Global research and education networks:

Factors influencing network deployment and use

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1. Introduction

From the birth of the internet, international network innovations have been tied to programs for connecting scientists through national research and education networks (NRENs). This trend continues today as a broad range of computational and network innovations, such as data mining and remote sensing, are becoming integrated into nearly all scientific disciplines, driving the demand for higher bandwidth and more sophisticated network services across a wider range of nations.

With advanced networks scientists are able to access unique scientific equipment and scarce phenomena as well as form virtual scientific organizations. For example, data for astronomical research is collected through a global network of telescopes in Antarctica, South Africa, Chile, Europe, Japan and the U.S., among others. These high resolution telescopes collect large volumes of data and in Chile a new high resolution array has required the construction of a dedicated 10Gb/s link to enable remote operation and global data access.

The international deployment of broadband infrastructure for e-science raises a variety of challenges. First, it requires the interconnection of national and regional research and education networks, even as these networks themselves are evolving. Second, the interconnection generates a need for joint planning to develop a coherent strategy for what is largely a decentralized global infrastructure. Third, joint planning in turn requires coordination between diverse international public and private entities. Fourth, global e-science requires integration of low income countries with limited network bandwidth.

To better understand the factors influencing deployment of global research and education networks, this study synthesizes published descriptions and analyses of several U.S. and international projects. In particular, the synthesis provides insight into important questions, including: 1. Through which mechanisms are international network investments carried out? 2. What factors determine the nature of public-private partnerships in these projects? 3. What factors influence the types of access these projects facilitate? 4. What factors influence the outcomes of these deployments?

The paper is organized as follows. I begin with a description of the general role of NRENs in national systems of innovation followed by a detailed explanation of the factors driving their development, issues faced in connecting scientists and NRENs' role as a testbed for network innovation. Next I discuss the issues encountered in developing globally interconnected NRENs, identifying issues for developing country NRENs and the costs and benefits associated with regional and global network integration. The paper concludes with a discussion of the future challenges for NRENs.

2. Networks, scientists and innovation

National research and education networks are a critical component of a nation's national system of innovation, enhancing research across a variety of scientific disciplines, from high energy physics to the social sciences. While these networks were being developed as early as the 1960s, in their first two decades visibility remained somewhat limited. This changed in the 1990s when the commercialization of the internet brought the recognition that NRENs are a fundamental component of a National Information Infrastructure (NII) (McClure et al., 1991; Hill, 1994).

NRENs play a variety of roles within the NII, which in turn influence their funding sources. For example, in some countries the national government will support a single NREN, which operates almost exclusively with their support. In others, government support is minimal or the networks may operate independently, via contributions from members which may include academic institutions, industry, scientific organizations, or other RENs. In the latter case the NREN organization may have evolved from a quasi-governmental to a non-profit entity (Divakaran et al. 2007). Also, in some countries multiple NRENs compete, with each other or state/provincial/regional networks. For example, the Canadian NREN, CANARIE, receives roughly 40% of its funding from the Canadian national government and 60% from provincial investment and member dues[1].

While the primary goals of an NREN are typically to connect the country's scientists and in some cases develop new network technologies (as will be expanded on below), additional activities may include giving grants to scientific communities to develop specific scientific domain applications (e.g. Canada's CANARIE), providing authentication services that foster shared access to national resources (e.g. The Netherland's SURFnet, Latin America's RedCLARA), fostering economic development through testbed access for ICT firms (e.g. Canada's CANARIE) and outreach to promote ICT use by the educational sector and the public.

In the following sections I examine the fundamental goals, explaining the motivation to connect scientists through a separate network infrastructure and discussing issues inherent in connecting early adopters and late majority users. Following this, I provide insight into the role of NRENs in a national system of innovation through their research activities and provide examples of projects being carried out.

2.1 Separate networks?

The motivation to connect scientists through a separate network infrastructure derives from three factors: 1) increasing domestic and international collaboration among scientists, 2) the unique needs of these scientific collaborations, and 3) the networks provide a testbed for network innovation.

Increasing collaboration. Domestic and international research collaboration is growing due to five factors (Ponds 2009)[2]. The first is the increased costs of conducting research, including faculty salaries and benefits as well as the cost of some types of equipment. This in turn generates resource constraints that can be ameliorated by the resource pooling. The second factor is increasing specialization. As international investments in science grow, with larger numbers of countries engaging in scientific discovery (e.g. China, Saudi Arabia), competitive scientists need to specialize. However, most problems require system-wide solutions, thereby driving the need for more collaboration. This in turn creates demand for specialized equipment, which contributes to the overall cost. A third factor is the emergence of interdisciplinary fields, such as computational biology, which eases collaboration between scientists from different disciplines. These specific trends are further bolstered by the general trends of the growth of English language speakers in the scientific community as well as the reduction in telecommunications costs. These trends are occurring across the globe, creating pressure for U.S. scientists to collaborate both domestically and internationally in order to remain competitive.

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[1] See CANARIE Annual Report 2010-2011 at http://uturn.cyansolutions.com/canarie/2010/en/

[2] These trends may vary across countries as Ponds' (2009) study of Dutch scientific collaboration (as indicated by co-authorship) shows international collaboration in that country has achieved a steady state (no increase), while an increase in domestic collaboration was observed.

Network requirements. While the above discussion provides evidence of the increasing need for collaboration, it does not explain why these collaborations require specialized network infrastructure, separate from that available through public networks. The answer is that some scientific collaborations have unique network requirements that cannot be met by carrier-managed services or are cost prohibitive, and the scientific community has the technical knowledge required to provision the services.

To explain the network requirements DeFanti et al. (2003) divide users, based on bandwidth and service needs, into Classes A, B, and C. Home users, Class A, require switched services to provide many-to-many connectivity. Organizational users, Class B, use mostly switched services, virtual private networks, and full Internet routing uplinks, often through firewalls. Class B users typically need many-to-many connectivity, requiring protection. Class C users, on the other hand, represent only a few hundred collaborative projects and their specialized applications, which need multiple Gbps for just a few minutes or up to hours at a time and originate and terminate at just a few locations. Unlike classes A and B, class C traffic does not require routing as it always takes the same route from source to destination.

Given that the total bandwidth demand from class A and B users is roughly 1Gbps, the typical university or public network can accommodate this demand. However, the 5Gbps class C user requires specialized solutions, including guarantees of bandwidth and latency (as some applications are very sensitive to delay), and the ability to schedule services, which most carriers do not provide. Also, the provision of these services through separate networks provides the scientists with a level a control they cannot have in public networks. These private networks fulfill these particular needs, providing scientists remote access during a specific time windows to expensive and overscheduled equipment. In these circumstances the best-effort routing model typically does not suffice. State, national and regional science funding agencies have been convinced of this and have and continue to make the necessary investments. Hence, NRENs may provide service to Class B and C users directly or may provide the backbone for discipline-specific networks of Class C users, in some cases in grid configurations.

A meeting hosted by the US National Science Foundation in 2007 directly addressed the question of the role of commercial carriers:

> “In asking the hard question of whether the commercial sector could provide all that it is needed, it was clear that the answer is still "no." The commercial participants were particularly helpful in elaborating on why a strong research networking program is important. Research networks challenge the economic viability of commercial providers and push the envelope of inter-domain services beyond what the competitive environment has fostered. Many requirements of the research community -- extremely high-bandwidth driving control plane work for dynamic circuit provisioning, low latency for real-time interaction, end-to-end performance management, multicast, IPV6 peering -- are not available across arbitrary commercial backbones. And yet these are required for international science.” (Blatecky et al. 2008, p.2)

In addition to service constraints, state, national and regional science funding agencies may have been convinced of the value of NRENs based on cost savings alone. For example, in a comparison by DeFanti et al. (2003), they describe the price for one month of a carrier-managed broadband circuit (1 Gbps Ethernet) across the city of Chicago as being equivalent to the cost for university to provision and manage a similar connection *for 20 years.* The authors are, however, also quick to point out the comparison assumes the scientific community has the capacity and willingness to establish and manage such services for themselves. Thus, establishing private networks for e-science is justified not only by the network requirements of high bandwidth, low latency and scheduled services, but also the reduced costs of establishing and managing a private network, particularly given the availability of skills.

To date the scientific community, at least in some disciplines, has demonstrated these skills. One such community is High Energy Physics, which operates the Large Hadron Collider (LHC) at CERN near Geneva, Switzerland. Some of the experiments being conducted in the Collider generate up to 1.25 gigabytes per second of data (Bird et al 2009). To manage, store and provide remote access to the data the community developed a grid network infrastructure that evolved into the Worldwide LHC Computing Grid (WLCG), which includes 150 sites in 35 countries. The network connects CERN to 11 regional (tier 1) computer centers, which in turn send processed data to smaller tier 2 centers where physicists access data directly. The required aggregate data rate from CERN to the tier 1 centers is minimally 1.3 gigabytes per second (Bird et al 2009). The WLCG is a discipline-specific grid that is an overlay on internationally connected NRENs.

Gaining a testbed. In addition to accommodating increasing scientific collaborations and their network requirements, a separate network also provides a testbed for new network technologies and high bandwidth applications. As such the network can serve as both a production network, providing existing service levels, as well as a development network, wherein new network technologies are designed and tested. From the outset the internet successfully combined development and production networks (Weis, 1992). As a production network it provides the services scientists require while testing interfaces and compatibility. Also, production networks demonstrate need and provide incentives for further applications development. As development networks, technology developers, whether they be academics or industry partners, can cost share on network innovations and leverage government seed funds.

These factors can be observed in the LHC grid network discussed above. In that project, the four main detectors at the Large Hedron Collider produced 13 petabytes ($13X10^{15}$) in 2010 alone. The network for moving that data is described as the most sophisticated data-taking and analysis system ever built (Brumfiel 2011). To facilitate collaboration and access, the data is moved from CERN (one day's worth might exceed 5 terabytes) on 5 gigabytes per second links to the 11 Tier 1 centers. These Tier 1 centers not only transmit data to the 140 Tier2 centers, but also facilitate distributed analyses, which the large datasets and limits to processing capacity require (Brumfiel 2011). These activities require discipline-specific applications and interfaces, while overcoming local differences in technical protocols and practices. As such, they provide invaluable experience on high capacity grid networking for all involved.

2.2 Connecting Scientists

The example of WLCG describes service provision to a community that has historically made use of advanced computational infrastructure. This community is one of a small number of groups within the engineering and scientific community that first made use of supercomputing facilities, despite their being difficult to access and use (Zimmerman and Finholt 2007).

In these advanced user communities network design, as well as the services and applications it would provide, may be undertaken simultaneously with design of the scientific equipment. This is particularly the case for large equipment investments such as the collider and high power telescopes. These communities have been involved in e-science for decades, gaining years of experience, yet issues of usability and accessibility of data and applications, common in all information systems, persist. To overcome these issues and ensure benefits accrue from network investments, NRENs play an important role in understanding and meeting user requirements.

However, unlike discipline-specific networks such as the collider's WLCG, NRENs serve multiple scientific communities. To foster this service provision they may form, support and in some cases fund associated discipline-specific organizations, sometimes referred to as gateways or virtual organizations. For example, the Enabling Grids for E-science in Europe (EGEE) project supports more than 200 discipline-specific virtual organizations (Bird et al., 2009). In its role as a coordinator, EGEE provides direct support such as application porting as well as representation, for example ensuring integration of special features into grid middleware during its development.

Similarly, the U.S.-based TeraGrid project interacts with individual scientific communities through TeraGrid Science Gateways, providing services to meet their specific needs (Zimmerman and Finholt 2007). The services include establishing 'community accounts' that eliminate the need for each scientist to submit a proposal and code to reserve network bandwidth and computing facilities, as well as tools for large data set analyses and interfaces that reduce the need for learning about computer operations such as job queue policies, the number of nodes to select and setting time and memory limits. These Gateway organizations exhibit many of the characteristics of general gateway organizations in their attempt to enhance the compatibility in values and experiences between the supercomputing system and potential users as well as reduce the systems complexity and enhance its trialability (Zimmerman and Finholt 2007).

While important to experienced e-scientists, these services are even more crucial to newcomers. As e-science spreads from traditional supercomputer-using disciplines to the social sciences, arts and humanities the experience, skills and interests of these users may be different in some cases. Growth in the number of users is important to some NRENs, particularly those whose government funding is tied to outreach to these communities. Also, in countries where NRENs compete, the ability to attract and serve these communities can provide further justification for the existence of the NREN.

2.3 Testbed for network innovation

The third motivation for establishing separate networks for scientific collaboration is the networks provide a testbed for network innovation. Network innovation faces two fundamental challenges, namely fragmentation of ownership and operation inherent in an interconnected network and the conflict between reliable service and experimentation.

Even from the outset, the internet was associated both with advanced technology as well as a fragmented and diverse network and ownership structure. In 1992 Weis described the T1 bandwidth (15Mbps) achieved in NSFnet in 1989 has having pushed the state-of-art in speed, routing and network management. At the same time he notes "The 5,000 plus networks [of the internet] are owned by federal agencies, state governments, non-US governments, private industry, international carriers, not-for-profit companies, universities, and various combinations of these.”

Fragmented ownership can create challenges for innovation in that it makes it difficult to adopt new ideas, approaches and technologies, as various parties may have differing levels of commitment to the embedded technology and fragmentation reduces incentives to cooperate on fundamental improvements (Gammon, 2010).

In addition to fragmentation and commitment to the embedded base, which may also have economic and practical motivations, network innovation is also constrained by the need to balance reliable service with system-wide experimentation. As DeFanti et al. (2003) observed:

> “It is unclear whether routers will ever provide deterministic guaranteed bandwidth; huge marketing and technical barriers stand in the way of offering widespread guarantees. However, disrupting production-oriented research and education production networks to find out is not conscionable; moreover, convincing proofs-of-concept for new technology would never emerge from modest laboratory-scale testbed networks or simulations alone.”

While science funding programs continue to separate production and experimental networks, technological change warrants re-examination of the assumption that experimentation causes disruption. Indeed in meetings hosted by the U.S. National Science Foundation in 2007 network experts pointed out that new optical networking technologies provided the opportunity to provide production network services while deploying new technologies in a non-disruptive fashion and that the closer ties with users creates an additional benefit for testing on production networks (Blatecky et al. 2008).

3. Creating globally connected NRENs

While some countries have decades of experience with NRENs, others are relatively new or are now just in the planning phase. Connecting these newer NRENs to create a globally integrated e-science infrastructure can in some cases raise significant challenges. In the following sections I discuss the status of NRENs in developing countries and the challenges they face, followed by a discussion of the costs and benefits of international interconnection.

3.1 NRENs in less developed nations

While many low income countries have established NRENs, others are just in the planning stage. For example, in Africa, countries yet to establish NRENs include Benin, Burkina Faso, Gabon and Mali (Barry 2011). In these countries dialog is commencing and the costs and benefits of achieving connection between universities are being discussed. These discussions are supported in part by the Association of African Universities (AAU) REN group.

These discussions include the benefits of NRENs for low income countries, especially their ability to overcome both the high cost of bandwidth as well as the relative isolation faced by scientists. Additionally NRENs can help address problems associated with the lack of higher education institutions, particularly increases in the demand for IT-enabled education (virtual or persistent lectures, distance education) (Barry 2008). For example, the MIT server which hosts MIT Open Courseware was one of the first resources available on the Malawi REN (MAREN) infrastructure (Fryer 2011).

Once developed, NRENs in less developed nations vary both in their domestic and international connectivity. For example, in Africa whereas South Africa boasts a 10Gbps international connection, and Kenya and Sudan have 760Mbps and 155Mbps respectively, due to high costs and limited connections Malawi's network has only a 12Mbps international connection (Fryer 2011). Even in middle income countries this is the case. A comparison by Divakaran et al. (2007) of international connectivity shows significant differences, with South Korea having 10 times the international link capacity as compared to Mexico.

Interestingly, according to Barry (2011) capacity and funding are rarely the issue, with costs being the major determinant of bandwidth. High costs are attributed to equipment (VSATs versus fiber) and monopolistic telecommunications market structures. For example, in Africa 80% of international traffic is controlled by only 8 operators. Additional constraints include human resources and power supply reliability (Fryer 2011).

To overcome these hurdles it is important for an NREN to have an ally, typically in the government, to help obtain favorable prices and service terms with incumbent carriers. In particular, carriers often attempt to charge NRENs the same rate as commercial carriers, making it too costly to provision internationally competitive bandwidth for their scientists. Also, international network connections may require service commitments which the NREN must negotiate with the carrier.

Clearly the organization operating and managing the NREN must have diverse capabilities. Typically, their responsibilities include mobilizing and aggregating demand for high-speed networking, managing owned and leased infrastructure including contracts with carriers, and delivering services at agreed standards, including international connections (Divakaran et al. 2007). If successful, these organizations may represent the cutting edge of network technology in their country. For example, in China the China Educational Network (CERNET2) is the largest IPv6 backbone and connects roughly 200 universities.

Once established, NRENs must continue to evolve both in terms of technology but also in terms of the context of the country. As mentioned previously, within a country there may be a single NREN or many RENs in competition. Competition, such as that found in the U.S. and other countries, can be beneficial for redundancy and innovation, however it can have detrimental effects.

A case in point of evolving governance structures and a competitive network environment is India. Historically, India's research and education network arena was dominated by ERNET and its grid companion GARUDA. However, in 2005 the Indian government formed a high level body known as the Knowledge Network Commission. The Commission recommended the development of a new national network, known as the National Knowledge Network and in 2008-2009 money was allocated in the national budget for its construction. The reasoning for the development of this national network was multifaceted (Divakaren et al. 2007).

First, it was argued a centrally managed national network would reduce redundancies that were emerging as an increasing number of domain-specific networks (e.g. bioinformatics) and grids were being established. Similar concerns exist In wealthier nations as well, where fears arise of a fragmented, discipline-specific scientific infrastructure (Blatecky et al. 2008). Second, the central management would ensure new ventures met international standards as some of the emerging networks were viewed as being based on old technologies with minimal levels of bandwidth. Third, it was proposed that a single national network might be more attractive for international network connections (Divakaren et al, 2007). While centralization within a country may achieve some of these benefits, the challenges faced by NRENs also have implications for regional and global networks.

3.2 NREN interconnection

The interconnection of NRENs can occur on a bilateral, regional or global scale. While bilateral connections between large national networks, such as Japan and the U.S., are common, global integration has over the past two decades been aided by the development of regional networks.

In Europe the NRENs are connected through GEANT/GEANT2 and in southern and western Africa the UbuntuNet Alliance and WACREN are creating economies of scale for their members. Similarly in the Caribbean, C@ribNET is a regional network with planned connections for the island RENs to four nodes (U.S., Jamaica, Dominican Republic and Trinidad). Through these nodes island RENs can connect to the Internet2 (US), RedCLARA (Latin America) and GEANT (Europe) (Samuels and Edwards 2011).

Challenges to interconnection include the cost of in-country connectivity, funding models for NRENs, telecommunications regulatory environments and a dearth of effective collaboration frameworks to build on (Samuels and Edwards 2011).

Despite these challenges there are numerous benefits to interconnecting NRENs, beyond the obvious expansion in the base of scientists for collaborations. The benefits include 1) harmonizing network technologies, interfaces and management, 2) possibilities for enhanced services provision and 3) leveraging of investments.

Harmonization. In the early days of the internet competing protocols existed, particularly in Europe where their ISO protocol was favored over IP. Over time, following NORDUnet, the regional Nordic network, with its IP-based direct connection to the internet, the European regional network GEANT adopted IP. This enabled NORDUnet to abandon its independent link, joining GEANT in 2003 to take advantage of cost savings (Lehtisala 2005)[3].

In addition to harmonizing networking technologies, international interconnection provides harmonization interfaces, management and applications. For example, in Europe it has been observed that beyond the national level, standards become important to allow ease of connectivity and sharing of applications. It is noted the European grid program Enabling Grids for E-Science (EGEE) helps ensure grid infrastructure does not fragment into national and thematic infrastructures, with little coherence at the European level (Bird et al 2009).

Enhanced service provision. In addition to providing network connectivity most NRENs offer a variety of services to facilitate collaboration between scientists. As the NRENs integrate, particularly at the regional level, it may be possible for the members to share or offer services across national boundaries, thereby enhancing service

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[3] NORDUnet adopted IP in favor of the then popular ISO protocol, and they established a direct Internet connection to the U.S. prior to other European NRENs. While there were earlier project-based connections between the U.S. and Europe, they did not provide access to university students.

provision for end users. Such a program is exemplified by NORDUnet's service exchange system, whereby members can copy services offered by other members (Bech 2011).

In additional to facilitating service sharing among members, regional networks may also offer services themselves. The RedCLARA regional network in Latin American recently launched a portal (March 2011) that provides a variety of services, including web and videoconferencing, content management, Video on Demand, partner search and hosts wikis and blogs. It also provides unified authentication (Utreras 2011).

In addition to improving services for scientists, international interconnection can also improve basic network services. This is particularly the case when expanded international interconnection provides redundancy for established links. For example, U.S.-Asia connectivity is supported through at least three projects, namely GLORIAD (connecting to China-CSTnet, Russia, and Korea); Transpac2 (connecting to Japan, China-Cernet, and Asia countries connected through the EU-supported TEIN2 network); and TransLight/Pacific Wave (connects to Australia) (Blatecky et al. 2008).

Interestingly, investments made on one direct bilateral link may have additional benefits for other routes. "The US benefits from Korean participation in GLORIAD not only for US-Korea collaborative activity – but the 10G circuits from Hong Kong to Daejeon and Daejeon to Seattle support US-China activity also. By routing CERNet traffic between Hong Kong and Seattle, the US gains uncongested network capacity with universities across China (in addition to the research facilities routed by GLORIAD partners at CNIC)" (Blatecky et al. 2008).

New links may not only enhance redundancy but they may provide more direct routing. In the U.S. the AmLight network started as the Western Hemisphere Research and Education Network (WHREN) in 2005, within which the Links for Interconnecting Latin America (LILA) program was established. Prior to WHREN, data transferred between certain South American countries and the U.S. transitted through Europe.

> "For example the European Union stipulated that the ALICE intercontinental link from South America to Europe could traverse North America, but could not route data there. U.S. investigators connecting to U.S. owned telescopes in South America would without WHREN need to route from the U.S. to Europe, then back to the U.S. This exactly what happened before WHREN." (Blatecky et al. 2008)

Leveraging investment. A third benefit of international interconnection is leveraging the investment of each nation. For developing countries, the ability to quickly connect to the global NREN provides a strong incentive for investment in domestic infrastructure and may further bolster investments in science and education (Williams 2011). This is particularly true when high income partners are willing to provide partial investment. For example, Europe's ALICE2 project provides funding for interconnecting Europe and Latin America with an investment of 12 million euros by the EU and co-funding of 6 million euros by Latin American NRENs (Utreras 2011).

However, it is not only low income countries that reap the benefits of leveraged investments. It is estimated that U.S. investments in international connections of $24.3M from 2003-2008 were matched by investments by other nations at a level generating a 10:1 return on investment (Blatecky et al. 2008). Investments include both costs of bandwidth (e.g. $120,000 for a 10G circuit between US-China-Korea) but also investments in network management, programming, applications support and equipment.

The range of countries making such investments and indeed the investments levels themselves are expanding. For example, between 2004 and 2007 the U.S. National Science Foundation invested $2.4 million in international networking and during that same period the EU spent $11.4 million connecting to a regional network in Latin America (CLARA), where the regional network itself contributed $3.6 million. Brazil spent $2.8 million with a commitment to match all NSF funds directed toward developing bilateral connections. Additionally, in the same time period the countries of Venezeula, El Salvador, Panama and Mexico collectively spent $2.3 million for connectivity to the U.S. (Blatecky et al. 2008).

Evolution in management and configurations. Regional networks, similar to the NRENs they connect, must also evolve not only with changing technologies but in their governance and agreements. One example of such an evolution is NORDUnet, which evolved from a consortium to a private, limited liability firm. As a limited liability firm the organization felt it could more easily enter into legal contracts with providers of network and other services. This move required passage of legislation in some of the member states to allow government investments in a private entity. While providing some enhanced flexibility, this status has resulted in comparisons being drawn between NORDUnet and other private network providers, requiring NORDUnet to articulate its unique position and services to maintain government support (Lehtisala 2005).

In addition to evolving governance, regional networks have also evolved to providing support to new grid and cloud services. As grid technology has evolved in the last two decades, regional networks have provided the basic network infrastructure for an increasing variety of grid programs. Grids exist at both regional and national levels, such as the Enabling Grids for E-science (EGEE; www.eu-egee.org) in Europe and the Open Science Grid (OSG; www.opensciencegrid.org) in the US. In turn these general grid infrastructures provide support to domain-specific grids. For example, the computing centers that are part of the Worldwide Large Hedron Collider grid, known as the WLCG, receive support in the form of tools, services and support structures that enable them to fulfill the WLCG MoU service level requirements (Bird et al. 2009).

Low income country NREN interconnection. As mentioned above, a wider variety of countries are making investments in NRENs and seeking international connections. In these endeavors, low income country NRENs can pose particular challenges. The first challenge is related to the degree of autonomy of the NREN. In some countries where the NREN lacks independence, it is unable to make decisions and enter into contracts and consequently negotiations for international connectivity must occur between the international network and the ministry. This occurred during the process of connecting the GLORIAD network to the Egyptian NREN.

Another obstacle also experienced by GLORIAD, this time in its connections both with India and Russia, is being caught up in national political disputes between contending forces. In the case of connecting with Russia, the GLORIAD project found itself between contending entities attempting to control networking in Russia. As control changed hands, the number of institutions allowed to connect declined significantly. Fortunately, after two years the connection was eventually returned to the more open network.[4]

These challenges are indicative of the hurdles faced by carriers in general international interconnection, indicated by the case of VSNL and FLAG in India. VSNL is a former Indian government owned national telecom operator and FLAG is an international submarine cable operator. VSNL and FLAG clashed in the early 2000s when FLAG claimed VSNL was blocking access to its Mumbai marine landing point to protect its monopoly. The case was brought to the International Chamber of Commerce which made a ruling granting FLAG access to the landing point. The landing point's other customer is the Sea-Me-We cable, which is owned by a consortium of about 100 carriers some of whom were looking to FLAG to establish redundancy[5].

Interconnecting with low income country NRENs may also involve funding contributions. In some cases a national NREN may look to their high income country counterpart for financial assistance to connect. In these cases, it may appear prudent, particularly given the frequently experienced bureaucratic hurdles, to for expediency to handle much of the logistics related to the network. However, experience has shown that without involvement and buy-in from the NREN the international link may falter or remain underused[6].

4. Analysis and discussion

NRENs are an evolving part of national and global information infrastructure. They play a unique role in the system of network innovation and serve as the basis for international scientific cooperation. In the following I return to the original set of questions posed, providing an analysis for each in turn. Subsequently, I discuss future opportunities and challenges for NRENs.

4.1 Analysis

1. Through which mechanisms are international network investments carried out?

International network investments are carried out primarily through interconnection of NRENs. These connections may also be made by discipline specific networks, however in some cases these networks will rely on infrastructure provided by the NRENs. In high income countries there may be situations in which universities establish direct connections for their scientists, which is most likely to happen for low cost links – those where competition has driven down prices (e.g. US-Europe).

In the interconnection of NRENs, connections may be made at the national or regional level. Regional level connections have been shown to provide enhanced economies of scale and typically lower prices for their members. It may also be the case that for international networks connecting at the regional level is preferable as the regional networks tend to bare the responsibility for working out national level issues.

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[4] See Gloriad history at www.gloriad.org.

[5] See news article "ICC order VSNL to grant access to FLAG's Mumbai cable landing" http://news.oneindia.in/2006/05/26/icc-orders-vsnl-to-grant-access-to-flags-mumbai-cable-landing-stn-1148652624.html and news article "FLAG hits out at VSNL monopoly" http://www.lightreading.com/document.asp?doc_id=45953

[6] See Gloriad history at www.gloriad.org.

The specific mechanisms through which the international connections are made include MoUs and contracts with carriers. In international and regional consortia members agree to MoUs that set out levels of service. Connected NRENs must then work with their carriers to provide the required level of service. The international links connecting the NRENs are provided by international carriers via leased facilities agreements.

2. What factors determine the nature of public-private partnerships in these projects?

At the national level, the degree of competition among NRENs is likely to influence the nature of the partnership. In countries where there exists just a single NREN, that network is likely to be solely a public endeavor. However, as NRENs are provided more autonomy they are likely to seek and attract a broader diversity of partners, including academic institutions, firms, NGOs, etc.

The nature of the partnership may also be influenced by the telecommunications market structure. Where the dominant carrier has significant market power (or in some cases a monopoly), an NRENs relationship with or association to a ministry can be valuable.

3. What factors influence the types of access these projects facilitate?

The access facilitated by NRENs depends largely on the 'last mile.' The need to invest in not only the international links but also the university networks, that tend to be the bottle neck for high speed connections, is recognized in nearly all countries, from the US to India.

The types of access also vary with the services offered by the NREN or regional network. Offering services requires funding (at least at the start) and hence the diversity of services is likely to depend on funding. Additionally, the range of services offered may expand through collaboration generated in a regional network. Also, regional networks may also expand the range of service offerings.

4. What factors influence the outcomes of these deployments?

The outcomes rely not only on the ability to develop diverse network connections to facilitate collaborations with a variety of scientists but also the quality and costs of those linkages. With a broadly connected, high quality and reliable network infrastructure, outcomes are likely to depend on the services provided by the networks as well as their capacity to connect with user communities to adequately meet their needs.

4.2 Future opportunities and challenges

NRENs, as providers of basic network infrastructure, will continue to provide necessary services as long as the carriers are unable to. Given the high level of interaction required between network providers and the scientific community it is unlikely these needs will be adequately met with NRENs in the near future.

However, while network operators are not likely to challenge the position of NRENs, other models of organizing networks for scientific collaboration may be. The introduction of optical network technology, or lambdas, has called into question the traditional nature of NREN interconnection. The need for so-called GLIF Open Lightpath Exchanges (GOLEs) was articulated in a position paper of the GOLEs ad hoc Policy Group[7]. The policy group

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[7] See http://www.glif.is/publications/papers/20110519BStA_Open_Exchanges.pdf

characterizes NRENs as essentially hierarchical and monopolistic, calling for more open mechanisms of interconnection that includes NRENs but is also open to all interested parties. In the past, resource limitations and technical constraints have caused exchanges to enact policies that limited participation and established priorities among users. The GOLE Policy Group calls for increased transparency and openness in access, membership and decision making.

5. Conclusions

Advances in computing and networking technologies have ushered in an era of e-science wherein scientists around the globe collaborate to solve the most pressing issues for the globe. These scientists represent advanced users of networking and computing technologies and as such have needs that are not easily met by standard telecommunications service offerings.

NRENs and more specifically internationally interconnected NRENs can provide these services, at least as long as the scientific community is willing and able to provide the necessary expertise. NRENs achieve international connections through direct connections to international networks or through regional consortia. Both national and regional networks are continuing to grow and develop, in both high and low income countries. The latter pose particular challenges for creating globally connected networks.

While NRENs continue to grow and develop, recent advancements in grid and computing architectures have called into question the hierarchical orientation and close nature of many NRENs. Future development in these technologies and consensus among scientists will likely play a determining role in the future of NRENs.

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