Networking to Support Data-Intensive Research
A View from the Campus

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This paper provides an introduction to the special networking needs of data-intensive research programs and some of the approaches that have been developed to address those needs. It is intended for IT leadership and staff who are familiar with enterprise networking.

Introduction

This paper is intended primarily for IT leadership and staff who are broadly familiar with enterprise networking but who may be unfamiliar with the special aspects and issues involved in networking intended to support research programs. Network-intensive research becomes ever more widespread as research practices continue to change and evolve in a wide variety of disciplines, and a growing number of institutions will encounter these issues for the first time—they are certainly no longer the territory of the research-intensive universities alone. A secondary audience includes researchers or departmental research support staff who want to better understand networking in support of research and how the campus networking team might support their own research work.

Networking to support research is very different from general enterprise (commodity internet access) support, and the kinds of networking technologies needed depends critically on the kinds of research being conducted. Key differences include the following:

- Compared to other campus network traffic, research flows are large and sustained, and this trend will continue as more areas of research become data-intensive and instruments become more powerful.

- There are often specialized requirements for performance (bandwidth, TCP buffer size, and latency), reliability, and security for research workflows that may span multiple applications, platforms, and institutional networks. This is much more complex than simply ensuring there is enough bandwidth to support aggregate enterprise traffic to the internet.

- There are explicit and important trade-offs between security and performance, for example, when researchers need to move large volumes of data on friction-free networks or require highly secure routes to the cloud or campus data center for restricted data.

- There are sometimes needs for special static, long-term, or dynamic-on-demand configuration of both routing and provisioning to enable transfers across wide areas, fast access to local data, or low error rates.
• Engagement with researchers is critical for determining their needs, solving connectivity issues that may be unique to a given research project, and planning local and regional architectures that will enhance research workflows in the future.

Researchers and research silos usually have an unclear understanding of the capability and flexibility of the network. IT may not have a clear idea of the unique research requirements. Hence it is imperative that researchers and IT staff work together to design appropriate architectures that enable research. While the design considerations may be complex, it’s important to understand that there’s a sizeable base of knowledge, best practices, and expertise to draw upon.

Technology and Research Trends

Research is increasingly collaborative, interdisciplinary, and complex. It is also both data- and compute-intensive and often involves sharing and analysis of data through layered applications and across multiple institutional networks. It follows that the movement of research data has become a strong driver in the design and architecture of institutional networks and this requires collaboration. A set of trends related to how the institutional network is used for research (as contrasted with enterprise usage) is occurring in parallel with technology developments and with science drivers. These technology and research trends impact network architecture decisions, whether they are on-premises or in public clouds.¹ Those decisions include how to manage the boundary between research and enterprise networks.

Most campus networks were originally designed to support smaller traffic flows and enforce routing of traffic through firewalls. In response to the demands of scientists who need to move data quickly between data and computational resources on and off campus and share data with external collaborators, many institutions have re-architected their networks to enable a high-bandwidth express lane to the internet and faster connections between research centers on their campuses. At the same time, some institutions are using software-defined networking (SDN) for provisioning dedicated or dynamically allocated connections between endpoints to meet the diversity of research needs.

Science DMZ

Since 2012, the Campus Cyberinfrastructure program at the NSF has funded network redesign based on the Science DMZ framework at 112 institutions.² The
DMZ architecture, developed by the US Department of Energy, sees the complexity and security requirements (firewalls) of the commodity enterprise networks on most campuses as having a substantial overhead that interferes with the ability to move large data at maximum speed. The DMZ architecture was designed to separate, simplify, and facilitate efficient movement of data-intensive science workflows.¹

The architecture is typically implemented by isolating a segment of the existing network adjacent to the network perimeter, outside the enterprise network firewall. This section is referred to as the Science DMZ and is reserved for the movement of research data using data transfer nodes (DTNs). These dedicated servers feature high-end components and high-speed disk subsystems to support transfers of data to and from the wide area network (WAN). To maximize the speed of data transfer, security is usually implemented with access control lists (ACLs), host-based firewalls, and security software rather than with an edge-firewall appliance, as would be common in most production campus networks.

Security is maintained in layers, sometimes but not always with the benefits or liabilities of deep packet inspection firewalls, intrusion detection systems (such as Bro), or similar conventional perimeter security appliances. Point-to-point ACLs, isolation from the production network, strict limitations of permissions to nodes, and formal change control are used to help secure the network. Functionality is provided via specific applications that are connected to federated identity management systems. A common high-performance data transfer application example is Globus. Globus automatically tunes performance parameters, monitors progress, and validates data transfer correctness, which is important for large-scale data transfers. Globus can authenticate users via a federated InCommon identity so that users can employ their institutional credentials.

The DMZ paradigm firmly embraces active monitoring of end-to-end network performance through tools such as perfSONAR. This software, along with low-cost 1–10GB/s hardware, allows administrators of these data-intensive networks to have greater insight into the performance of their WAN connections. perfSONAR tools yield information useful for understanding which routes are best for larger data movements, when data-intensive flows fail, and where bottlenecks in performance have occurred.

Institutional benefits of this data-intensive networking architecture are many: Internal and external production links reduce congestion; organizations avoid the expense of purchasing traditional commodity network protections; and
researchers experience lower packet loss and error rates as data traverse firewalls and local and regional network segments on their journey across campus or from one campus to another. Additionally, the Science DMZ architecture has been helpful in bridging the infrastructure silos at national and international institutions. Due to the standard architecture and tools (perfSONAR, Globus, etc.), moving data between Science DMZs is much simpler than it was when institutions had very different vendor-specific architectures and lacked common community applications (e.g., Globus, perfSONAR, MaDDash, Bro, etc.). In effect, the DMZ has become a research data gateway that enables easy movement of data within the DMZ and to other DMZs across the world.

Software-Defined Networking

In 2014, an EDUCAUSE working group published *The Promise and Reality of SDN*, highlighting both the potential benefits of software-defined networking and its emergent status, lack of convergence around standards, and the complexity of integrating with existing campus enterprise network solutions. While SDN is still considered an emerging technology, networking for research is one area that has seen some implementations of SDN in ways that have focused on security, dynamic access control, and quality of service.

In the future, SDN may provide methods for dynamically provisioning portions of the network for on-demand high-bandwidth circuits between endpoints for big data transfers such as between lab instruments and computation clusters at different locations on campus or between individual research groups and national data hubs. At the national level, the SENSE (SDN for End-to-End Networked Science at the Exascale) project is exploring the use of SDN as a component of global-scale architectures with optimized paths and application layers for end-to-end workflow performance for scientists engaged in large-scale collaborations. CloudLab and Chameleon are serving as testbeds for how OpenFlow-enabled networks could allow researchers to dynamically create network circuits when they need to transfer data from their departmental storage to computational clusters across geographical distances and in the cloud.

Data-Intensive Research

The magnitude of data resulting from instrument- and sensor-based science domains such as astronomy and particle physics is on par with the amount of data generated by Twitter and YouTube. As instruments become more sensitive and
more data are collected and processed, the network requirements will increase in scale and complexity. For example, the Square Kilometre Array telescope (scheduled to be operational in 2020), the Large Synoptic Survey Telescope (operational later this year), and the High-Luminosity Large Hadron Collider (slated for 2025) will generate tens to hundreds of terabytes (TB) per day. While the greatest bandwidth requirements in these scenarios will be at institutions serving as the primary collection, processing, and archival sites, the complexity of the workflows required to process and visualize data will mean that scientists at tier 2 and 3 sites will need high resilience, low delay, multiple paths, and an efficient control plane to fulfill their role as workflow endpoints in the end-to-end path connecting all sites in the virtual organization.

Genomics is another area of research that is witnessing an explosion of data volume as more and more species’ genomes are sequenced and communities and shared workflows develop around these genomes. As personalized medicine fulfills its promise, it is likely that medicine will see rapid growth in data hubs exploring the genome and transcriptome of collections of individuals. Individual researchers at institutions can access and query national data sets such as the Cancer Genome Atlas and other projects at the NIH National Cancer Institute’s Genomics Data Commons. For researchers at individual institutions, accessing and analyzing this human-subjects data may require specialized secure network connections and methods to ensure efficient transfer of data.

The following examples illustrate how these global trends lead to data transfer activities that researchers at a typical higher education institution perform on a regular basis:

- Scientists in the astronomy department download terabytes of data from an international observatory in Chile each day via the high-bandwidth campus WAN and transfer the data across internal campus links to the institution’s high-performance compute cluster for processing and storage.

- On the humanities side of campus, a political science professor harvests, tags, and archives millions of Twitter posts with political content and syncs her database nightly with a collaborator in the computer science department who runs machine-learning algorithms on the data using local and national grid computing resources.

- On another part of campus, a life sciences researcher runs alignment workflows on his microbial genomic samples against records in a genomic hub that is hosted at another university 800 miles away and then runs pairwise computations using alignment data and data from environmental sensors attached to the campus wireless network.
Networking to Support Data-Intensive Research

These scenarios demonstrate the unique needs an individual researcher may have for network connectivity. And the future promises to hold more challenges as more and more areas of science are driven by large volumes of data and the insights gained by its analysis, incorporation into models and simulations, and visualization—all activities that involve significant data transfers across individual campus networks and between institutions.

**Partnering with Researchers**

Higher education networking, although most often thought of as an enterprise utility requiring the high availability typically necessary for a production environment, must address research demand in a much different way.

The inherent complexity of research networking requires technical staff who can engage with researchers in discussions that may include unique local area needs or campus policy conflicts instead of being solely focused on break/fix support for wired and wireless connections. Details in the exchange should also include information about the researcher’s data sources, data sharing needs, and data access for collaborators at other institutions. This represents a cultural shift from the support model for the enterprise, in which technical support personnel have no need to understand additional requirements because they largely do not exist.

However, it may also be unrealistic to think that we can develop and deploy a new, purpose-based network for research data and the scientific enterprise with a “build it and they will come” mind-set. Simply building a Science DMZ or a purposed campus research network will not lead to these technologies’ being used by faculty. We must identify and work with early adopters whose requirements can help drive network design and whose success stories help communicate how networking can help accelerate the time to scientific discovery to other research communities.

The sections below examine how to partner with researchers at the campus, regional, and national and international levels to better understand network needs and communicate capabilities.

**At the Campus Level**

As we consider research networking, we need to be mindful of the fact that having engaging conversations with faculty about their scholarly research work may require a major cultural shift for traditional networking support experts. These
conversations may be new for both IT networking professionals who are not used to engaging with end users and for researchers who are often unaware of the crucial role of the network in accomplishing their scholarly research. These engagements, however, are critical to optimizing the network for research and helping researchers derive maximum benefit from it.

Because the conversation between the researcher and the networking professional is the coming together of two complex specialties, much like a conversation between two individuals who speak different languages, a translator or facilitator becomes necessary to optimize effectiveness. The efforts to fill the role as translator and the follow-on research networking expert, sometimes including IT implementer, are evolving in different ways. At some larger institutions, there are resources to engage dedicated personnel to fill the roles of facilitator and that of the research IT professional, often specified as a research cyberinfrastructure engineer (CI engineer). At other institutions, the facilitator and the research network specialist roles are filled by the same person, while the job titles, the scope of responsibilities, and the percentage of the FTE dedicated to research support vary. Several national efforts under way understand and address the unique need for facilitation and research technical support engagement to fill this communication gap at the local institution. Efforts to train and professionalize the roles of facilitator, as developed in the Advanced Cyberinfrastructure Research and Education Facilitator (ACI-REF) program\(^6\) are being adopted at research institutions, while organizations like the Campus Research Computing Consortium (CaRC) are engaging emerging professionals to join the community of practice for both the research facilitator and the research CI engineer.

A support model that focuses on high touch, rather than on traditional transactional ticket-based workflows, will optimize the effectiveness of the researcher’s use of the cyberinfrastructure network. The research facilitator, working closely with the CI engineer, has a unique pairing of research understanding and technical expertise that work together to transform user support. These capabilities enable the research facilitator to translate across and communicate with domain-centric researchers, IT professionals, and a myriad of other administrative, institutional culture and policy, and national and international research roles. It is neither productive nor efficient to continue to separate enterprise networking from research networking, and the research facilitator bridges this gap, providing immediate expertise in the timeline necessary for research computing purposes.
At the Regional Level

Collaborative research is currently understood to be data-, compute-, and bandwidth-intensive. As new facilities are designed and deployed they are provisioned with the needs of the 21st-century research and education (R&E) community in mind. The regional approach with high aggregate network and compute capacity and efficient operations has resulted in significant collaborative research and funding. It is complex. It required multiple network groups working with multiple research groups to design an architecture to support current and future research needs. Because of the collaborative and distributed nature of research and its dependence on network connectivity, campus networks and IT organizations need to be attuned to providing support to researchers that crosses multiple administrative domains (campus, regional, national, international), and that assumes an end-to-end view for service development and problem resolution. As higher education outsources more critical services to the cloud, this end-to-end view becomes more a part of enterprise network thinking, yet research applications present a much more dynamic set of problems requiring end-user support strategies that go beyond the campus level.

There is special concern for small campuses with fewer resources that may need to access nearby resources rather than have resources all their own. Regional collaborations can be of benefit to these smaller campuses in providing end-to-end support services for their users. State or regional research networks may provide the context for forming such a support organization.

At the National and International Levels

From the earliest days of NSFNET, networks have been integral to large-scale, collaborative science and engineering efforts and experimentation. The computational, data sharing, and communication needs of researchers have stimulated the design, development, and improvement of these networks and networking protocols. Reliable and efficient networks, in turn, stimulated the design of novel instrumentation (e.g., Large Hadron Collider, Network Engineering for Earth Sciences Grid [NEESgrid], and the Laser Interferometer Gravitational-Wave Observatory [LIGO]).

Researchers who work collaboratively across the world continue to innovate and test the limits of R&E networks. This challenges the network engineering community’s collective ability to engineer and support innovative services. This
also challenges campus IT organizations to take a larger role in engaging with researchers on their campus by doing the following:

- Providing network staff who understand the dynamic nature of research requirements for networking (dependence on many outside sources of data, computing infrastructure, and analytical services) and who have the technical skills to offer novel solutions to emerging data-movement requirements to help address the needs of individual research groups

- Informing the research community about how their work depends on the details of network connectivity across campus, regional, and national networks

- Participating in regional and national R&E networking and cyberinfrastructure organizations to understand the larger picture of emerging research needs and to craft collaborations and alliances to meet those needs collectively

**Conclusion**

The internet’s origins date back to federally funded research to develop robust, fault-tolerant networks, so it is not surprising that research continues to drive network innovation. Research is increasingly collaborative, interdisciplinary, and complex. More than ever, research in all disciplines is data-driven and compute-intensive. The movement of research data necessitates a change in approach for how we design and architect modern institutional networks and network operations. Much like the research it supports, research networking is complex and requires collaborative and interdisciplinary approaches to be efficient and effective. In response, we are seeing the adoption of new technologies such as Science DMZ and SDN to address research network needs beyond those required by traditional administrative computing networks. Additionally, new roles such as the cyberinfrastructure engineer and research facilitator are emerging at many institutions to bridge the gap.

IT leaders should consider several key strategic questions:

- If you are not a data-intensive campus, do you have a research networking issue today or is everything “just working” for your campus? Not all research work has specialized networking needs, though specialized needs are becoming more commonplace. How will you identify unmet needs, and when and how will you address them? What are your options, and what is realistic?
• If you already have network-intensive research under way, there are undoubtedly researchers who are having problems but do not understand what the research networking support teams can offer. What’s your strategy to identify, reach out to, and engage these researchers?

• How to you stay out in front of new research that may represent new support demands (for example, by reviewing grant awards and proposals, early interventions, etc.)? Is this working as well as it should be? What is an appropriate balance of proactive and reactive strategies for your campus?

• What are your strategies for collaboration and partnering? How do you engage with nearby research universities, regional networking organizations, or organizations such as Internet2 for national and international level needs?

The history of the internet tells us that needs and trends in research today will likely be the standard tomorrow. Preparing for that now is key.
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Appendix A: Additional Resources

Science DMZ
- ESnet, “Science DMZ: A Scalable Network Design Model for Optimizing Science Data Transfers”
- NSRC, “Science DMZ Overview”  
  Training video with Eli Dart from ESnet
- ESnet, “Science DMZ: Data Transfer Nodes”
- There are a number of examples of in-production Science DMZs, including:
  - Montana State University: The Bridger High Performance Research Network
  - Penn State: Science DMZ Research Network
  - Tulane University: The Science DMZ
  - University of Washington: High Speed Research Network

Software-Defined Networking
- The Promise and Reality of SDN (EDUCAUSE, December 2014)
- Mid-Atlantic Crossroads (MAX): SDN for End-to-End Networked Science at the Exascale (SENSE)
- Some examples of SDN implementations include:
  - Indiana University’s SciPass: A firewall bypass application for 100Gb/s flows that uses an OpenFlow switch as a load balancer to direct safe traffic past the firewall or block unsafe traffic from the network
  - Duke University SDN: A service allowing researchers to request and provision high-speed expressways between two endpoints
  - Princeton University’s Software-Defined Border Router: An OpenFlow-enabled switch that functions as a border router, peering with Princeton’s Internet2 connection provider and routing institutional traffic in and out of Internet2

Partnering with Researchers
- ACI-REF Leading Practices of Facilitation: A very helpful guide for undertaking such conversations with researchers, particularly the section on “Engagement with Researchers”
- ESNet: Science & Network Requirements Review: A set of resources on gathering researchers’ requirements, including understanding network requirements
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- NSF Program Solicitation: Campus Cyberinfrastructure (CC*) - CI Engineers
- XSEDE Campus Champions: Campus champions help researchers “with their computing-intensive and data-intensive research, education, scholarship and/or creative activity, including but not limited to helping them to use advanced digital capabilities to improve, grow and/or accelerate these achievements.”

Notes

1. Research in the cloud has been discussed previously. See, for example, the July 2015 EDUCAUSE Working Group paper Research Computing in the Cloud: Functional Considerations for Research, the December 2016 NSF-funded Cloud Forward Workshop, and the January 2018 NSF-funded Enabling Computer and Information Science and Engineering Research and Education in the Cloud Workshop, among others.
3. To learn more about Science DMZ and its importance to higher education, see Science DMZ: Technology Spotlight (EDUCAUSE, 2015).
6. See Advanced Cyberinfrastructure-Research and Education Facilitators (ACI-REF) program funded by NSF (OAC-1341935).
7. Learn more about the beginnings of the internet at IPTO—Information Processing Techniques Office.

About EDUCAUSE

EDUCAUSE is a higher education technology association and the largest community of IT leaders and professionals committed to advancing higher education. Technology, IT roles and responsibilities, and higher education are dynamically changing. Formed in 1998, EDUCAUSE supports those who lead, manage, and use information technology to anticipate and adapt to these changes, advancing strategic IT decision making at every level within higher education. EDUCAUSE is a global nonprofit organization whose members include U.S. and international higher education institutions, corporations, not-for-profit organizations, and K–12 institutions. With a community of more than 99,000 individuals at member organizations located around the world, EDUCAUSE encourages diversity in perspective, opinion, and representation. For more information please visit educause.edu.

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