Research Statement

SUSMIT SHANNIGRAHI

My primary academic interest is to support scientific communities to efficiently curate, distribute, discover, and retrieve large volumes of data. Scientific communities have spent a considerable amount of resources for creating intelligent data management tools and yet, continue to struggle with the vast amount of data. As data volume continues to increase exponentially, next-generation tools and protocols that reduce the burden of data management will be needed to ensure regular functioning of scientific workflows.

My work follows two simultaneous research directions towards this goal; first, I study current data management problems and build intelligent protocols, both in the network and the application layer, that can mitigate individual data management problems. Second, I study how to combine these different protocols to collectively create an advanced yet flexible framework that can support existing as well as future data management needs.

The first part of my work involves identifying data management problems in several scientific domains. I have collaborated with scientists from climate and High Energy particle physics, to understand better the common threads, as well as nuances involved in scientific data management. I plan to utilize these use-cases to create novel network and application layer protocols capable of addressing the problems both at the network as well as the application layer. I plan to adjust the protocols to suit the use cases by rapidly iterating over them.

The second part of my research builds on these protocols; I study how to combine these individual protocols into an advanced yet flexible data management framework. I deploy and study the improvements achieved by the framework, both qualitatively and quantitatively. I envision the architectural concepts, the protocols, and the framework to be complementary, each providing feedback to the others and pointing out inefficiencies, a collaboration crucial for solving the puzzle of large data management.

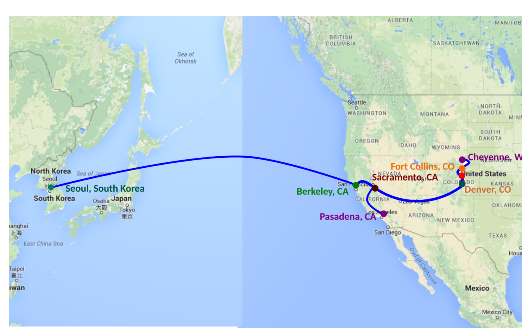

Fig. 1. Distributed NDN Testbed exploring scientific data management protocols and tools

Using two NSF grant that I co-authored and another that I participated in, we deployed an eight-node specially built NDN testbed for investigating scientific data management problems. My work so far has been creating, deploying and evaluating prototype protocols[1][2] on this testbed. I have also created and implemented on this testbed a data management framework that currently hosts and supports several terabytes of climate and high-energy particle physics data. In the course of deploying the testbed and the framework, I have collaborated with domain scientists from CSU, LBNL, LLNL, CERN, and CalTech to better understand the data management problems they face.

1 THE PROBLEM OF LARGE DATA

Many scientific fields are entering a new era of data-driven exploration and discovery, from Climate Science and High Energy Particle Physics to astronomy, genomics, and others, each with their complex workflows requiring sophisticated data management, computing, and network infrastructure. In spite of the recent technological advances, each of these domains faces unprecedented challenges in data publication, distribution, processing, access, and analysis, often exacerbated by the massive data sizes. Indeed, the data volume in data-intensive programs such as CMIP6 and LHC high-energy physics program is predicted to reach exabytes in very near future. Besides, the global nature of the scientific communities require geographically distributed sites where data is produced, processed and analyzed by thousands of scientists. In addition to the growing challenge of increased data volumes, the traffic flows are also projected to outstrip the affordable network capacity. The bottlenecks are thus in multiple dimensions - network, storage, and computing power, necessitating the optimization of workflows in a way that makes the most efficient use of the available resources. Successful collaboration within global scientific enterprises will, therefore, require not only network, computing resources or sophisticated data management applications but the integration of all the components into a next-generation data management framework.

2 NDN-SCI: A NEW FRAMEWORK TO SUPPORT SCIENTIFIC DATA

Various scientific communities have been trying to solve their own problems; they have so far developed and maintain custom software, highly specialized computing and networking facilities. While there are similarities, different workflows adopted by various scientific communities means these communities have created highly specialized solutions that fit only their particular workflows. These solutions are almost always at the application layer, developed with significant effort and cost. These solutions, however, are not reusable and do not always work as intended, hampering scientific research and possibly delaying significant discoveries. In my work, I have created an deployed over the testbed a scientific data management framework. In the following section I describes the problems I observed and how I addressed them.

2.1 Naming Data

My 6-year experience from the design and development of Named Data Networking (NDN) - a proposed future Internet architecture (FIA) fi?! suggests that data naming is at the heart of all data sharing challenges. To date, very little research exists on naming schemes for scientific datasets. Questions such as efficiency, aggregation, ease of lookups, proper hierarchy structure, etc. are essential, yet not well understood, especially for global names. Often names are disorganized, ad-hoc and naming conventions nonexistent. With feedback from the scientists, my first published paper [3] describes a name translation framework that converts existing dataset names into hierarchical, human-readable names. The behavior of a translator is expressed as a configuration file comprising a list of ordered name components along with instructions for retrieving the values from the directory structure, filename, file content, or user-defined configuration. Communities can translate and organize existing names using the translator.

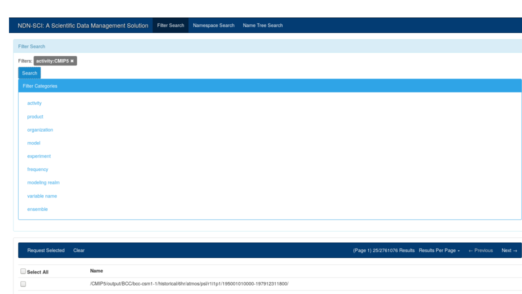

Fig. 2. NDN-SCI UI: A sample search performed on climate data

2.2 Names in the network

HTTP/FTP over TCP/IP is the de-facto model for content distribution in the current Internet. However, HTTP is often tied to the filesystem structure, which makes it non-portable. Moreover, scripts and other tools in existence need to make assumptions about the structure and location of the data. Second, TCP/IP is end-to-end. In order to retrieve a piece of content, a client must find a host that has the data and establish a connection to it before a transfer can begin. This is a fundamental mismatch between the applications and the protocol leading to increased complexities.

Named Data Networking (NDN) is a new Internet architecture where content is addressed directly rather than through an end host. NDN is an instance of Information-Centric Networking (ICN), an area that is receiving significant interest in the networking community and the funding agencies. In NDN, a consumer directly expresses an "Interest" to the network. The Interest carries the requested content name inside it. The network routes the Interest based on the name towards the producer. Once content is located, the host returns the content along the same path. NDN pushes some of the functionality currently implemented at higher layers to the network layer. At first, this might seem as increasing network complexity, but these features are more effectively implemented at the network layer. Take for example the selection of the best server out of a pool of available servers. Applications either have to create complex monitoring protocols for a highly dynamic environment, or run experiments to dynamically determine the best server (a real such example is the server selection in Netflix). Neither is necessary for NDN, which is aware of all feasible paths and maintains state information about each of them at the strategy layer.

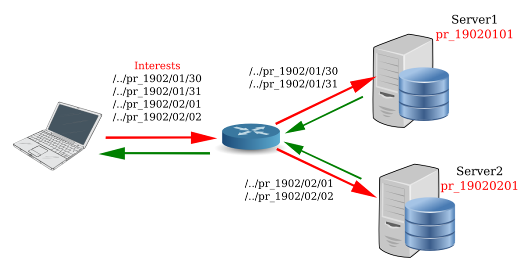

Fig. 3. Example NDN communication using data names. Server1 announces a prefix "/pr_1902/01". NDN routes all Interests with that prefix to server1.

Since NDN operates on content names, we can simply take the names from our translator and use them for publishing and retrieving content. Using NDN for data distribution eliminates the need for tracking the hosts and maintaining connections. Besides, requests for popular content are automatically served from network caches and do not overwhelm the publishers.

2.3 Distributed Publication

Another common problem among the scientific communities is distributed data publication. Currently, data publication is mostly centralized and accomplished using a few hosts that act as trusted publishers.

In NDN, all data is digitally signed and therefore publicly verifiable. A distributed publishing model is easier to create when all data is publicly verifiable. For my work, I found scientific projects are often organized in a hierarchical fashion. Various institutions participate in a larger project and publish datasets under a common organizational name. For example, data from CERN can be published under a common prefix, e.g., "HTTP://⟨Hostname⟩/CERN/⟨InstituteName⟩".

With NDN, several simplifications are possible. We can remove the host part of the name; now same data can be published from several places without being bound to the publisher location. I could also simplify the current data publication model. In my model, each data publisher has a digital key delegated by the project that they use for signing the data they publish. In my model, data name and the name of the key signing the data must be under the same prefix. For example, data named "/CERN/data" must be signed by a key "/CERN/somekey". A paper I published in 2015 [1] shows how such namespaces, keys, and trust mechanisms can work together to create a secure but distributed data publication framework.

2.4 Finding Data

Another acute problem is organizing, updating datasets so that they are easy to find. Currently, communities maintain data catalogs with a list of URLs and some metadata, helping users to perform keyword search and retrieval. We noticed several problems with this approach; names are bound to the data location using URLs. If a host goes down, data becomes unreachable. Keeping multiple copies of data requires recording and updating multiple URLs in the catalog.

With NDN, data names are location transparent and keeping just the name in the catalog is sufficient. NDN can route the requests for data to the nearest copy without involving the host location. Even with NDN, the catalogs are a single point of failure. Since NDN catalogs only record the names and are lightweight, keeping multiple synchronized copies of the catalog is relatively lightweight. We use a number of such distributed but synchronized catalogs on our testbed. The catalogs act as the back-end for the data management framework on the testbed.

2.5 Retrieving data

Currently, scientific data must be downloaded from trusted hosts, often located in another country or continent. Even when multiple replicas are present, TCP/IP cannot use them in parallel, and the network has no role in directing requests to the nearest replica. These make data retrieval slow and susceptible to failure. An NDN-based retrieval protocol can download data from multiple sources and at the same time, choose the most optimal servers. NDN can also utilize cached copies reducing both download time and load on the server. In my work submitted to ICN 2017[4] , I have described, implemented, and evaluated a nearest-replica retrieval strategy.

2.6 Quantifying the improvements

In a quantitative study [4] using real scientific data access log, I explored the improvements NDN can make in scientific data distribution. In this paper, I presented the first trace-driven study that investigates NDN in the context of a real scientific data management workflow. First, I analyzed a three-year climate data server log and characterized data access patterns. Using an approximated topology derived from the log, I replayed the requests in real-time over an NDN simulator to evaluate how NDN improves traffic flows through aggregation, caching, and network strategy. My simulations showed NDN could dramatically improve data distribution, in some cases reducing the server load by 95% and at the same time, reducing the client latency by orders of magnitude.

3 RESEARCH AGENDA

Over the past year, while continuing to improve the protocols and tools I have designed so far, I have started to expand the scope of my studies. There is a significant interest in addressing the challenge of scientific data management both from the scientific communities and the funding agencies. So far, my work has been part of three NSF grants, and I plan to submit additional proposals shortly. I hope to utilize these interests to support my future research. Below I describe my short and long-term research goals including publications and grants I plan to submit.

3.1 Security and User authentication

The last missing part of my prototype framework [5] is security and user authentication. My short-term goal is to investigate and implement data-centric integrity, authenticity, and user-authentication for all scientific data as well as metadata. I am currently co-authoring a proposal that explores data-centric security for scientific data which we plan to submit NSF.

Data security is immensely important in scientific communities but is either nonexistent or an afterthought in most science data management systems. Since scientific findings often have far-reaching impacts, it is imperative that the raw, as well as derivative data, is secure and publicly verifiable. User authentication is also important for several reasons; first, data often need to be analyzed and curated before they are made available to the world. During this time, a mechanism for selective access is required. Authentication is also required for statistics generation and accounting purpose. Currently, the authentication mechanisms are complex and commonly recognized as a huge pain point within the communities. A data-centric approach has the potential to these problems.

3.2 Finding the common threads using more use cases

Since my research focuses on the commonalities among scientific data management communities, I plan to collaborate with more diverse groups and learn about their data management problems. This will include the communities I have working with as well as new communities. Collaborating with diverse groups has the potential to provide unique perspectives into data management problems.

So far, I have explored a limited number of workflows and their data access patterns. I plan to find more diverse usage data that will provide better insight and point out problems with the current approaches. Diverse access logs are also required for deciding which in-network strategy will be most suitable for a workflow.

3.3 Deploy and study data management framework with real users

Having created, deployed, and tested with a limited number of scientists, I plan to deploy the NDN based data management framework side-by-side with an existing tool, e.g., ESGF, a tool for distributing climate data. This deployment will serve several distinct purposes; first, this deployment will test how well NDN based protocols can handle the immense pressure of large data management. Second, the study will provide a baseline for NDN's performance. Finally, it will help me compare NDN based framework's performance against contemporary tools.

While communication over pure NDN is presently possible without the help of IP, NDN is still a research protocol and therefore, present devices and software stacks do not yet widely support the new paradigm. I am currently working on a publication that outlines how we can overcome the deployment problem by using an NDN/IP gateway that works as a proxy between the IP and the NDN world.

3.4 Improving and interfacing with contemporary tools

While my study outlined above will happen over a longer arc of time, I believe that the findings will be immediately useful for contemporary tools and workflows. For example, in one of my studies, I found that requests for scientific datasets are highly localized and deploying small caches at the edge of the network can dramatically reduce the server load. Such findings are agnostic of the underlying protocols and can be immediately used; I plan to incorporate my findings into existing data management tools and workflows.

Besides, I plan to explore how we can integrate future concepts with current tools. Currently, I have a publication under preparation that shows such an example; in this work, I explore how we can interface NDN with a current tool, OSCARS, for creating on-demand end-to-end reserved network paths that will speed up data delivery.

The integration with contemporary tools is a two-way path. Often, concepts from current and proven tools need to be ported into NDN. In one such work, I have ported traceroute [6] into NDN for troubleshooting connectivity and data availability problems.

4 CONCLUSION

My work is highly interdisciplinary; my research uses Computer Science and Networking concepts to solve scientific data management problems. I have collaborated with scientists from computer science, climate science, high energy particle physics, genomics, and others to understand better the data management problems they face. I plan to continue my existing collaborations while fostering new ones; my goal is to create a flexible yet advanced framework that will reduce the data management burden and help to advance scientific frontiers.

REFERENCES

[1] Chengyu Fan, Susmit Shannigrahi, Steve DiBenedetto, Catherine Olschanowsky, Christos Papadopoulos, and Harvey Newman. Managing scientific data with named data networking. In *Proceedings of the Fifth International Workshop on Network-Aware Data Management*, page 1. ACM, 2015.

[2] Susmit Shannigrahi, Christos Papadopoulos, Edmund Yeh, Harvey Newman, Artur Jerzy Barczyk, Ran Liu, Alex Sim, Azher Mughal, Inder Monga, Jean-Roch Vlimant, et al. Named data networking in climate research and hep applications. In *Journal of Physics: Conference Series*, volume 664, page 052033. IOP Publishing, 2015.

[3] Catherine Olschanowsky, Susmit Shannigrahi, and Christos Papadopoulos. Supporting climate research using named data networking. In *Local & Metropolitan Area Networks (LANMAN), 2014 IEEE 20th International Workshop on*, pages 1–6. IEEE, 2014.

[4] Susmit Shannigrahi, Chengyu Fan, and Christos Papadopoulos. Request aggregation, caching, and forwarding strategies for improving large climate data distribution with ndn: A case study. In *Proceedings of the 4th ACM Conference on Information-Centric Networking*, ICN '17, pages 54–65, New York, NY, USA, 2017. ACM.

[5] NDN-SCI, https://github.com/named-data/ndn-atmos.

[6] Susmit Shannigrahi, Daniel Massey, and Christos Papadopoulos. Traceroute for named data networking. Technical report, Colorado State University, 2013.