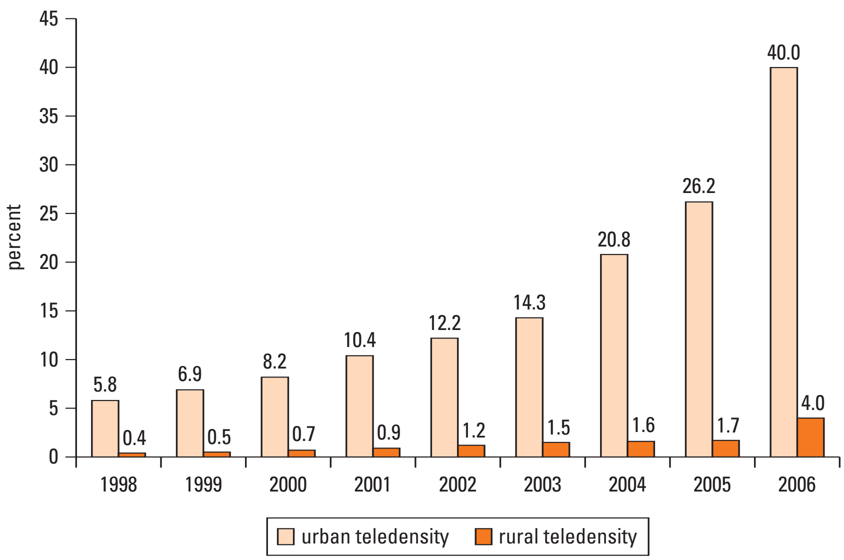
Table 6.3 Mobile and Broadband Penetration in Various Countries, 2005–06

Country	Mobile subscriber penetration, Q4 2006 (per 100 people)	Broadband penetration, 2005 (subscriptions per 100 people)
Brazil	54	1.0
Russian Fed.	111	1.0
India	13	0.1
China	33	3.0
Korea, Rep. of	84	28.0
Mexico	51	1.0

Sources: www.wirelessintelligence.com (mobile); PricewaterhouseCoopers 2006 (broadband).

Note: Mobile penetration rates of more than 100 percent can arise for a number of reasons—use of more than one handset per person or a single handset with multiple SIM cards, double counting as people switch networks, or the inclusion of dormant accounts. These figures should be considered a broad indication of users that allow comparison between countries.

Figure 6.1 Urban and Rural Teledensity (Fixed and Mobile) in India, 1998–2006



Source: Telecommunications Regulatory Authority of India.

Development of India's ICT networks will depend on the private sector. In India, as in most countries, competition has been the key driver of higher network rollout and lower prices for ICT services. The provision of telecommunications services has proven profitable for private companies, even in relatively poor and sparsely populated communities. Innovations in the manufacturing of communications equipment and in the design, operation, and retailing of mobile services have cut costs and made services more affordable—providing access to communications services to parts of the population that once had not been expected to be profitable. Policies to ensure that networks reach deeper into rural areas should build on this success by encouraging competition and private investment in ICT. Looking ahead, there will be increased emphasis on the availability of broadband to businesses and households. Thus, policies should encourage the private sector to invest in innovative broadband infrastructure—particularly in areas not currently served, such as rural communities.

Recommendations for Improving Access to ICT

The recent improvements in India's communications infrastructure must continue. But the emphasis should increasingly be on providing rural ICT infrastructure and ensuring that high-speed data services are more widely available, particularly in underserved areas. A multifaceted approach to improving access to telecommunications services in both urban and rural areas is required. Key action areas include the following:

- *Reducing network costs to make marginal areas more commercially viable.* This could be done through measures such as reducing domestic roaming tariffs, promoting infrastructure sharing between operators, and facilitating access to land and building space at low cost and access to existing backhaul networks.
- *Expediting allocation of spectrum for wireless broadband rollout.* Freeing up more radio spectrum and making it available to operators of voice and data services would reduce rollout costs and enable operators to accelerate the provision of services, including broadband wireless services in rural areas. The government has de-licensed the 5.15–5.35 gigahertz (GHz) and 5.725–5.875 GHz bands for indoor use, and should de-license them for outdoor usage as well. De-licensing would allow users to deploy wireless networks at much lower cost and provide opportunities for innovation in wireless systems. Spectrum in other bands (such as 2.3, 2.5, and 3.5 GHz) should be reallocated for broadband wireless access. Spectrum in the 3.3–3.4 GHz band has been allocated to Internet service providers on a citywide basis. The government should consider allocating this spectrum in smaller geographic units to make more effective use of the resource.
- *Cutting taxes.* The government imposes various fees, levies, and taxes on telecom services. These include annual license fees of 6–12 percent, spectrum charges of 2–5 percent, and service taxes of 8–12 percent. For an industry growing so quickly, these taxes and fees should be reduced. In a high-volume business, lower taxes create a win-win situation for everyone. The government also imposes an 8 percent tax on Internet service providers. Reducing or waiving this tax would lower the cost of broadband access. In addition, some Indian states levy a 30 percent entertainment tax on broadband subscriptions. The central government should encourage state governments to waive this tax.
- *Revising policies.* The government should revise its policy definition of broadband, now defined as a minimum "always on" 256 kilobits per second (Kbps) connection. Comparator countries (Brazil, China, the Republic of Korea, the Russian Federation) have much higher definitions for broadband speeds.

- *Lowering network costs.* Network costs could be lowered by facilitating the rollout of backbone networks, encouraging competition in the provision of leased lines, and facilitating access to the networks of operators in dominant economic positions. Access to last-mile connectivity should also be facilitated, because its absence inhibits competition in backhaul and leased-line networks.
- *Providing targeted subsidies for rural mobile and broadband rollout.* This should be done in a way that rewards efficiency, maximizes private investment, and does not distort competition. Subsidies should be linked to the sharing of infrastructure and be for a limited period—say, five years—to avoid distorting competition.

Developing ICT Infrastructure for Universities and High-End Research Institutes

There is growing awareness that high-speed research and education networks accelerate the pace of new discoveries and the expansion of knowledge by enabling collaboration. Around the world, national research and education networks (NRENs) have become an essential part of R&D infrastructure (box 6.2). More than 70 countries connect researchers and scientists through high-speed networks with an emerging standard connectivity of 10 gigabits per second (Gbps), capable of transmitting data at 1 trillion bits a second—the equivalent of transmitting a two-hour DVD in

Box 6.2 What Are National Research and Education Networks?

National research and education networks (NRENs) were conceived to meet the needs of high-end users through a dedicated infrastructure that restricts data traffic to high-end purposes. Although the Internet is a sufficient data transfer vehicle for the average user, the target clientele of NRENs is high-end users—such as research scientists—who need to transmit and access images and large amounts of data for computationally intensive problems.

NRENs typically operate as a layered hierarchy of national backbone, state or provincial networks, and metropolitan area networks connecting individual campus networks. Institutions can either connect directly to a point of presence on the backbone or to a regional or metropolitan area network run by the NREN or a third party. Given the high capacity of the typical NREN backbone network, traffic congestion usually occurs at the local area network level. Thus, regardless of how much capacity the core has, the connectivity that researchers experience at each institute is limited by the connectivity of their local area networks.

NRENs integrate scientists into a wider research community and provide easier access to networked resources and equipment than would otherwise be available to users in different regions. Given the dedicated infrastructure and selective membership of NRENs, scientists are also assured better security for data transfer and can authenticate their collaborators.

Source: http://internet2.edu; www.geant2.net; Seth 2006.

four seconds.[3] These networks generally connect almost all the universities in their countries and foster scientific and technological innovation. Their main impact on the innovation economy is through the potential for higher academic and research productivity using a high-speed mechanism to create and absorb knowledge by tapping into a global network. NRENs facilitate international collaboration through sharing of research data, joint experiments, conferences, building of databases, setting of standards, and sharing of equipment, and provide a motivating force for solving global problems such as climate change and infectious disease control (Wagner and others 2001: 102). The networks are also important for conducting frontier research in next generation networking technology that can lead to even higher-performance networks, and applications in health and education through the use of imaging and telepresence—such as distance medical diagnostics and operating procedures, and interactive distance education (box 6.3).

Although the United States and Western Europe are global leaders in high-speed research and education networking, many other regions are also investing in this

Box 6.3 Applications by National Research and Education Networks

High energy and nuclear physics (HENP). Worldwide, HENP scientists have been leading adopters of high-speed networking. Bandwidth use in the field is 1,000 times that of 10 years ago, enabling huge datasets to be shared and processed by collaborators studying heavy-ion collisions. The HENP network grew by 70 percent a year between 1992 and 1999, and since then by 100 percent a year. But the digital divide that prevents a number of HENP scientists in different regions from having access to high-performance networks has meant that these researchers cannot collaborate as equal partners in pushing out the HENP frontier.

Transmitting high-resolution images in real time. In October 2006, high-level specialists at the National AIDS Research Institute (NARI) in Pune participated in an interactive clinical education program on HIV/AIDS with counterparts at the Johns Hopkins University in Baltimore, Maryland (United States). The program was unusual in that neither group of scientists had left their home countries. Instead, clinical demonstrations were conveyed from Baltimore to Pune using a high-resolution, multipoint video conference in real time.

During one of the demonstrations Dr. Sanjay Kedhkar, a Johns Hopkins clinical instructor of ophthalmology, talked NARI scientists through his examination of an HIV-positive patient's retina while the scientists observed a three-dimensional image of the retina live onscreen. The image was transmitted through high-resolution video from Dr. Kedhkar's equipment to Johns Hopkins University's area network, which conveyed it to the European transnational network, GÉANT2, through the U.S. network, Internet2. GÉANT2 transmitted the data to India's network, Education and Research Network (ERNET), allowing NARI scientists to observe the image through the institute's connection to ERNET—all in real time. A year ago such an event would not have happened, simply because ERNET was not linked to GÉANT2.

Sources: Newman 2004; Johns Hopkins 2006.

Table 6.4 High-Speed Networks in Various Countries

Country	NREN	Core (domestic) network capacity (Mbps)	International connectivity (Mbps)
Brazil	RNP	Up to 10,000	1,000
Russian Fed.	RBNET	622	622 (multiple links)
India	ERNET GARUDA	8–100	45
China	CERNET CERNET2 CSTNET	2,500–40,000	4,500
Korea, Rep. of	KOREN KREORNET2	2,500–10,000	10,000
Mexico	CUDI	155	1,000

Source: Authors.

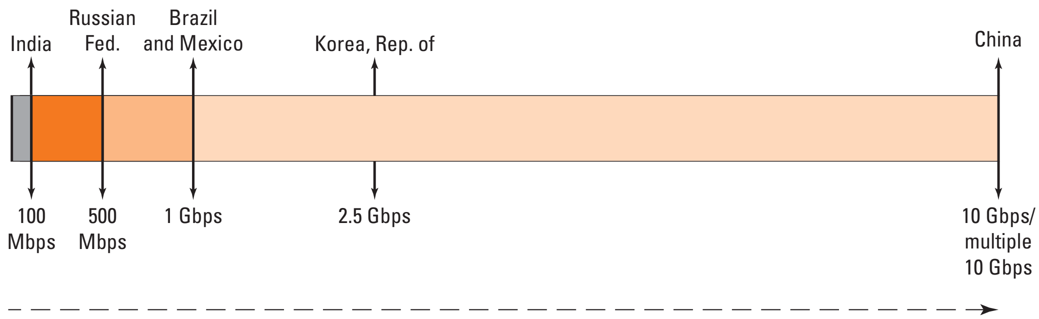
infrastructure. In the United States a nonprofit consortium, Internet2—created 10 years ago by academics at U.S. research universities—is the NREN entity that operates the high-speed national backbone network. This backbone uses a dedicated pair of optical fibers across the United States to provide a capacity of 10 10-Gbps wavelengths (100 Gbps)[4] to Internet2 members, who include more than 200 U.S. universities, 70 corporations, 45 government agencies, 45 international organizations, and 35 state education networks. All members have a purpose related to research, education, or both.

Similarly, the U.K. Delivery of Advanced Network Technology to Europe (DANTE) is a nonprofit entity based in Cambridge, established in 1993 by a number of Europe's NRENs. DANTE runs GÉANT2, a transnational European high-speed network that provides high-bandwidth connectivity between European research and education institutes (see box 6.3).[5] Similar networks operate in many other countries and regions, including East Asia and the Pacific and Latin America, with increasingly high-speed networks (table 6.4).

Yet India lags behind global comparators in high-speed networking for research and academic institutions. Two of the main factors that determine the effectiveness of an NREN for domestic and international collaboration are the capacity of the core network (measured as the rate at which data can be transferred through the core, in bits per second) and the bandwidth of links to international NRENs (figure 6.2). India's core capacity, provided by networks such as Education and Research Network (ERNET) and GARUDA (National Grid Computing Initiative), is 8–100 megabits per second (Mbps)—a fraction of the global standard connectivity of 10 Gbps.

Only in October 2006 did India establish a dedicated international link for research and education networking, when ERNET linked to GÉANT2 at a speed of 45 Mbps (with funding from the European Commission and Indian government).[6]

Figure 6.2 Capacity of International Links to National Research and Education Networks



Source: Authors.

Note: Emerging standard capacity of international links to NREN is in gigabits per second. Mbps = megabits per second.

Although this connectivity is a significant improvement from having no international link, it is still far more limited than its comparators—such as the multiple 10-Gbps links between GÉANT2 and Internet2, or the 2.5-Gbps link between GÉANT2 and Chinese research and education networks—restricting both the quality and amount of data that can be transferred to and from India.[7] Moreover, most Indian scientists and researchers cannot effectively collaborate on scientific research or exchange ideas with their international counterparts because only a small portion of this community is connected to high-speed networks. South Asia in general compares poorly with the United States, Europe, East Asia and the Pacific, Latin America, and North Africa in core network capacity of NRENs and international connectivity.

No single entity in India is responsible for building an NREN, resulting in parallel high-speed networking efforts and duplicated resources. High-speed networking for research and education institutions in India is conducted by two organizations under the Department of Information Technology (DIT): ERNET and the Center for Development of Advanced Computing (C-DAC). ERNET was set up in 1986 using funding from the United Nations Development Programme and DIT (then called the Department of Electronics), with a mandate to create a research and education network for select universities and institutions of national importance. In April 2006 DIT also provided Rs 14.5 crore (approximately $3.2 million) to fund C-DAC in launching a proof-of-concept initiative to connect 17 cities in India using a nationwide grid (*Times of India* 2006b). That grid, GARUDA—set up in partnership with ERNET—connects 45 research and education institutes through a virtual private network (a private communications network that can be used to connect over a publicly accessible network) with a backbone connectivity of 100 Mbps (*Times of India* 2006a). GARUDA is expected to supply about 60 percent of the supercomputing power available to the institutes and will be used for a range of data-intensive applications of national importance, including forecast models for disaster management.[8] The Department of Biotechnology (DBT) is also involved in networking—through Biogrid, a virtual private network designed to connect DBT's bioinformatics centers

(Kolaskar 2006). Currently, the network connects 11 of the 62 bioinformatics centers through 2-Mbps dedicated leased circuit lines.

The Council of Scientific and Industrial Research (CSIR) recently proposed setting up a grid to connect its 38 labs using a backbone network of 155 Mbps, providing 2 Mbps connectivity to each (Seth 2006). However, with technology for high-performance networking progressing rapidly, most of these are examples of past technologies and capacities no longer being used by leading NRENs. In addition, the National Knowledge Commission, a high-level body created by the Indian government in 2005, has proposed building a National Knowledge Network that would connect 5,000 universities and research institutes all over India at a connectivity of 100 Mbps (National Knowledge Commission 2007). The lack of a single entity aggregating high-end user demand is possibly unattractive to international NRENs seeking to co-fund links to Indian networks.

The main responsibilities of entities that operate NRENs are to mobilize and aggregate demand for high-speed networking, manage underlying infrastructure through owned or leased models, and deliver services—including connections to high-speed global networks—at agreed standards. To ensure independence from the government in network operations, NRENs are typically designed as separate legal entities (usually nonprofit organizations) controlled by the research and education community, though they can be government funded. NREN funding arrangements vary by country. Internet2, for instance, receives no federal funding: it is supported entirely by corporate, university, and affiliate members.[9] GÉANT2, however, is co-funded by the European Commission, with 93 million euros (or roughly $120 million) for a four-year period that started in September 2004. Partnering NRENs connected to the network provide the remaining funding through subscription fees. For more information, see box 6.4 and table 6.5.

Box 6.4 Trends among National Research and Education Networks in Europe

- The most common capacity among NRENs in 28 European Union/European Free Trade Agreement (EU/EFTA) countries is 10 Gbps.
- In 2006, only three EU/EFTA NRENs did not have a capacity of at least 1 Gbps.
- Primary and secondary schools are increasingly being connected by NRENs in many countries, with connections mainly funded by ministries of education.
- More NRENs are switching to dark fiber—unlit fiber put in place for future use—which gives them more control over network infrastructure and makes upgrading capacity easier.
- Developments in fiber optic technology are increasingly allowing NRENs to leapfrog to higher-capacity networks. (See table 6.5.)

Source: TERENA Compendium of National Research and Education Networks in Europe (www.terena.nl/compendium/).

Table 6.5 Core Network Capacity in Selected EU/EFTA National Research and Education Networks
(megabits per second)

Country	NREN	2001	2002	2003	2004	2005	2006
Belgium	BELNET	622	1,000	4,976	4,976	4,976	10,000
Czech Republic	CESNET	2,488	2,488	2,500	2,488	2,488	10,000
Finland	Funet	2,488	2,488	2,488	2,488	2,488	2,488
France	RENATER	2,488	2,488	2,488	2,488	2,488	2,488
Germany	DFN	622	2,488	10,000	10,000	10,000	10,000
Hungary	NIIF/HUNGARNET	155	2,488	2,488	2,488	10,000	10,000
Italy	GARR	—	2,488	2,488	2,488	2,488	10,000
Netherlands	SURFnet	2,488	10,000	10,000	10,000	10,000	10,000
Norway	UNINETT	2,488	2,488	2,488	2,488	2,488	2,488
Poland	PIONIER	155	155	622	10,000	10,000	10,000
Spain	RedIRIS	155	155	2,488	2,488	2,488	2,488
Sweden	SUNET	622	10,000	10,000	10,000	10,000	10,000
United Kingdom	UKERNA	2,488	2,488	10,000	10,000	10,000	10,000

Source: TERENA Compendium of National Research and Education Networks in Europe, 2006 edition (www.terena.nl/compendium/).

Note: EU/EFTA = European Union/European Free Trade Agreement countries; = not available. Although the TERENA survey compiles information from 47 NRENs in 46 countries, the table provides information only on select EU/EFTA NRENs.

Recommendations for Improving ICT Infrastructure for Universities and High-End Research Institutes

India should upgrade its high-speed networking capacity for research and education institutions—with achieving clarity on the entity to manage the network an urgent priority. Although Indian policy makers recognize the importance of advanced networks in the knowledge economy, they are constrained by two issues: the cost of NREN infrastructure and the appropriate organizational structure to deploy and manage the networks. Discussions on the precise configuring of a top-level NREN are beyond the scope of this report. Thus, the three recommendations below point to broad steps that India needs to take in setting a strategy for nationwide high-speed networking.

1. *Establish a clear NREN entity.* A new entity could be established to circumvent the problem of multiple existing initiatives, each with its own interests. Alternatively, an existing organizational initiative could be reconfigured and its mandate broadened. Whatever approach is taken, what is essential is clarity on the NREN entity's structure. A panel of willing partners of major NRENs could be convened to help the entity strategize on scale, implementation methods, network operations, and global partnerships. The entity has to be a forward-looking, technically oriented organization that will allow India to leapfrog into state-of-the-art technology and skip the network development phases that other NRENs

have undergone. The entity must also oversee the engineering and operation of NRENs, as well as drive the community that participates in developing it.[10]

2. *Foster programmatic rollout.* Any NREN entity would need to take into account international best practices when setting up a prototype high-speed network model before phasing into a larger-scale network—aggregating unused infrastructure and building on it as needed. The prototype phase would be used to test the selected management model, partnership arrangements, and forecasted demand, and to incorporate lessons from other national and international infrastructure management models. The NREN entity would also need to decide whether to use an own or lease model for wider outreach and the type of telecom carriers (public or private, and by region) that would be the best partners. Finally, the entity should provide connectivity for end-user research and education institutions in phases—for instance, first to high-demand areas and clusters with a concentration of universities and research institutes, then to institutes of national importance and secondary and primary schools.

3. *Encourage demand.* The high capital investment required to establish a top-level NREN implies higher risks if the infrastructure is underused. The business model used to operate the NREN (including aspects such as the business arrangement with partnering telecom carriers and internal fee structure) can have enormous implications for its success. Making the NREN affordable in the early stage can be an effective way of demonstrating the many uses of high bandwidth (*Hindu* 2006). Ensuring that NRENs are used also means subsidizing academic institutions in their cyber infrastructure investments at the campus and local levels. Given the high capacity of the typical NREN backbone network, traffic congestion usually occurs at the local area network level. Thus, regardless of how much capacity the core has, the connectivity that researchers experience at each institute is limited by the connectivity of their local area networks, which can be a barrier to adoption. Government grants could circumvent this dilemma and increase the use of NRENs. The National Science Foundation, for instance, provided critical funding to U.S. universities in the three to four years following Internet2's inception to subsidize their connections to the national backbone network. In addition, if the culture and incentive regimes in academic and research institutions do not demand the quality of research that requires the use of an NREN, nationwide connectivity of these institutes could result in the infrastructure being underused. Thus, the success of a top-level NREN partly depends on institutional conditions that create demand for its use.

Notes

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1. WTO data cited in Fernandez and Gupta (2006).
2. India census, 2001.

3. http://internet2.edu
4. Internet2 recently started to migrate its traffic to a new backbone that offers connectivity 10 times that of the previous one, Abilene, which had a capacity of 10 Gbps. The first 10 10-Gbps links connected Washington, DC, New York, and Chicago in late 2006. Full migration is expected to be complete in summer 2007.
5. More information is available at http://www.geant.net/.
6. At the time of writing, Internet2 was negotiating a 45-Mbps link with ERNET that would provide a dedicated connection from Chennai to Singapore. This link would be cofunded by the U.S. National Science Foundation.
7. Johns Hopkins University 2006; informal communications with Heather Boyles, Director, Member and Partner Relations, Internet2 (January 2007) and Michael Foley, Consultant, South Asia Region, World Bank (January 2007).
8. *Hindustan Times* 2006. (See also www.hindustantimes.com and http://www.garudaindia.in/press_release.htm.)
9. Internet2 universities have made more than $80 million a year in investments on their own campuses and corporate members have committed more than $30 million over the life of the project.
10. Personal communication with Prof. Harvey Newman, California Institute of Technology, January 13, 2007.

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