GENI Enabled Software Defined Exchange (GENI-SDX)
Project Final Report
Project 2003
Year 1: March 1, 2016 – February 28, 2017
Year 2: September 1 2017 - August 31, 2018

I. Major accomplishments

A summary of the major accomplishments for the overall project, years 1 and 2 is provided below. After that the remainder of this section provides detailed summary of the Major accomplishments organized based on year. Major accomplishments for year 2 are followed by year 1.

Summary of Overall Major Accomplishment (Years 1 and 2)

The focus of the project was on development of a Software Defined Exchange (SDX) and leveraging the GENI technology and systems to facilitate this work. Transition of an existing Research and Education Exchange Points to a Software Define Exchange (SDX) was the approach adopted. The GENI infrastructure core capability includes the creation of slices across distributed resources in the form of GENI Racks and the connecting networks. Leveraging this capability, Exchange Point resources, such as the Washington International Exchange (WIX) in McLean Virginia can be added to the GENI resource portfolio. The addition of public cloud access connections to these Exchange Point provided an opportunity for GENI slices to include network provisioning across Exchange Points along with integrated connections to public cloud infrastructures such as Amazon Web Services (AWS).

The Mid-Atlantic Crossroads (MAX) GENI Aggregate Manager (AM) was modified to cover the WIX and integrate a Direct Connect to the US-EAST Region of AWS. The AWS Direct Connect allows for private dedicated connections into the AWS Cloud. The MAX GENI AM was modified to allow use of the Direct Connect as part of regular GENI Slices. A modified Request RSpec with and SDX Extension was defined which allowed use of standard GENI tools to request slices which connected user specific GENI resources to user specific AWS resources across the Direct Connect link.

This same technology was also applied to the MAX Software Define ScienceDMZ (SD-SDMZ) such that users directly connected to the MAX regional network, or a connecting institution could utilize these services without leaving the regional and going to the SDX. In addition, the SD-SDMZ facility included direct attachments to local compute and storage and the MAX InstaGENI rack. In this manner, connections to other resources could more easily included as part of GENI slices.

The project also developed mechanisms to connect GENI Slices to other public cloud resources such as Microsoft Azure and Google Cloud Platform (GCP). Since direct physical connections to these cloud resources were not available, Virtual Private Network (VPN) based connections were utilized. The MAX AM SDX Extension was modified to enable GENI based provisioning of these connections as part of slice establishment. The VPN mode of connection to public cloud resources is considered prototype but is available for experimentation by GENI users.

Year 2 Major Accomplishments

1) Network Service Interface (NSI) based Network Element Control

The MAX GENI Aggregate Manager (AM) software has an NSI driver and an instance is deployed to cover the MAX Software Defined ScienceDMZ (SD-SDMZ). The NSI system here is based on the ESnet OSCARS system with their NSI API module. Another instance of the MAX Aggregate Manager is also covering the WIX (Washington International Exchange Point) SDX. This also has an and NSI driver. The MAX GENI AM software for both of these deployments can be configured to use either the NSI or the native OSCARS interface. ESnet is planning to release a new OSCARS version in Fall of 2018, and we expect to upgrade both deployments at that time. We may find that the native OSCARS interface is better to use for this version, since it will support multipoint topologies, whereas the NSI interface does not.

2) Amazon Web Services (AWS) Connection as an SDX Resource

The WIX includes a connection to the MAX AWS Direct Connect, and this is accessible via the WIX GENI AM using the "GENI RSpec SDX Extension". Access to this AWS Direct Connect resource is now generally available to GENI Users and considered production ready. The access for this system has been designed such that GENI users can submit a Request RSPEC to the WIX GENI AM, and the AWS DirectConnect will be automatically configured to allow the user AWS resources to flow traffic across the Direct Connect path. This mode of operation uses the GENI RSpec SDX Extension to specify connection of the GENI Slice to that user's specific AWS resources. In this mode no pre-coordination with MAX is needed since all AWS billing goes directly to the user, as it normally would. The GENI RSpec with SDX Extension also allows for resources (Instances and Virtual Private Cloud) inside AWS to be automatically instantiated as part of GENI Slices. This requires pre-coordination with MAX to decide how to handle AWS account and billing issues.

3) OtherCloud Resources

We have completed initial work to allow access to Microsoft Azure and Google Cloud Platform (GCP) access as part of GENI Slices via a Request RSPEC with an SDN Extension. For these cloud platforms we did not have the equivalent of the physical AWS Direct Connect in place (ExpressRoute for Azure, and Dedicated Interconnect for GCP). As a result, the connections to Azure and GCP are based on Layer3 Virtual Private Network (VPN) connections. If Azure ExpressRoute and GCP Dedicated Interconnect connections are available in the future, much of the work to include these as part of GENI AM based access is in place. For the VPN based access to these cloud infrastructures, there are several modes of access, which include dynamic set up of cloud resources with a VPN endpoint or attaching GENI Slices to existing cloud resources and associated VPN endpoint. We consider this VPN based access to Cloud resources to be prototype, but it is available for GENI user experiments. Pre-coordination with MAX team is needed before using this service.

4) GENI Racks (InstaGENI Rack, ExoGENI Rack, OpenGENI Rack) connections to SDX

The work here focused on integrating the MAX InstaGENI Rack with the UMD/MAX Software-Defined ScienceDMZ (SD-SDMZ). The UMD/MAX SD-SDMZ is similar to an SDX, with the main difference in this context is its location, which is at the edge of the MAX network (facing

connecting institutions), instead of between MAX and Internet2/ESnet like the WIX SDX. The other key difference is that the SD-SDMZ has its own compute and storage resources. These compute and storage resources are utilized to facilitate connections to Cloud resources via a Request RSPEC with SDX Extension. As a result, the connections to cloud resources via the AWS Direct Connect or VPNs for Microsoft Azure and Google Cloud Platform are also available from the SD-SDMZ in a similar manner as described for WIX. A separate instance of the MAX GENI AM covers the MAX SD-SDMZ for this purpose.

During this project period the MAX InstaGENI Rack connection was moved so that it was directly attached to the MAX SD-SDMZ. This positions the GENI Rack to better service domain science use cases due to richer connections to other resources such as HPC and storage systems.

The MAX GENI AM covering the MAX SD_SDMZ, which includes compute and storage, could also be deployed inside an Exchange Point as an SDX. In a similar manger, a standard GENI Rack could also be deployed inside an Exchange Point which is under GENI AM control, which would represent another deployment model for and SDX with compute and storage.

We may also upgrade the connection between the MAX InstaGENI Rack and the MAX ScienceDMZ to 10Gbs interface in the future. All of the other connections are 10Gbps or higher to the R&E networks and Cloud resources. This would allow better support for use of GENI Racks to support domain science related activities. With the connections to the ScienceDMZ, external cloud resources, multiple external networks, the MAX GENI Rack is now positioned for this type of use.

5) Attended the Global Experimentation for Future Internet (GEFI) Workshop, Rio de Janeiro, Brazil, October 26-27, 2017
Co-chaired a session on "Software-defined exchanges and infrastructure (SDX & SDI)". Presented on Software Defined Exchange (SDX) Distributed Infrastructure. Provided inputs for the workshop report.

Year 1 Major Accomplishments
1) GENI Enabled Software Defined Exchange (GENI-SDX)
This objective of this project is to develop and deploy GENI enabled Software Defined Exchanges (SDXs). This includes developing an operational SDX Aggregate Manager (AM) that can be deployed at existing and new exchange points. This activity builds on previous work which resulted in a prototype GRAM based MAX Aggregate Manager (GRAM/MAX-AM) deployment on the Washington International Exchange (WIX). The initial WIX SDX prototype focused on the network resources available in the WIX. The larger vision for SDX is one that includes network, storage, and compute resources. In pursuit of this objective, the following types of systems can be embedded, or attached, to an SDX:

-Network Service Interface (NSI) based Network Element Control
-Amazon Web Services (AWS) Connection as an SDX Resource
-OtherCloud Resources
-GENI Racks

During this reports time period the following activities and accomplishments are noted:

-Completed restructuring of the MAX Aggregate Manager (AM) to accommodate the switch from SFA to GRAM and to provide a proper framework for SDX resource and feature incorporation. This restructure facilitates flexible incorporation of a variety of SDX attached resources such as local compute, storage, and public cloud attachment points. This restructuring leveraged the UMD/MAX developed StackV is an open source model driven orchestration system: github.com/MAX-UMD/stackV.community.

-Completed implementation of MAX AM with support for NSI, GRAM, and AWS. Two instances of this have been deployed. One is covering the MAX Regional Network dynamic circuit infrastructure. The other is covering the Washington International Exchange (WIX) where it interacts with the GRNOC run OSCARS system.

-Work is ongoing to utilize the same technology on the UMD/MAX Software Defined ScienceDMZ. The objective is to show that the same technology base (GRAM based MAX-AM with SDX resource management enhancements) can also be utilized for Software Defined ScienceDMZs. An initial deployment of a GENI Enabled Software Defined Science DMZ was deployed in October 2016.

2) GENI Engineering Conference (GEC) 24, March 8-9, 2016, Arizona State University, Phoenix, Arizona
Presented a demonstration of a GENI enabled Software Defined Exchange (SDX) which utilizes Network Service Interface (NSI) for network element control, and included public cloud resources from Amazon Web Services (AWS) as part of GENI Stitched topologies. The work demonstrated is driven by a vision for future R&E cyberinfrastructure that consists of an ecosystem of ad hoc and dynamically federated Software Defined Exchanges (SDXs) and Software Defined ScienceDMZs services. GENI technologies are leveraged in the form of the MAX Aggregate Manager which utilizes the GENI Rack Aggregate Manager (GRAM) software for GENI Federation functions. This MAX/GRAM AM utilized the Open Grid Forum (OGF) NSI protocol to provision services across the network elements within the Washington International Exchange (WIX) located in McLean, Virginia and the MAX Regional Network. GENI Request RSpec extensions were defined to allow AWS resources to be included in GENI stitching topology requests. The demonstration poster is available here:

- https://wiki.maxgigapop.net/twiki/pub/GENI/Publications/2016-03-8-geni-gec24-sdx-poster-umd-max.pdf

3) Global Experimentation for Future Internet (GEFI) Workshop, April 18-21, 2016, Brussels, Belgium

-Organized and acted as co-chair for a session on "Federation, software defined infrastructure, testbeds and connectivity".
Presented on "Washington International Exchange (WIX) as a Software Defined Exchange (SDX)". This presentation provided an overview of the WIX SDX, the MAX GENI AM, and

AWS integration. The presented slides are available here:

- http://groups.geni.net/geni/attachment/wiki/MAX-GENI-SDX/2016-04-18-gefi-session2-tlehman-v3.pdf

-Presented during the session "Cloud and big data" on "Hybrid Cloud Services Software Defined ScienceDMZ". This presentation provided an overview and a vision for Software Define ScienceDMZ architecture and services with GENI AM access. The presented slides are available here:

- http://groups.geni.net/geni/attachment/wiki/MAX-GENI-SDX/2016-04-19-gefi-session3-tlehman.pdf

-Presented at the co-located NetFutures 2016 Conference on "Software Defined Exchange (SDX): Vision, Development, Collaboration". This presentation discussed a vision for an ecosystem of distributed SDXs and Software Define ScienceDMZs to provide a service innovation marketplace. The presented slides are available here:

- http://groups.geni.net/geni/attachment/wiki/MAX-GENI-SDX/2016-04-20-netfutures-gefi-tlehman.pdf

4) GENI NICE Conference, December 12, 2016, Irvine California
Held as part of CoNEXT 2016, The 12th International Conference on emerging Networking EXperiments and Technologies

-Presented a demonstration on the GENI Enabled "Software Defined Exchange (SDX)" and a "Software Defined ScienceDMZ (SD-SDMZ)" deployed at the Washington International Exchange (WIX) and the University of Maryland/Mid-Atlantic Crossroads (UMD/MAX), respectively. The demonstration poster is available here:

- http://groups.geni.net/geni/attachment/wiki/MAX-GENI-SDX/2016-12-12-geni-sdx-sd-sdmz-poster-v3.pdf

-Presented and participated in a panel “What's next for SDX research?”. The presented slides are available here:

- http://groups.geni.net/geni/attachment/wiki/MAX-GENI-SDX/20161212-lehman-sdx-panel.pdf

5) GENI Engineering Conference (GEC) 25, March 15-15, 2016, Florida International University, Miami, Florida.
Participated in a demonstration of a distributed SDX environment which included the WIX, Starlight, SOX, and Ampath SDXs. Paths across Internet2 AL2S and DOE ESnet were utilized to connect the SDXs. The WIX SDX slides presented as part of this demonstration are available here:

- http://groups.geni.net/geni/attachment/wiki/MAX-GENI-SDX/20170314-wix-sdx-max-v1.pdf

Presented at the GENI Transition session regarding plans for operational support and future SDX development. The slides presented at this session are available here:

- http://groups.geni.net/geni/attachment/wiki/MAX-GENI-SDX/20170314-geni-transition-max-v1.pdf

A. Milestones status

Milestones/Deliverables

This section is organized based on year. Milestone status for year 2 is followed by year 1.

Year 2 Milestones status

a) GENI Enabled WIX SDX

Status: As described above, the GENI Aggregate Manager is deployed covering WIX. This GENI AM allows for regular GENI Stitching of VLANs as well as use of an SDX Extension to connect to AWS resources over a dedicated AWS Direct Connect to the US-East region in Ashburn, Virginia. This deployment also includes an experimental deployment of VPN based connections to Microsoft Azure and Google Cloud Platform (GCP) resources.

We began looking in to methods to interconnect GENI Enabled SDXs which goes beyond AL2S based VLAN stitching. This include use of the Internet2 SDN Overlay network as a mechanism to connect SDXs and GENI Racks. This was not part of the initial work plan for this project, so the work to date is early evaluation including some initial deployment and testing activities. The Internet2 SDN Overlay network is based on CORSA switches where multiple overlays can be built and then flows can be managed using OpenFlow. We may to continue with this work as part of future activities.

b) Deploy updated WIX Aggregate Manager and inter-aggregate links to AL2S, MAX to GENI operational topologies.

Status: The WIX GENI AM is connected to AL2S, MAX and AWS Direct Connect. GENI Slices can be established which include the WIX VLAN and AWS Direct Connect access.

c) Provide monitoring data on WIX SDX status and resource usage (VLAN, interface, peering etc.) to GENI monitoring collector.

Status: The WIX GENI AM has the same monitoring features as the current GENI AM covering the MAX ScienceDMZ. We have not added the WIX GENI AM to the official GENI Monitoring web page yet.

d) Document and release the WIX SDX API and related software.

Status: The MAX GENI Aggregate Manager software is intended for deployment on an SDX, such as WIX, or a Software Defined ScienceDMZ, such as the MAX deployment. The software and documentation is available here:

- MAX Aggregate Manager
    - https://github.com/xi-yang/GENI-DCN-AM/tree/SDX-0.2
- MAX Aggregate Manger and Stitching Computation Service (SCS) Instructions
    - https://wiki.maxgigapop.net/twiki/bin/view/GENI/NetworkStitchingSoftware
- MAX Open Source Orchestration System
    - github.com/MAX-UMD/stackV.community

Note: All software includes the GENI Public License.

e) Make WIX SDX services, including access to Amazon Web Services Direct Connect generally available to GENI experimenters, subject to local access policies.
Status: The WIX SDX, including access to AWS US-East region via a Direct Connect is available for use by GENI Experimenters. Additional information regarding use of the SDX Extension is available here:

- https://wiki.maxgigapop.net/twiki/bin/view/GENI/NetworkStitchingSoftware
- http://groups.geni.net/geni/wiki/MAX-GENI-SDX

f) Continue to prototype the GENI Enabled Software-Defined Science DMZ (SD-SDMZ) using the MAX InstaGENI rack.
Status: As described in more detail above, the MAX InstaGENI rack was moved to be directly connected to the MAX Software Defined ScienceDMZ. In addition, the MAX Software Defined ScienceDMZ includes separate compute and storage resources. As a result, GENI AM slices can include resources inside the SD-SDMZ.

g) GENI Production Support
Status: Support of GENI production operation has been ongoing during the reporting period. This typically includes support for GENI Stitching, updating stitching topologies, Stitching Computation Service (SCS) software updates, and troubleshooting any stitching issues. UMD/MAX runs the test and development instance of the SCS. GRNOC runs the operational SCS instance.

Year 1 Milestones status
a) GRAM and SDX based MAX-AM System Restructure
This task will restructure and refactor the MAX-AM to accommodate the switch from SFA to GRAM and to provide a proper framework for SDX feature incorporation. This adjustment to the MAX-AM is also needed to facilitate future feature incorporation and to enhance supportability associated with deployments on other infrastructures, such as ScienceDMZs.

Status: Completed restructuring of the MAX Aggregate Manager (AM) to accommodate the switch from SFA to GRAM and to provide a proper framework for SDX resource and feature incorporation. This restructure facilitates flexible incorporation of a variety of SDX attached resources such as local compute, storage, and public cloud attachment points. This restructuring leveraged the UMD/MAX developed StackV open source model driven orchestration system:

github.com/MAX-UMD/stackV.community.

b) GRAM based MAX-AM Release (AWS and NSI Support)
This release will include NSI support that will provide the ability to talk to NSI network controllers such as OSCARS. It is also expected that OESS will have an NSI API available in this time frame. This task will include testing and verification with the latest OSCARS and OESS. This release will also add AWS Connections as a resource to SDX and MAX-AM

Status: Completed implementation of MAX AM with support for NSI, GRAM, and AWS. This open source software has the GENI public license and is available on github at this location: github.com/MAX-UMD/stackV.community.

c) SDX Deployments
This task will deploy the GRAM/MAX-AM to cover the WIX.

Status: Two instances of this have been deployed. One is covering the MAX Regional Network dynamic circuit infrastructure. The other is covering the Washington International Exchange (WIX) where it interacts with the GRNOC run OSCARS system.

d) GENI Racks as an SDX Resource
This task will add support for GENI Racks as a resource to MAX-AM. We expect that this will be based on InstaGENI or OpenGENI Racks.

Status: We included connections between the MAX InstaGENI rack and the WIX SDX as part of demonstration topologies. This demonstrated the basic concept of thinking of GENI Racks as being resources available as part of flow management at SDX locations. We have also completed a design for moving the MAX InstaGeni rack to a location at UMD/MAX where we can have multiple dataplane connections to WIX, AL2S, and the local ScienceDMZ. This will allow us to further demonstrate the use of GENI Racks as integrated components of SDX flow management. We plan to complete addition work in this area during the next years activities.

e) GRAM Policy Enhancements Addition
The GRAM policy features will likely need some enhancements to address the various SDX use cases. We will work with the GRAM developers to define and document the enhanced policy requirements. We will also modify the MAX-AM to support these new GRAM policy features. We anticipate that these will include adding more granularity to the policy decisions to allow resource control at the user and network element level. This task will include implementing the associated changes in the MAX-AM to support the GRAM enhancements added by the GRAM developers. We assume that the enhanced GRAM software will be available one month prior to the MAX-AM release deliverable due date below.

Status: We leveraged the GRAM ABAC like policy mechanism to control access to WIX SDX resources based on Federation (Clearinghouse) level, Virtual Organization (Project) Level, Slice Level, and User Level. We plan to enhance the policy features as part of the next years activities. In particular we would like to add more granularity on the policy statements to allow the policy controls to be applied to specific vlans and resources (ports, links, etc). Based on

work so far, we think the currently implemented GRAM Policy engine will allow us to do this. As a result we do not think we need any changes to the currently implemented GRAM policy engine. If we find that changes are needed to the GRAM implementation we may need to seek guidance or additional information from BBN implementation team.

f) Other Cloud as an SDX Resource
This task will add Other Cloud as a resource to MAX-AM. We expect that this will be based on Rackspace.

Status: We have begun looking at how to add other cloud resources in addition to the integrated AWS VPC and Direct Connect resources now supported. This activity is planned to be continued as part of next years work. One area we are investigating is integrating the Equinix Cloud Exchange resources into the set of WIX SDX available resources. This requires further study but the idea is that additional cloud infrastructures such as Microsoft Azure, Google Cloud, and others are available there.

g) GRAM Based MAX-AM System Update
This task will focus on updating the overall GRAM base MAX-AM system based on lessons learned during the previous deployment and testing. We anticipate that there will be many features and functionalities that we will want to revaluate based on real use case testing. This task will consist of defining needed enhancements, implementation plan development, and implementation.

Status: We did not need any GRAM updates for the work completed so far. There may be some GRAM updates required as part of next years work. We will provide additional information on this once design work has been completed for the finer granularity policy features.

h) Application of GENI Enabled SDX Technologies
A key objective of this work is application of the GENI enabled Software Defined Exchange (SDX) technology to a variety of infrastructures and use cases. This task will focus on applying these technologies to other systems such ScienceDMZs and other SDXs. The initial ScienceDMZ use case will be at MAX/University of Maryland. This ScienceDMZ deployment will be used to define an example use case for discussions with others who are deploying ScienceDMZs. The WIX SDX deployment will be used to define a reference SDX deployment for discussions with other exchange point operators. A key part of the SDX deployment vision will be that of a notion of distributed SDX ecosystem. The hope is that we will be able to deploy the GENI Enable SDX technology at multiple SDXs and ScienceDMZs and demonstrate distributed policy based operations.

Status: Work is ongoing to utilize the same technology on the UMD/MAX Software Defined ScienceDMZ. The objective is to show that the same technology base (GRAM based MAX-AM with SDX resource management enhancements) can also be utilized for Software Defined ScienceDMZs. An initial deployment of a GENI Enabled Software Defined Science DMZ was deployed in October 2016.

i) GENI Production Support

We will continue to support GENI Production operations including supporting stitching operations and Stitching Computation Service (SCS) support/bug fixes. This will also include supporting Internet2 if they change their Aggregate Manager to support multipoint stitching on OESS. This support will include requirements definition, design support, testing support, and any modifications needed to the SCS. This is an ongoing task and will be supported as needed during the time period.

Status: During this reporting period we continued supporting the operational MAX developed Stitching Computation Service (SCS) which is now run by the GENI NOC at Indiana University. The open source SCS software is available on a public GitHub repository: https://github.com/xi-yang/MXTCE-GENI-SCS.

During this time period we continued to support GENI Operational Stitching. This included supporting GENI NOC running, upgrading, and testing of the operational SCS. In addition, UMD/MAX also continued running multiple instances of the SCS for test and development. Information for SCS software deployment, maintenance, and upgrade is maintained here:

-https://wiki.maxgigapop.net/twiki/bin/view/GENI/NetworkStitchingSoftware

B. Deliverables made

This section is organized based on year. Deliverables made for year 2 is followed by year 1.

Year 2 Deliverables Made

a) GENI Enabled WIX SDX
b) Deploy updated WIX Aggregate Manager and inter-aggregate links to AL2S, MAX to GENI operational topologies.
c) Provide monitoring data on WIX SDX status and resource usage (VLAN, interface, peering etc.) to GENI monitoring collector.
d) Document and release the WIX SDX API and related software.
e) Make WIX SDX services, including access to Amazon Web Services Direct Connect generally available to GENI experimenters, subject to local access policies.
f) Continue to prototype the GENI Enabled Software-Defined Science DMZ (SD-SDMZ) using the MAX InstaGENI rack.
g) GENI Production Support

Year 1 Deliverables made

a) MAX AM restructure with GRAM and architecture to support SDZ and ScienceDMZs
b) MAX AM with GRAM, AWS, and NSI support
c) SDX Deployment on WIX
d) GENI Racks as an SDX Resource
e) GRAM Policy Enhancements
Specification Document
MAX-AM with support for Enhanced GRAM Policy Features
f) OtherCloud as an SDX Resource
g) GRAM Based MAX-AM System Update

Update Plan document
MAX AM Update Release
h) Application of GENI Enabled SDX Technologies
ScienceDMZ Deployment Reference Document and deployment at UMD/MAX
SDX Deployment Reference Document
Outreach to and Coordination with other SDX and ScienceDMZ Operators
i) GENI Production Support

All deliverables were completed as described in section I.A Milestone Status. Additional details on the overall project status and milestones are available on the GENI project wiki page: http://groups.geni.net/geni/attachment/wiki/MAX-GENI-SDX

The documentation deliverables were in the form of presentations as listed above and below.

II Description of work performed during last quarter

A. Activities and findings

A key finding as a result of these activities is that GENI federation and stitching technologies can be utilized for multiple use cases. We demonstrated the benefit of applying GENI technologies to use cases such as Software Define Exchanges (SDX) and Software Defined ScienceDMZ (SD-SDMZ). A GENI Enabled SDX at the Washington International Exchange (WIX) was deployed and demonstrated. It appears that SDXs will likely be an important component of future R&E infrastructures. During this reporting period a GENI Enabled Software Defined ScienceDMZ was also deployed which included direct connection of the MAX InstaGENI Rack. Work completed during this project demonstrated that GENI software and technologies can be readily utilized to power these types of infrastructures. In particular the GRAM based AM seems like a good starting point for developing GENI based SDXs and

Our work with other SDX deployments at Starlight SDX, SOX SDX, and Ampath SDX have provided an early indication of the power of distributed SDX topologies for specialized flow management processes.

B. Project participants

Tom Lehman (MAX)
Xi Yang (MAX)
Alberto Jimenez (MAX)
Various UMD Students

C. Publications (individual and organizational)

No formal publications were published during this time period.

D. Outreach activities

The core of our outreach activities was in the form of collaboration with other GENI aggregate operators and users at various community forums. This included presentations and/or demonstrations at GENI Engineering Conferences (GEC), Global Experimentation for Future Internet (GEFI) Workshops, and other community forums.

E. Collaborations

This project included outreach across a broad spectrum of organizations and projects thru our work with other aggregate and SDX providers such as Starlight SDX, SOX SDX, Internet2 AL2S, Ampath SDX, and other GENI Rack deployment sites.

F. Other Contributions

none.