Exploring and Strengthening US-Brazil Collaborations in Future Internet Research

Project Report

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1. Executive Summary

The current Internet architecture will experience substantial changes in the near future to incorporate innovative applications and new computing paradigms with growing demand on networks for performance, security, and ubiquity. There have been important advances in the Future Internet research, both in US and across the globe, which aims at revolutionizing the existing Internet architecture to accommodate future applications of content distribution and service delivery. Prominent examples include Global Environment for Network Innovations (GENI) and US Ignite. These activities in U.S. coincide with several ongoing Future Internet research initiatives in Brazil. One such example is FIBRE, or Future Internet testbeds/experimentation between Brazil and Europe for creating a federated large-scale Future Internet experimental facility between Brazil and the European Union.

There is a clear desire from both Brazilian and U.S. researchers to establish more concrete collaborations on Future Internet research. Already there have been grass-root efforts on individual collaborations between the Brazilian and US researchers. However, there is a lack of long-term direction, large-scale coordination and oversight, and programmatic guidance and assistance to deepen the impact of these collaborative efforts.

The SwitchOn project has been funded by the U.S. National Science Foundation to explore potential collaborations between the U.S. and Brazil on Future Internet research. An important part of this project is to organize two workshops to bring together U.S. and Brazilian Future Internet researchers for exploring existing and future collaboration opportunities. The first SwitchOn workshop took place in January 2015 in Miami, Florida, USA. Approximately fifty attendees participated in the two-day event, which includes keynote speeches, presentations on various subjects, breakout sessions, panel discussions, as well as group social events. More than one third of the participants came from Brazil, which demonstrated a tremendous interest in the collaborations.

This report captures the important discussions and findings from this workshop. In particular, the report provides a summary of the discussions on the major challenges in Future Internet research, as well as important research problems, which have been identified by both U.S. and Brazilian researchers. The report contains a summary of the important discussion topics on Future Internet research collaborations between the two countries. In particular, the report highlights some of the important findings from the workshop. Recommendations are provided for continued efforts for strategically strengthening and expanding existing and future research collaborations.

2. Introduction

2.1 Internet is changing

There are an increasing number of sensors and mobile devices connecting to the Internet. They depend on efficient Internet content delivery as well as security and reliability. The nature of data carried over the Internet is also changing. For example, there has recently been tremendous growth in video streaming services. Similarly, there is also significant development in cyber-physical systems that depend on Internet, such as Internet of Things (IoT), Smart Grids, and Smart Cities.

There is a demand on sustained quality of network experience everywhere. Responding to such demand has inevitably altered and will continuously alter the landscape of Internet. For example, Content Data Networks (CDNs), such as Netflix, Google and others, have changed the structure of the Internet. The same can be said about the Internet exchanges and peering continuously flattening the Internet. In addition, the rise of clouds and cloud services is also placing significant demand on the network interconnectivity.

One can easily identify the technological trend in merging big data analytics, high-performance computing, and high capacity networking. There are also trends related to the social, political, and economical aspects. Examples include online social networking, online advertising, crowd sourcing, and the proliferation of mobile applications. The network also needs to respond to emerging issues, such as e-bullying, and cyber tracking and stalking. There will surely be growing tensions between security and privacy. There is also ample evidence of growing cyber attacks, some of which can also be elevated to state-sponsored cyber terrorism and cyber warfare.

2.2 Challenges and issues for global network research

The research community has been challenged to design a secure full-functioning Internet that meets the needs of the 21st century, with bold architecture research, and fostering innovative systems research. Important issues include:

- Deep Understanding of Current Internet and Design Tradeoffs
- Network Designs with Full “Internet” Functionality
- Research Community Focusing on Innovative, Big Systems/Architecture Design & Implementation
- Integration of Big Systems and Security

To addressing these trends, the network research community is taking on several research directions and exploring new opportunities enabled in some key areas, such as seamless machine virtualization, new types of cloud services (also known as XaaS, such as infrastructure-as-a-service, IaaS, platform-as-a-service, PaaS, software-as-a-service, SaaS, monitoring-as-a-service, MaaS, and communication-as-a-service, CaaS), OpenFlow and Software-Defined Networking (SDN), Network Function Virtualization (NFV), and optical devices and wireless technologies (such as MIMO and Pico Cells).

In response to the research challenges and impending issues, several nations have designed and built national-scale experimentation platforms for studying future Internet at scale. For example, in the U.S., the National Science Foundation has taken several initiations. For example, the Global Environment for Network Innovations (GENI) is an initiative for building a collaborative and exploratory network experimentation platform for studying future networks. Follow-up efforts include various cyber-infrastructure design, development, and build-out projects, such as GENI racks, the campus cyber-infrastructure (CC-NIE, CC*IIE, CC*DNI) programs, and the recent mid-scale cloud-computing testbed development projects called NSFCloud. Another program definitely worth mentioning is the US Ignite program, which aims at fostering the development of next-generation gigabit network applications in important areas of education and workplace, energy, health, public safety, transportation, and advanced manufacturing.

Similar efforts have also sprung up across the globe, including, for example, the Future Internet Research and Experimentation (FIRE) in the European Union, and the New Generation Network Testbed JGN-X in Japan. These activities also coincide with several ongoing Future Internet research initiatives in Brazil. One such example is FIBRE, or Future Internet testbeds/experimentation between BRazil and Europe, which creates a federated large-scale Future Internet experimental facility between Brazil and the European Union.

Cross-country collaborations have also taken place. For example, U.S. NSF and the Japan National Institute of Information and Communications Technology (NICT) provided the Japan-U.S. Network Opportunity (JUNO) program dedicated for enhancing collaborations in next-generation networking technologies between the two countries. There have been similar programs between U.S. and EU. The EU and Brazil also created a federated large-scale Future Internet experimental facility, called FIBRE. The main goal of the FIBRE project is to design, implement, and validate a shared Future Internet research facility, supporting the joint experimentation of European and Brazilian researchers. There seems to be a missing link between U.S. and Brazil for future Internet collaborations.

3. Goals and Objectives of the SwitchON workshops

The SwitchOn project has been funded by the U.S. National Science Foundation to explore potential collaborations between the U.S. and Brazil on Future Internet research. An important part of this project is to organize two workshops to bring together U.S. and Brazilian Future Internet researchers for exploring existing and future collaboration opportunities.

Specific objectives of these workshops are:

1. Help strengthen and expand existing and future collaborative research projects in Future Internet research between the U.S. and Brazil.
2. Explore mechanisms to stimulate participation of U.S. researchers (faculty and students) in conducting Future Internet research in collaboration with Brazilian research partners.
3. Search for a coordinated strategy for enkindling and strengthening high-impact research collaborative activities between the US and Brazil.
4. Explore and identify common interests in research and development in Future Internet between U.S. and Brazil to prepare for future large-scale long-term collaborative research programs between the two countries.

4. Activities of the 1st Miami Workshops

The first SwitchOn workshop took place in January 2015 in Miami, Florida, USA. Approximately fifty attendees participated in the event, which includes keynote speeches, presentations on various subjects, breakout sessions, panel discussions, as well as group social events. More than one third of the participants came from Brazil, which demonstrated a tremendous interest in the collaborations.

To achieve our goals and objectives, the first SwitchOn workshop consisted of the following activities spread over 1.5 days:

Day One:

(1) Keynotes;
(2) PICO: Introduction by each participant;
(3) Breakouts;
(4) Reports from the breakouts with Q&A; and
(5) Panel: Funding Opportunities.

Day Two:

(1) Infrastructure Talks;
(2) Future of USA-Brazil Research Collaborations.

The remainder of section 4 describes each of the activities in more detail. For each activity, its objectives and outcomes will be described in the follow-up sections.

4.1 Keynotes

There were three keynote speeches. The first keynote speech is given by Dr. Darleen Fisher from NSF. The title of the talk is **Future (International) Internet Research**. In her talk, Dr. Fisher explored possible ways to discover and explore potential new research topics. She used the Future Internet Architecture (FIA) projects, which pursued the grand challenge of designing new secure Internets that meet the needs of the 21st century, as case studies of innovative collaborative research and drew on 25 years of networking research program management. Research ideas can come from emerging social, technical and networking trends and research enablers, such as new technologies and resources, as well as from demands and requirements of new networking environments. Dr. Fisher suggested ways to explore a research problem that makes for successful research proposals.

The second keynote speech is by Dr. Antônio Jorge Gomes Abelém, from UFPA in Brazil. The title of the talk is **Brazilian Testbed for Future Internet (FIBRE) and the Research Opportunities Between The US and Brazil.** The talk provided information on the FIBRE project. Recently a group of R&E Brazilian organizations designed and implemented a large-scale Future Internet (FI) research facility in a collaboration project with Europe. The FIBRE (Future Internet Brazilian Research Environment) testbed is currently composed by a federation of 10 local testbeds (a.k.a. experimental islands) and combines heterogeneous physical resources and different technologies, including OpenFlow, wireless and optical communications. The FIBRE testbed promotes involvement of and technology transfer to the industrial sector, to prepare for Future Internet needs, especially involving OpenFlow and SDN approaches. The rich research and experimentation realistic environment creates a lot of opportunities of collaboration in Future Internet area. Dr. Abelém highlighted some research opportunities between the US and Brazil in this theme, which could enable and encourage closer and more extensive bilateral cooperation in FI research and experimentation, as well as strengthening the participation of both communities in the increasingly global collaborations in this important area of network research and development.

The third keynote speech is by Dr. Chip Elliott for BBN Technologies. Dr. Elliott is the Principal Investigator for the GENI Project and is current GENI Futures Director. His talk is titled **Looking Beyond the Internet**. In the talk, Dr. Ellott mentioned that major transformation of Internet has begun. There are converging trends (such as multi-tenant datacenters, software defined networks, network function virtualization, distributed data centers). The driving force behind the transformation is a radical change in “router” economics, which will lead to a more general “software defined infrastructure” in the near future. SDN is just an opening act. A major transformation of the Internet has begun. We can now catch glimpses of what lies beyond. Best of all, we can get there by a series of step-by-step actions.

4.2 Breakouts

We organized three breakout sessions each on a different set of topics:

1. Future networks design and applications, led by Dr. Rodrigo Fonseca (Brown U) and Dr. Christian Rothenberg (UNICAMP). The topics include network protocols, routing, management, modeling, wireless networking.
2. Clouds and data center networking, led by Dr. Kate Keahey (U Chicago) and Dr. Carlos Kamienski (UFABC). The topics include cloud computing, cloud security, cloud testbeds, and cloud applications.
3. Cyberinfrastructure design and development, led by Dr. Russell Clark (GaTech) and Dr. Antônio Abelém (UFPA). The topics include network testbeds (GENI, FIBRE, CCNIE, etc.), deployment, federation, management, and measurement.

4.3 Panel: Funding Opportunities

This panel explored the funding opportunities to develop international research collaboration between the U.S. and Brazil. The panel members are expected to impart knowledge to guide the organizers and the researchers on the kinds of funding that could be useful to develop an international collaboration between the U.S. and Brazil. Existing funding programs at the NSF and in Brazil's funding agencies that could be leveraged were discussed. The panel also explored the requirements to support creating a joint program of future Internet research collaboration between the NSF and Brazil's funding agencies.

The panelists include: Bryan Lyles (US NSF), Luis Lopez (ANSP), Michael Stanton (RNP) and Dorgival Guedes (UFMG).

4.4 Infrastructure Talks

The goal of the infrastructure session is to inform the researchers of the network infrastructure that's available for conducting "at-scale" network experiments, and to report on the milestones that have been achieved over the past 10 years.

Presentations have been organized to focus on evolution of different levels of the end-to-end network infrastructure: (1) The Campus, Exchange Points and Regional CI; (2) National Research and Education Networks; (3) State Networks; (4) Network technologies to enable future internet research; and (5) Linking all of these levels together into a coherent coordinated end-to-end network infrastructure.

The goal of this session is to stimulate researchers' interest to propose collaborative research, pairing USA and Brazilian researchers and students to work on challenging problems; to conduct at-scale end-to-end experimentation to explore solutions to these problems; and to foster the formation of meaningful long-lasting relationships between US-Brazil researchers and students, as they trial and prototype their work.

We arranged six talks:

- "NRENs USA", by Inder Monga, ESnet Chief Technologiest, Lawrence Berkeley National Laboratory.
- "Optical infrastructure to support R&E networking in Brazil: recent developments and future plans", by Michael Stanton, RNP.
- "ANSP, An academic network at Sao Paulo", by Luis F. Lopez, Center for Advanced Network Applications, Discipline of Medical Informatics Medical School, University of São Paulo.
- "Brocade SDN/OpenFlow", by Norival Figueira, Brocade.
- "Company Overview and Case Studies", by Enrique Lozoya, Padtec.
- "SDN@AmLight: How could it help your research?", by Jeronimo Bezerra, Florida International University.

4.5 Future of USA-Brazil Research Collaborations

We organized six talks on the existing and future US-Brazil collaborations. These talks were expected to provide an angle from individual research projects to look into the issues and challenges identified by the breakout discussions. The presenters of the talks are:

1. Christian Esteve Rothenberg (Unicamp)
2. Tereza Cristina Melo de Brito Carvalho (USP)
3. Malathi Veeraraghavan (UVA)
4. Flávio de Oliveira Silva (UFU)

5. Alessandro Anzaloni (ITA)
6. Glenn Ricart (US Ignite)

5. Breakouts

5.1 Themes and guidelines

We organized three breakout sessions each on a different set of topics:

1. Future networks design and applications, led by Dr. Rodrigo Fonseca (Brown U) and Dr. Christian Rothenberg (UNICAMP). The topics include network protocols, routing, management, modeling, wireless networking.
2. Clouds and data center networking, led by Dr. Kate Keahey (U Chicago) and Dr. Carlos Kamienski (UFABC). The topics include cloud computing, cloud security, cloud testbeds, and cloud applications.
3. Cyberinfrastructure design and development, led by Dr. Russell Clark (GaTech) and Dr. Antônio Abelém (UFPA). The topics include network testbeds (GENI, FIBRE, CCNIE, etc.), deployment, federation, management, and measurement.

Each breakout session has been attended by about the same number of participants. There are four high-level objectives for the breakout sessions:

1. Identify strategic research topics and themes in different areas
2. Identify research opportunities in these areas for both countries
3. Identify existing and future collaborations and collaborators
4. Identify the needs for large-scale international collaborations
5.

5.2 Charge to participants

Corresponding to the objectives mentioned above, the breakout sessions are charged to address the following four questions, respectively. Each breakout session can also expand on these questions.

1. What are the challenges and important research issues in this area? We focus on the broad and general research questions and landscape. What are the new phenomena, new research areas, new problems, new concepts that will set the trend? The goal is to identify a list of research themes and strategic topics in the area.
2. What are the existing major projects and programs in the area (in US and in Brazil, respectively)? What are the important issues addressed by the projects/programs? Are there complement projects/programs in the other country? What are remaining research challenges and issues (when compared with those listed in the previous question)? The goal is to identify potential research opportunities in the area for both countries.
3. Where are the research collaborations? What are the existing collaborations (joint research projects) between US and Brazil? What are the potential collaborations (and common interests) in addressing the challenges and opportunities discussed in the previous two questions? The goal is to identify existing and future collaborations and collaborators in the area.
4. What are issues, demands, and potentials for large-scale international collaborations? What are the barriers and limitations (e.g., cyberinfrastructure, technical, social)? What are the mechanisms and methods suggested for breaking down barriers? The goal is to identify the need for future large-scale international collaborations in the area.

5.3 A summary of discussions

The participants of the workshop had extensive discussions on several important issues related to various collaborative Future Internet research areas. We hereby summarize the discussions and organize them into three main areas: cloud computing and data center networking, future network design and applications, and cyber-infrastructure. After that, we focus on important questions related to existing and future collaborations between Brazil and U.S.

5.3.1 Cloud computing and data center networking

5.3.1.1 Challenges and important research issues

The participants identified several important research challenges and issues in the cloud computing research area. One important challenge for cloud computing is security. With the newly adopted models and policies on clouds, there are serious concerns about how to deal with the security and privacy issues. How to ensure the data be kept private in the cloud? (What does privacy mean in the cloud environment?) How to ensure the compliance in different types of clouds, whether they are private or public clouds? In a multi-tenant environment, these problems become more acute.

One interesting area is related to the proper abstraction for building cloud services. How to define the abstraction layers for supporting various virtual machines and virtual networks? How to federate the clouds? How to ensure interoperability? There are significant research issues on coordination, orchestrating of different clouds.

Another interesting research area is on how to build systems that can combine and connect sensors, computing resources, data storage facilities using programmable networks. Such infrastructure would allow one to collect data from different data sources, process, compress and combine the heterogeneous datasets. Similarly, how to conduct high-performance computing (HPC) on clouds? This may require design of lightweight hypervisors with built-in reliability, low noise, little overhead, and fast interconnect. In the HPC domain, few concern about virtualization. Cloud in this case would mean on-demand availability. There are two types of clouds, for business users and for scientific computing. As a result, the requirements are different. The question is whether the same cloud could provide both services?

In the cloud management area, one important aspect is related to optimization and programmability. It is more difficult for multi-tenant systems or software-defined systems, where management must consider both data plane and control plane. For example, many aspects design solutions need to overlap to achieve efficient power management.

5.3.1.2 Existing projects/programs in US and Brazil

There have been major research investments in the U.S. on cloud computing research. NSF has been funding research projects in cloud computing areas. In addition, most recently NSF started a mid-scale cloud-computing testbed development initiative, called NSFCloud. The Chameleon and CloudLab projects are funded under this initiative in 2014. The Open Science Data Cloud (OSDC) NSF-sponsored Partnerships for International Research and Education (PIRE) program provides a mechanism for U.S. students and early career researchers to collaborate on data science research with researchers in United Kingdom, Namibia, the Netherlands, Japan, China, Brazil, and other countries.

In Brazil, there are similar projects at a smaller scale, including, for example, the RNP Cloud Initiative, Cloud@USP, and the UNESP HPC project. The latter offers computing resources for schools in state of Sao Paulo. Brazil and Europe have established partnership and collaborations in the cloud computing area. They have coordinated call for proposals in the cloud research areas. The first call (five projects) was focused on secure future cloud; the second call (four projects) was focused on scientific cloud. Currently, the third call is in place, which is more focused on security aspects.

5.3.2 Future network design and applications

5.3.2.1 Challenges and important research issues

The participants identified several main research challenges in future network architecture design and development. First and foremost, there are issues related to network trouble-shooting. There is contention on the visibility of network state at different layers and across domains. What information can be visible and what needs to be hidden? There is an OAM-related gap when moving towards operating a Software-Defined Network (SDN). The adoption of the SDN framework presents challenges to interoperate with other network technologies, such as MPLS. There are also significant issues related to fault management due to the lack of models.

The complexity involved in the SDN architecture is also an area of future research. How to build abstractions to manage its complexity? How to express the complicated end-to-end policies and cross-domain policies? How to apply security expression and enforcement? The distributed control in networks is much less understood.

Another important issue is providing infrastructure support for research and development of new network architectures. How to provide a generic slicing capabilities in multiple dimensions, such as mobility, security, naming, routing, etc., so as to support various technologies, including TCP/IP, XIA, MobilityFirst, NDN, ETArch? How to enable federated and distributed control? How to define the boundaries, such as inter-domain or pervasive sliced architectures? How to allow communication between the slices, in terms of information sharing among the slices, and the exchange of the “boundary conditions”?

Economics in network is also an area of intense research interest. How will it impact new network designs? How to define the “contest” or “market-like” dynamics? In the wireless domain, one of the important research issues is to find the middle point between the fully meshed and fully centralized mechanisms. What would happen if one could roam between the providers’ infrastructure networks in real time?

5.3.2.2 Existing projects/programs in US and Brazil

In the U.S., NSF has a fairly long history (ten years) of supporting future network design and applications. It can be divided into three phases: 1) the FIND program, which focused on the individual components of network design; 2) the FIA program, which looked into the future Internet architectures; and 3) the FIA-NP program, which focused on system building and application to environments. These programs provided a deep understanding of current Internet and design tradeoffs. Other programs, such as Smart Grid, Cyber-Physical Systems, all have components related to future network design and applications.

In Brazil, the FIBRE project is a collaborative effort between EU and Brazil. The main goal is to create a common space between the EU and Brazil for Future Internet experimental research into network infrastructure and distributed applications, by building and operating a federated EU-Brazil Future Internet experimental facility. The project designed, implemented and validated a shared Future Internet research facility between Brazil and Europe, supporting the joint Future Internet experimentation of European and Brazilian researchers. An experimental Brazilian infrastructure has been designed and deployed as a result. FIBRE has been shown as an important project promoting international collaboration in the Future Internet research. It has demonstrated the local capacity to collaborate with leading researchers in this important area. It provided local experimental facilities for validating and demonstrating new research projects. It provided the opportunity for connecting to researchers from other countries. It promoted the involvement and technology transfer of the industrial sectors, and the preparation for the Future Internet needs, especially involving the OpenFlow and SDN approaches.

Besides FIBRE, there are multiple punctual, smaller projects. For example, The Centre of Research and Development in Information and Communication Technologies (CTIC) program is intended to develop the national skills for innovation in information and communication technologies (ICT). Created by the Federal government and incubated at RNP, the program has focused its actions on the following matters: virtualization of networks and services, cloud computing and smart cities. INCT is a long-term multi-institution project funded by CNPq.

5.3.3 Cyber-infrastructure

5.3.3.1 Challenges and important research issues

The cyber-infrastructure area focuses on designing and developing testbeds for new technologies. The first main challenge identified by the participants is the deployment of testbeds. Another challenge is to make the testbeds as a service, which can allow automatic plug and play for the experimenters. How to improve manageability and provide more intuitive, easy-to-use interface to attract end users and researchers to interface with the testbeds? It is also important to support interoperability and federation of various testbeds.

A separate but equally important issue is on the sustainability and evolution of testbeds. How to find a model for sustaining the operation of current research testbeds once the funding runs out? How to plan for the testbeds' lifecycle, ensuring survival through multiple iterations of technology refresh?

A more general question is how to build a generic testbed for problems that have not being articulated or how to build a testbed for specific purposes?

5.3.3.2 Existing projects/programs in US and Brazil

In U.S., in addition to the GENI and NSFCloud programs mentioned earlier, NSF has also funded other cyber-infrastructure programs, such as the Campus Cyberinfrastructure - Data, Networking, and Innovation (CC*DNI) program. This program is a continuation of the previous two programs: the Campus Cyberinfrastructure - Network Infrastructure and Engineering Program (CC-NIE) and the Campus Cyberinfrastructure - Infrastructure, Innovation and Engineering Program (CC*IIE). The programs invest in campus-level data and networking infrastructure and integration activities tied to achieving higher levels of performance, reliability and predictability for science applications and distributed research projects. The U.S. Department of Energy (DOE) also funded ESnet (since 2009), which is a dedicated high-performance science network connecting more than 40 DOE research sites, including the entire National Laboratory system, its supercomputing facilities, and its major scientific instruments. ESnet also connects to 140 research and commercial networks, permitting DOE-funded scientists to productively collaborate with partners around the world.

FIBRE, mentioned earlier, is a Brazilian experimental infrastructure of the future Internet research for researchers and advanced users. It has been designed and deployed. The infrastructure is composed of ten heterogeneous islands with wire and wireless network infrastructures interconnected with high-capacity links. There are three control frameworks (OMF, OCF and ProtoGENI) managing the infrastructure with a single portal that exposes the federated virtual resources of the ten islands to the researchers or advanced users.

6. Analysis of the Breakout Reports

As described in the previous section, there were three breakout groups for the following three areas: (1) Future Internet Research; (2) Cloud Computing and Data Center Networks; and (3) Cyberinfrastructure. The reports from each breakout provided the data that was then used for this section and section 7.

Analysis was performed on the data using a grounded theory methodology (Ref) to identify concepts and themes, and to organize the data. Grounded theory is useful when working with data that is fragmented (Ref). Much of the data was in the form of concepts and phrases, documented as bullets and sentence fragments. The objective of the analysis was to interpret this data and to construct complete coherent statements in each category.

To organize the data, we started with the research questions given to the breakout groups. The research questions served as categories for the data. Section 6.1 contains the analysis of the first question. The first research question inquired about challenges and important research issues. Two sub-categories were created to further organize the data. These two sub-categories were "Challenge" and "Response to the Challenge". The Challenge sub-category consists of either a statement in the form of a claim, a theme, or a question for further clarification. By organizing the data in this fashion, we created a structure that consists of a 3-tuple: (Concept or Theme, Challenge, Response to Challenge). For several concepts or themes, responses to challenges were often not provided. When this happened, a response was inserted in the form of: Research is needed to understand how to …

The data from the Future Internet Research breakout is organized in the 3-tuple format in section 6.1.1. The data for the Cloud and Data Center Networks breakout is organized in section 6.1.2. Finally, for the Cyberinfrastructure breakout, the data is organized in section 6.1.3.

Section 6.2 contains the analysis of the second question: "What are the existing major projects and programs in the USA and Brazil?" The data from each breakout was very similar. As a result, the analysis and interpretation from all three breakouts are collectively described in section 6.2.

Section 6.3 contains the analysis of the third question: "Where are the research collaborations?" The data is again organized in the 3-tuple format of (Concept or Theme, Challenge, Response to Challenge) that was used in section 6.1. Section 6.3.1 contains the analysis for FI Research breakout; section 6.3.2, contains the analysis for the Cloud and Data Center Networking breakout; and section 6.3.3 contains the analysis for the Cyberinfrastructure breakout.

Section 6.4 contains the analysis of the fourth question: "What are issues, demands, and potentials for international collaborations?" The 3-tuple format was used in this section as well.

6.1 What are the challenges and important research issues?

Data in response to the first question is organized in this section. The 3-tuple format, described in section 6, is used to organize the data.

6.1.1 Future Internet (FI) Research

Data from the FI Research breakout is organized in this section. Each Challenge and Response section is numbered. Each challenge contains a theme. Themes will be counted as well.

Theme 1: Troubleshooting, Fault Management:
Challenge (1): Troubleshooting of Future Internet environments is complex, for the following reasons:

- There is a lack of visibility in different layers and across multiple domains.
- There is an absence of tools for troubleshooting through multiple network layers and monitoring state information across multiple network domains. This is impacting network operators ability to support SLAs.

- There are gaps in OAM processes and procedures in the operations of SDN networks. For example, compared to MPLS, operators are lost with SDN.
- There is a lack of trust in SDN applications.

Response (1): Troubleshooting of Future Internet environments is complex:

- Increase visibility of objects in multiple layers of SDN environments.
- Improve ease of operations and management in an SDN environment.

Theme 2: Modeling complexity of FI and SDN networks):
Challenge (2): There is a lack of models to guide understanding of FI and SDN network behaviors.

- There is a lack of understanding about SDN.
    - Is SDN a new network architecture?
    - How does SDN relate to architectural proposals, such as Named Data Networking (NDN)?
- Lacking models to manage the complexity in SDN architectures
- Lacking models for policy expression (end-to-end);
- Lacking models for security expression (end-to-end) and enforcement;
- Lacking models for cross-domain policy expression (SDX)
- Difficult to know whom to blame.
- Boundaries of SDN are not clear:
    - Inter-domain vs pervasive sliced architecture;
    - Lack of taxonomy for expressing boundaries;
- Allowing communication between slices, sharing or not sharing information, boundary conditions, slice permeability;
- Boundaries of applications versus the network are not clear:
    - What objects belong to the application versus what belongs to the network?
    - What is the application in an SDN?
- How can applications be provisioned on demand, with optimal network configuration?

Response (2): Build Infrastructure to support new FI network architectures: (NFV-like, in spirit of Chip Elliot's talk):

- Slices (TCP/IP, XIA, MobilityFirst, NDN, ETArch...);
- Dependence on the nature of traffic (e.g. smart-grid) Low-latency / high-responsiveness;
- Chameleon-like model for networks ("cooking slices with different properties").
- Operations for NDN requires a rethinking ("ping content", "traceroute content").

Theme 3: Distributed control mechanisms in FI and SDN networks
Challenge (3): Distributed Control mechanisms in FI and SDN networks are less understood than decentralized control mechanisms.

- There is a lack of understanding about federated distributed control mechanisms.

Response (3): Distributed control mechanisms in FI and SDN networks

- Research is needed to increase understanding of:
    - Distributed control in networks;
    - Federated distributed control FI and SDN architectures.
- Network infrastructure is needed to support new network architectures, such as NFV objects.

Theme 4: Network programmability of FI and SDN networks
Challenge (4): Network programmability of FI and SDN networks is not well understood.

- There is a lack of understanding about network programmability.

Response (4): Network programmability of FI and SDN networks

- Research is needed to increase understanding of network programmability for FI and SDN research.

Theme 5: Effects of economics on FI network designs
Challenge (5): The effects of economics on FI network designs are not well understood.
- What is the impact of economics[1] on new FI network designs?
- For example, security needs to be thought of or considered from design.
- Context or market-like dynamics.

Response (5): Economics of FI network designs
- Research is needed to increase understanding of the effects of economics on FI network designs.

Theme 6: Wireless FI network designs
Challenge (6): Wireless FI network designs are not well understood.
- Middle-point between full mesh and full centralized;
- What if one could roam between any provider's infrastructure in real-time?
- LTE-advanced in white space (unreliable control channel).

Response (6): Wireless FI network designs:
- Dimensions of FI Research: Mobility, Security, Naming and Routing were four dimensions that were identified.

Summary: A total of 6 challenges and 6 themes were identified from the data of the FI research breakout.

6.1.2 Cloud and Data Center Networks

Data was grouped into more levels of categories for the cloud and data center networks breakout. Five themes were constructed to further partition the data. An additional level of categories was used in the Cloud Model theme. Each category will be counted, and each challenge-response pair will continue to be counted. Each category will be followed by its theme number, a dot, then a category number, all within parentheses. For example, Security for Clouds is theme (7). The first category in the Security for Clouds them is Lack of Models. The category number is represented at (7.1); therefore, 7 for the theme number, and 1 for the category number.

6.1.2.1 Theme (7): Security for Clouds

Category (7.1) Lack of Models
Challenge (7): There is a lack of models to guide understanding of security for Clouds.
- Cloud computing changes the security model.
- What new models have been developed or are needed to improve security for clouds?
- Misclassification of different models is an issue.
- What are classifications of different security models for clouds?

Response (7): Lack of Models
- Devise different attacks.
- Devise approaches to exploit security models.

Category (7.2) Security policies for clouds
Challenge (8): There is a lack of knowledge about security policies for clouds.
- How is security for clouds impacting policies? For example, policies on the campus.
- What is secure in the cloud as a result of policies?
- What is the impact of security policies on public versus private clouds?

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[1] In the context of this workshop, economics could also translate to funding levels

- What are the security requirements for public and private clouds?
- What are the differences in security for public versus private clouds?
- Public clouds are not engineered for HPC.
    - This is a critical issue if the answer is to have two divergent models.
        - Extremely high cost to support divergent model.
        - Challenge: how to design a model that could be good for both.

Response (8): Security Policies for clouds:
- Research is needed to understand how security policies are impacting public and private clouds, and other types of clouds.

Category (7.3) Compliance
Challenge (9): There is a lack of knowledge about compliance for clouds.
- How is compliance impacting security for the cloud? For example, HIPPA compliance.
- How to know/confirm if data or other objects in the cloud are compliant?

Response (9): Compliance:
- Research is needed to increase understanding of how compliance is impacting security for clouds.

Category (7.4): Privacy for Clouds:
Challenge (10): There is a lack of knowledge about privacy for clouds.
- What are the challenges and research issues on privacy for clouds?

Response (10): Privacy for Clouds
- Research is needed to increase understanding of privacy for clouds.

Category (7.5) Public versus Private Clouds
Challenge (11): There is a lack of understanding about the impact of security on public versus private clouds.
- Supporting more than one type of cloud has a high cost.
- What are the differences in Security for public versus private clouds?
- Public clouds are not engineered for HPC.
    - This is a critical issue if the answer is to have two divergent models.
    - There is an extremely high cost to support a divergent model.
- How to design a cloud model that could support both public clouds and HPC?
- What is the impact of security on public versus private clouds?
- What are the security requirements for public and private clouds?

Response (11): Public versus Private Clouds
- Research is needed to increase understanding of the differences between public and private clouds, and security implications for each one.

Category (7.6) Security changes for the Cloud
Challenge (12): There is a lack of knowledge about the impact of security changes on different types of clouds.
- How do security changes impact different types of Clouds?

Response (12): Security changes for the Cloud
- Infrastructure vs. Apps or Service Types.
- Research is needed to increase understanding of how security changes impact different types of clouds.

Category (7.7) Obfuscated computation for the cloud

Challenge (13): What are the challenges and research issues on obfuscated[2] computation for the cloud?

Response (13): Obfuscated computation for the cloud:

- Research is needed to increase understanding of obfuscated computing and its impact on security of clouds.

Category (7.8) Multi-tenancy

Challenge (14): Multi-tenancy is Infrastructure for the cloud that is the most difficult to secure. (Why is that?)

- What is the impact of multi-tenancy on the security of cloud computing?
- What are the challenges and research issues on multi-tenancy[3] of clouds?

Response (14): Multi-tenancy

- Research is needed to increase understanding of multi-tenancy and its impact to the security of clouds.

Summary: 8 challenges and 8 categories were constructed in the Security for Clouds theme.

6.1.2.2 Theme (8): Abstractions for the Cloud

Challenge (15): There is a lack of knowledge about abstractions for the Cloud

- Abstractions for the cloud deserve more attention.
- VMs, Vnets, Platform as a Service, etc were referred to as forms of abstractions.
- What does security look like in this space?

Response (15): Lack of knowledge about abstractions for the Cloud

- Develop frameworks to build your own infrastructure as a service.
- Research is needed to increase knowledge of abstractions for clouds.

Summary: 1 challenge was constructed in the Abstractions for the Cloud theme.

6.1.2.3 Theme (9): Federation of Clouds

Challenge (16): Federating clouds is a challenge and an important issue.

- It is unclear how to map [cloud components] on to different systems.

Response (16): Federating Clouds

- Clouds are just a means to provide resources.
- Research is needed to increase understanding of the challenges and issues of federating clouds.

Summary: 1 challenge was constructed in the federation of clouds theme.

6.1.2.4 Theme (10): Heterogeneous data in Clouds

Category (10.1) Data Processing Mechanisms:

Challenge (17): There is a lack of data processing mechanisms for heterogeneous data.

- Data processing mechanisms are needed to squeeze data, in particular, heterogeneous data sets.
- Data Correlation:
    - Data needs to be correlated.

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[2] Note: Literature refers to secure obfuscation as a re-encryption function to hide information in the cloud. The obfuscated program can be oursourced to a cloud server without leaking information about the computation task. Cheng, R., Zhang, F., "Obfuscation for multi-use re-encryption and its application in cloud computing", Journal Concurrency and Computation: Practice and Experience, v27, n8, June 2015. Online storages are an example of obfuscated computation for the cloud?

[3] Note: Multi-tenancy is also discussed later in the context of management of clouds.

    - Data processing mechanisms are needed for data correlation.
- There is a lack of standardization of data in the cloud. For example, medical data in the cloud does not match regulations in Europe.

Response (17): Data Processing Mechanisms

- Metadata is key in response to the challenges of data processing mechanisms for heterogeneous data in clouds.
- Science driver example: LHC has millions of sensors. In the wild they need to be calibrated to work together. Calibration was not built into the sensors by default.
- Sensors for biosciences appear to have calibration built in.
- A baseline is important.
- Science driver example: Seismology simulates earthquake data to determine what is changing.
- Science driver example: Astronomy: data correlation is needed to observe what has changed.
- Need to put heterogeneous data layers together.
- Research is needed to increase understanding of standardization of data in the cloud.
- Mining heterogeneous data:
    - Data feeds avaialble from multiple sources; eg., data streaming for detection of earthquakes with smartphones, fitbit, people instrumenting cities, drones for capturing data, etc.
    - Dynamic questions could then be asked in a particular space.
    - If data cannot be processed, then answers do not count.

Summary: 1 challenge and 1 category were constructed in the Heterogeneous data in Clouds theme.

6.1.2.5 Theme (11): Cloud Model

6.1.2.5.1 Science Drivers

Challenge (18): Ocean Science: Requests end-to-end QoS in multiple layers

- Real time is a few days, compared to earthquake science (seismology), where real time is in seconds.
- Need to do end-to-end QoS in all layers: networks, storage, computing.

Response (18): Ocean Science

- SDN can help to cope with this problem.
- Sensors+Clouds+SDN: Programmable CI:
    - build a system with sensors;
    - build a CI that could be programmed in different ways;
    - combination of programmable networks, end-to-end combinations of programmable networks, storages, computing.

Challenge (19): Climate Science: Communications bottleneck

- Climate application that needs more than 1000 cores.
- Problem: communication is the bottleneck, in particular, apps that have tight requirements, such as MPI apps.

Response (19): Cloud Model: Climate Science

- New innovative network approaches are needed for these problems. For example, Infiniband has more than 100Gbps.
- Still there will be issues crossing layers.
- Programmability of the infrastructure; e.g., to reprogram the infrastructure to achieve SLA requirements.
- Feedback is important; e.g., flood is coming, and need to reprogram.

Summary: 2 challenges, and 1 category were constructed in the Science Drivers category.

6.1.2.5.2 HPC

Challenge (20): There are issues with reliability running HPC in clouds.

- How can HPC be changed so that it can run reliably in the Cloud?
- Can virtualization be leveraged?

Response (20): issues with reliability running HPC in clouds

- Use lightweight hypervisor, with low noise, and little overhead.
    - For example, infiniband, can support all sort of approaches.
- In this space people do not do virtualization in the Cloud.

Summary: 1 challenge and 1 category were constructed in the HPC category.

6.1.2.5.3 Data Centers

Challenge (21): Cloud interconnects and machine communications are issues in data centers.

- Context is single data centers and proprietary data centers.
- Interconnects are not able to execute VMs. [Why?]
- Whole machine communication is a problem. [Why?]
- Data centers are part of a larger problem. [Why?]

Response (21): Cloud interconnects and machine communication issues

- Research is needed to increase understanding of the challenges and research issues of clouds in data center environments.

Summary: 1 challenge and 1 category were constructed in the Data Centers category

6.1.2.5.4 Clouds for Business versus Science

Challenge (22): Clouds for business users and scientific users have different requirements.

- Can the same cloud provide services for both types of users?

Response (22): Clouds for business users and scientific users have different requirements

- NSF is working in Clouds.
- The way clouds for science are designed is very different:
    - Scientific clouds require lots of processing.
    - Volume is different than business clouds.

Summary: 1 challenge and 1 category were constructed in the Cloud for business versus Science category.

6.1.2.5.5 Cloud Services for Society

Challenge (23): There is a lack of cloud services for society.

- How to provide services to society?
- How can the cloud provide services independent of where you are physically?
- Is a new model needed?
- What if 1000 cores were allocated, and then they were no longer need?
- People need cloud services for society versus services for scientists.

Response (23): Lack of cloud services for society

- Amazon has different offering, depending on different demands.

Summary: 1 challenge and 1 category were constructed in the Cloud Services for Society category.

6.1.2.5.6 Multi-clouds

Challenge (24): There is a lack of understanding on multi-clouds

- What are research issues on coordination and orchestration of multi-clouds?

Response (24): Lack of understanding on multi-clouds

- Coordination and orchestration on multi-clouds could be a basis for research collaboration.

Summary: 1 challenge and 1 category were constructed in the Multi-clouds category.

6.1.2.5.7 Management of clouds

Challenge (25): There is a lack of understanding about management of load balance, and data management

- What are the research issues involving management of load balance, and data management?
- What are the research issues involving management of multi-tenant clouds?
- Multi-tenant issues become challenging to manage. [Why is that? Provide reasons].
- Management is difficult, because every tenant wants a different thing (service)?

Response (25): Lack of understanding about management of load balance, and data management; and management of multi-tenant clouds

- We are still thinking in the data plane, and not control and management.
- This is an issue between clouds [Note: Why is this an issue?].
- Old problems of the grid come back. [What are the old problems of the grid?].
- Software Defined Systems: [what is the relevance of software defined systems in the context of cloud management?]

Summary: 1 challenge and 1 category were constructed in the management of clouds category.

6.1.2.5.8 Power Management

Challenge (26): Achieving green in cloud power management is hard.

- What are reasons for why power management for the cloud is hard?
- What are research challenges in power management for the cloud?

Response (26): Achieving green in cloud power management is hard:

- Research is needed to increase understanding of power management for clouds.

Summary: 1 challenge and 1 category were constructed in the power management category.

Section Summary: 5 themes, 9 challenges, and 8 categories were constructed in the Cloud model theme.

6.1.3 Cyberinfrastructure

Challenge (27): Bridging SDN islands:

- There are islands of heterogeneous SDN-based networks that need to be interconnected.
- Facilitating reusability and operational manageability of SDN networks.

Response (27): Bridging SDN islands

- Collaboratively develop a proposal to connect multi-domain (heterogeneous CI and administrative domains) campuses using an SDI approach.
- This should result in connecting communities of users, researchers, educators, students and future collaborators.
- Create a next-gen CI that meets the needs of end users and researchers.

Challenge (28): Testbeds for new technologies:

- There is a lack of testbeds for the validation of new technologies.
- How to deploy testbeds?
- What are best practices?
- Manageability of testbeds needs improving.

- (28.1) Sustainability: How is a testbed sustainable once funding runs out?
    - Surviving multiple iterations of the underlying technologies:
    - Testbeds are difficult to sustain, because the underlying technologies change faster than the life of the testbed and the experiments using it.

- (28.2) Interoperability and Federation of testbeds:
    - What are the challenges and research issues involving interoperabiity and federation of testbeds?
    - Lack of isolation: Tesbeds lack the ability to provide isolation for experiments to test reproducibility.
    - Bridging or interconnecting SDN testbeds in different network domains.
        - Bridging SDN testbeds in USA (GENI or Esnet) and Brazil (FIBRE).

- (28.3) Evolution of testbeds:
    - How to plan for testbed lifecycle?
    - Testing a depreciation plan?

- (28.4) How can testbeds be made more attractive to researchers? Possible reasons:
    - Usability of testbeds is low (user friendliness is low;
    - Lack of support; does not satisfy researcher requirements);
    - Lack of incentives or reasons for researchers to use testbeds.

- (28.5) General-purpose testbeds or problem-specific testbeds:
    - Build a generic testbed for problems that have not been articulated or do you build a testbed for a specific problem?

Response (28): Testbeds for new technologies

- Testbeds as a service?
    - Plug-and-play for the experimenter.
    - Clean up should be automated.
    - If too many FTEs to manage, then becomes unsustainable.

- Manageability:
    - Interface, end user interacting with testbed, common infrastructure that testbeds can share can improve manageability.

- Evolution of testbeds:
    - Develop a technology refresh plan in response to the testbed's lifecycle.

- Lack of isolation:
    - Use of network virtualization and slicing to provide isolation?

- Testbeds surviving multiple iterations of the underlying technologies:
    - What solutions exist today that isolate the testbed and experimentation layer from the underlying technologies? ExoGENI? GENI Racks?

- Response to bridging SDN testbeds: Software Defined Exchanges (SDX) was recommended. The recommendation was that SDX provide a lens to explore architectures to bridge SDN testbeds between two network domains (two countries).

Challenge (29): Campus Networks, WANs, and Science DMZ implementation on the campus:

- What are the challenges and research issues involving Science DMZ?
- What are the opportunities to collaborate on technologies and architectures for Science DMZs?
- How can Science DMZs be used to increase good collaborations between USA and Brazil?
- Do Science DMZ and Cloud have similar challenges?
    - Interoperability?
    - Lack of standardization?
    - For example, standard interfaces? Federation?

- What's the right architecture given today's constraints?
    - [What are the constraints? Funding? Challenges on the Campus: (sharing network resources and other resources for research or enterprise)? Policy constraints?]
- How should the campus networks and WANs evolve given the SDI vision (refer to Chip's slides for the SDI vision)?
- The network is no longer just for the forwarding of packets
- Memory is expensive. Unlikely storage will be added to routers.
- What is the relationship with testbeds?
    - Build testbeds to explore what future campus networks should be like?
    - Build testbeds to explore what the trade-offs are for future campus networks?

Response (29): Campus Networks, WANs, and Science DMZ implementation on the campus:

- The NSF campus CI program (CC-NIE, CC*IIE, CC*DNI) has categories for innovation and infrastructure. Proposals have been funded, and projects implemented, that may offer insight towards creating synergistic projects with Brazil.

Summary: 3 challenges were constructed. Data in challenge 28: Testbeds for new technologies, was constructed into 4 categories.

6.2 What are the existing major projects and programs in the USA and Brazil?

In the U.S., the following NSF funded programs were identified: GENI[1], NSF Cloud[2], Future Internet Architecture[3] (FIA), NSF Smart Grid[4], and the Cyber Physical Systems[5]. Software Defined Infrastructure (SDI), Federations, and Wireless were referred to as major programs in GENI. Tree House/SDX and WAN SDN testbed were referred to as major programs in ESnet.

The NSF Cloud program supports two projects: Chameleon[6] and CloudLab[7]. Cyber Physical Systems was also referred to as the Internet of Things[8] (IoT). IoT was characterized as “information” and as “aspirational”. The Open Science Data Cloud (OSDC[9]) is deploying and operating cloud infrastructure for international research and education. MIT is publishing electronic textbooks for kids to run simulations in clouds (Ref needed).

In Brazil, the Future Internet Testbeds Experimentation between Brazil and Europe (FIBRE[10]) and Entity Title Architecture (ETArch[11]) were two FI projects identified. No big projects on Future Internets beyond FIBRE. Calls are usually not large. There have been multiple punctual, smaller projects. Future Internet Research and Experimentation (FIRE[12]) is a EU program on FI research that involves Brazil.

The Research and Development Center in Information and Communication Technologies (in Portuguese, CTIC) program: Created by the Federal government and incubated by the National Research and Education Network of Brazil (RNP), the CTIC[13] is intended to develop the national skills for innovation in information and communication technologies (ICT). The CTIC program has focused its actions on the following matters: virtualization of networks and services, cloud computing and smart cities. RNP leads a cloud initiative. University of Sao Paulo has a cloud initiative - Cloud@USP. The State University of Sao Paulo (UNESP) has UNESP HPC, which supports an education cloud project. Intel is a partner of the UNESP education cloud project, The UNESP – Intel cloud project provides resources for schools in the state of Sao Paulo, such as IaaS for high schools.

Brazil and Europe organized a coordinated call for proposals. This resulted in three calls on cloud themes to set up partnerships for cloud research. 1st Call (5 projects) - secure future cloud; 2nd (4 projects) - more on scientific cloud; 3rd call, now cloud with security aspects.

CTIC builds theme networks, and organizes exhibitions[14], with several groups and laboratories interested in the multiple facets of and approaches to a certain problem or technology. CTIC coordinates the Third Coordinated Call BR-EU[15].

National Institutes of Science and Technology (Portuguese, INCT[16]) manages larger and long-term multi-institution research-topic-based projects. INCT is funded by the National Council for Scientific and Technological Development (Portuguese, CNPq[17]).

Response to existing major projects and programs in the USA and Brazil:

By having discussion at the workshop, we learned that several of the projects described in the previous section have completed. Stakeholders of these projects continue to utilize the infrastructure to conduct Future Internet research. For example, the FIBRE project continues to be used by researchers in Brazil.

The Cloud and Data Center networks breakout group recorded that there is a gap between research questions and building infrastructure. Infrastructure is needed to conduct research. [note: there are several projects cited in this report that can provide infrastructure to support research for Clouds.]

6.3 Where are the research collaborations?

Data in response to the third question is organized in this section. The 3-tuple format, described in section 6, is used to organize the data.

6.3.1 Future Internet Research

The breakout group on FI research explored how research collaborations form. The following questions were posed to stimulate discussion:

Challenge (30): Forming Collaborations:

- How did existing FI collaborations start?
- How do existing collaborations work?
- How are existing collaborations managed?
- What is the scale of existing collaborations?

Response to these questions was the following:

- Explore exchange programs for faculty and students:
    - CNPq PVE initiative is a promising step.
    - CAPES/NSF on ICT initiative similar to the one existing are of Biodiversity, http://www.nsf.gov/bio/deb/suppopp.jsp - IREU
- Acquire seed funding.

Challenge (31): Cultural Issues can impact the outcome of research collaborations

- Large teams are challenging to manage. (A leader is important for managing larger teams).
- It's a challenge to understand how people work.
- People should be compatible, and they should understand collaboration.

Response (31): Cultural Issues can impact the outcome of research collaborations

- Establish PhD student exchange programs:
    - Exchange programs should be for 2 years.
    - Periodic documents with open points.
    - "Collaborations are successful if a student has vested interest".
    - Weekly meetings.
- Refer to or apply Open Source as a model for research collaboration
    - Open source is another type of collaboration. Funding could or should require open source, because it promotes reproducible artifacts.

6.3.2 Clouds and Data Center Networks

Challenge (32): There is a lack of case studies that describe research collaborations involving clouds and data center networks.

- Case studies are needed about the networks that support the research collaborations. For example, the 100Gbps network between Miami and Sao Paulo.
- More case studies about the network will be needed once the 100Gbps is provisioned.
- Case studies for big science drivers are needed, such as the LHC.

Response (32): Lack of case studies that describe research collaborations involving clouds and data center networks.

- Refer to existing collaborations between the U.S. and Brazil to develop case studies.
- Subsets are cloud specific; most are GENI related.
  - UFSCar and FIU - congestion control in cloud (additional description?)
  - UNICAMP and UVirginia - Hadoop schedule and SDN controllers (additional description?)
- Potential future collaborations:
  - Smart cities collaboration: UFABC and U Chicago.
  - Build new collaborations upon existing ones; for example, PlanetLab. Planetlab has long-standing research relations, which could be leveraged.
  - Leverage projects that are successful and make use of them as a foundation to spawn collaborations.

Challenge (33): Fostering future research collaborations for clouds and data center networks

- Research details are needed to foster future collaborations.
- Complementary programs: what types of programs at the NSF and in Brazil funding agencies could be complementary?
- Testbeds: What are the research projects that could use testbeds?
- Testbeds: Develop education materials to facilitate the use of testbeds?
- Data management: System layer research in one place, and data mining research in another place; neither one of them solve the full problem.
- Data algorithms and data infrastructure are needed?

Response (33): Fostering future research collaborations for clouds and data center networks

- Events should be organized to identify complementary expertise. SwitchOn workshop?

6.3.3 Cyberinfrastructure

Challenges and corresponding responses were not found.

6.4 What are issues, demands, and potentials for international collaborations?

Data in response to the fourth question is organized in this section. The 3-tuple format, described in section 6, is used to organize the data.

Challenge (34): There is a lack of coordinated international funding.

- In the US, the institution is funded in the grant. Everybody is obligated to work on the deliverables, and there is an obligation to show results. If there is not an international relationship, then it's difficult to find reciprocal funding together.

Response (34): **International Collaborations:**

- International Collaborations should start small; they need not be large.
- Start small, but think big.
  - Examples: ARPANET - 3 to 4 nodes, slow growth, 10 years.
  - Layer2 services – appeared in Campus Cyberinfrastructure (CC-NIE) grants.
  - Development of new control planes.
    - Create a seed, and then large scale.
    - Need to deploy.

    - Sustainability: cannot be large scale in the first year. Build up. For example:
        - CC-NIE program: 2-3 years
        - PIRE: 5 years
        - Major projects: building a new telescope, 10+ years.
    - Organize around successful project, and then sustain; e.g., PlanetLab.
- Explore coordinated funding: For example:
    - Student exchange program (need funds from both sides).
    - Culture should be complementary. For example, Miami has cultural ties through language and time zone similarities.
- Seed funding. For example, start with meetings to engage scientists.
- Smart City Collaborations
    - Portable
    - Running on GENI
    - Smart Grid
    - Sustainability/Energy
- Testbeds:
    - Join existing testbeds such as the NDN testbeds or even testbeds based on different network architectures.

Challenge (35): Motivating students to work/study abroad can be challenging

- It's challenging, because students want to go to industry to do internships.

Response (35): Motivating students to work/study abroad can be challenging

- Recommend a graduate student exchange program that is funded from both sides.
- The exchange program needs to provide value that students will receive from the exchange experience.
- Faculty advisor must be part of the collaboration with the student, so benefits both.
- Build upon international complimentary expertise:
    - Problems and challenges must be international (shared common problem/topics of interest).
    - For example, security is an international topic. US or Brazil is not secure; therefore, security is a good complementary area for research collaboration.
    - For example: Export control in crypt algorithms - domain that could come with new ideas.

Challenge (36): Breaking down barriers:

- What are mechanisms and methods for breaking down barriers?

Response (36): Breaking down barriers:

- Using testbeds to showcase potential solutions.
- Using testbeds for education purposes.
- Prototyping and innovations that result from a campus CI program, such as the NSF CC-NIE program.
- A goal of FED4FIRE is a potential solution towards a global testbed federation. FED4FIRE is an EU led project. FED4FIRE provides schemes for the federating of different testbeds. It includes the GENI control framework. The outcome of this program could result in a solution for the breaking down of barriers.

In summary for sections 6.1, 6.3, and 6.4, Themes, Challenges and Categories were counted. Section 6.2 did not apply counters, because it describes the data that was provided.

Section 6.1, FI Research (section 6.1.1) counters were the following: 6 themes and 6 challenges. Cloud and Data Center Networks (section 6.1.2) counters were 5 themes, 16 categories, 20 challenges. Cyber infrastructure (section 6.1.3) counters were 3 challenges and 4 categories. In total, 11 themes, 29 challenges, and 20 categories.

7. Recommendations

Please refer to tables in a separate file for lists of recommendations.

Appendix A. Program for the 1st SwitchOn Workshop on US-Brazil Collaborations for Future Network Research, Miami, Florida, January 8-9, 2015

7.1 DAY 1 (Thursday, 8-January 2015)

7:00 Bus leaves from Marenas Hotel to Kovens Conference Center
7:30 Continental Breakfast at Kovens Center

8:30 Welcome Address – FIU, Dean Amir Mirmiran
8:45 Welcome Address – NSF, Bryan Lyles

Keynotes
9:00 Keynote #1, Darleen Fisher, NSF
Future (International) Internet Research
9:30 Keynote #2, Antonio Abelem, Federal University of Pará (UFPA)
Brazilian Testbed for Future Internet (FIBRE) and the Research Opportunities Between The US and Brazil
10:00 Keynote #3, Chip Elliot, Raytheon BBN Technologies
Looking Beyond the Internet

10:30 Break – Morning Refreshment Break

11:00 PICO Talks (2-min introduction by each participant)
Moderator: Heidi Morgan

12:30 Lunch (Room 114)

Breakouts
13:30 Breakout Guidelines and Charge to Participants
Moderator: Jason Liu
14:00 Breakout Sessions
#1: Cyberinfrastructure Design and Development,
Lead: Rodrigo Fonseca and Christian Rothenberg
#2: Clouds and Data Center Networking
Lead: Kate Keahey and Carlos Kamienski
#3: Future Networks Design and Applications
Lead: Russell Clark and Antônio Abelém

15:30 Break – Afternoon Refreshment Break

16:00 Reports from Breakouts with Q&A

17:00 Panel: Funding opportunities
Panelists: Bryan Lyles, Luis Lopez, Michael Stanton, Dorgival Guedes
Moderator: Julio Ibarra

18:00 Wrap up for the day
18:30 Bus to restaurant for group dinner
19:00 Group Dinner (La Montanara, 18851 Northeast 29th Avenue)
22:00 Bus to return to hotel

7.2 DAY 2 (Friday, 9-January 2015)

7:30 Bus leaves from Marenas Hotel to Kovens Conference Center
7:45 Continental Breakfast at Kovens Center

8:55 Infrastructure Talks
Moderator: Julio Ibarra

- ***Campus, Exchange Points, Regional CI*, Julio Ibarra (FIU)**
- ***NREN USA*, Inder Monga (ESnet)**
- ***NREN Brazil,* Michael Stanton (RNP)**
- ***ANSP,* Luis Lopez (USP)**
- ***Brocade*, Norival Figueira (Brocade)**
- ***Padtec*, Enrique Lozoya (Padtec)**
- ***AmLight*, Jeronimo Bezerra (FIU)**

10:45 Break – Morning Refreshment Break

11:00 Future of USA-Brazil Research Collaborations
Moderator: Jason Liu

- **Christian Esteve Rothenberg (Unicamp)**
- **Tereza Cristina Melo de Brito Carvalho (USP)**
- **Malathi Veeraraghavan (UVA)**
- **Flávio de Oliveira Silva (UFU)**
- **Alessandro Anzaloni (ITA)**
- **Glenn Ricart (US Ignite)**

12:00 Wrap-up

Appendix B. List of Participants for the 1st SwitchOn Workshop on US-Brazil Collaborations for Future Network Research, Miami, Florida, January 8-9, 2015

US Participants:

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