G E N I

Global Environment for Network Innovations

GENI Spiral 1 Overview

Document ID: GENI-FAC-PRO-S1-OV-1.12

September 29, 2008

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NSF Cooperative Agreement CNS-0714770

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1 Document Scope

1.1 Purpose of this Document

This document provides a brief introduction to GENI Spiral 1, the first phase of GENI prototyping. It identifies the goals of Spiral 1, the various research projects that will be integrated to form Spiral 1, and the ways in which they will be integrated.

This document is intended as introductory guidance to everyone participating in GENI Spiral 1, and a high-level overview of Spiral 1 to other readers. Other documents should be consulted for broader overviews of the GENI project, and for details of the technical design; see Section 1.8 for a list.

1.2 Context for this Document

Figure 1-1 below shows the context for this document within GENI's overall document tree.

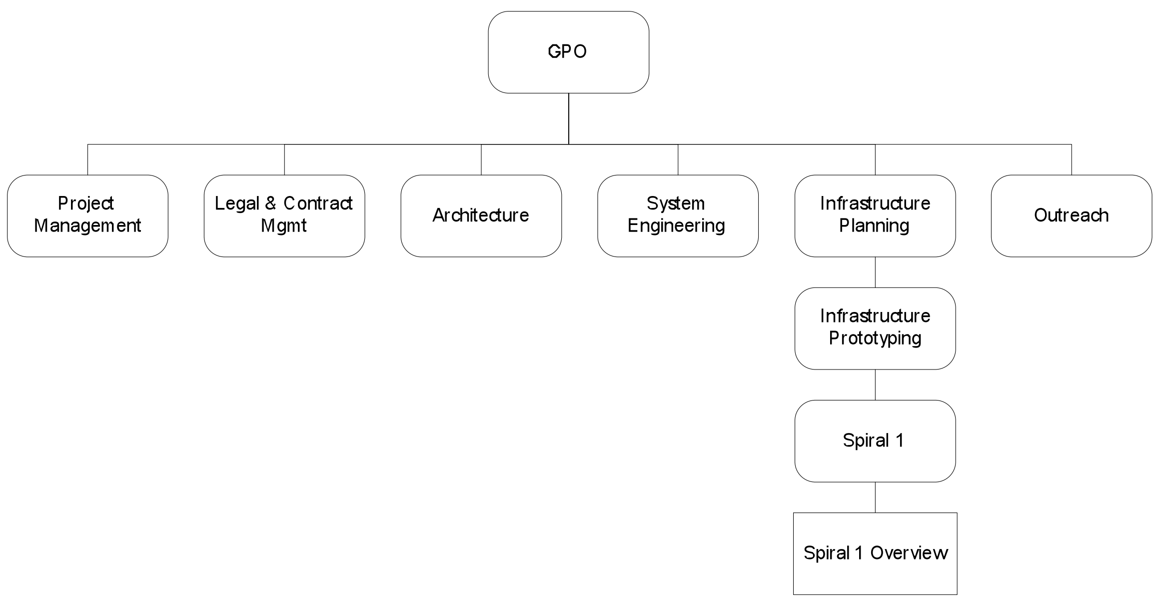

Figure 1-1. Location of this document within the GENI Document Tree.

1.3 Related Documents

The following documents of exact date listed are related to this document, and provide background information, requirements, etc., that are important for this document.

1.4 National Science Foundation (NSF) Documents

Document ID	Document Title and Issue Date
N / A	

1.5 GENI Documents

Document ID	**Document Title and Issue Date**
GENI-SE-SY-SYO-02.x	"GENI System Overview," version 2.x, (to be published)

1.6 Standards Documents

Document ID	**Document Title and Issue Date**
N / A	

1.7 Other Documents

Document ID	**Document Title and Issue Date**
N / A	

1.8 Document Revision History

The following table provides the revision history for this document, summarizing the date at which it was revised, who revised it, and a brief summary of the changes.

Revision	Date	Revised By	Summary of Changes
0.6	29-Aug-08	H. Mussman	Initial draft.
0.7	11-Sept-08	H. Mussman	Revised figures, shorten system decomposition section.
0.8	12-Sep-08	A. Falk	Formatting, diagram update, extended project descriptions
0.9	13-Sep-08	C. Elliott	Add more context and framing for Spiral 1.
0.10	14-Sep-08	A. Falk	Formatting, consistency edit
0.11	16-Sep-08	A. Falk	Revised based on GPO review
0.12	29-Sep-08	A. Falk	Revised based on PI review

2 Introduction

GENI Spiral 1 is the first phase of exploratory rapid-prototyping that will begin to inform technical and operational plans for the envisioned GENI suite of research infrastructure.

Spiral 1 will last for 12 months; it will then be succeeded by a second phase, GENI Spiral 2, which will last for a further 12 months, and so forth. We expect the community's evolving research agenda, combined with insights and experience from earlier spirals, to set specific goals for those later spirals.

GENI is being designed and prototyped by the research community, with project management and system engineering provided by the GENI Project Office (GPO). After an open solicitation process and extensive peer reviews, the GPO has selected an initial 29 development teams to participate in Spiral 1. We expect that a large majority of these teams will continue to participate in subsequent spirals, augmented by additional teams funded by later GPO solicitations. We also anticipate that other projects may join the GENI prototyping effort even if not explicitly funded through GPO solicitations.

2.1 Primary Goal of Spiral 1

Spiral 1's primary goal is to develop, integrate, and attempt to operate very rudimentary, end-to-end working prototypes, as rapidly as possible, then co-evolve them with the community's evolving research vision. An early, end-to-end working prototype will greatly help the community achieve a shared vision by providing a strawman example for arguments and discussions going forward.

Spiral 1 will attempt a first, trial integration of the large majority of ingredients that have been envisioned for GENI to date, including compute and storage clusters, multiple national backbones and regional optical networks, campuses, metropolitan wireless and sensor networks, instrumentation and measurement, and user opt-in.

The GPO intends Spiral 1 to address two major risks in the overall system concept, namely, whether a suitable control framework can be created, and whether end-to-end slicing across multiple technologies is feasible.

Control Frameworks - Because the GENI control framework software presents very high technical and programmatic risk, we have funded multiple design approaches to integrate and demonstrate different technologies of the control software. We expect the different approaches to be illuminating to all involved. There is no pre-ordained outcome for these frameworks: in particular, we do not currently intend to force a "down select" or "sudden death" at any point in the prototyping process but rather to let developers vote with their feet over time.

End-to-End Slicing - Spiral 1 includes multiple versions of almost all the technologies envisioned in GENI's conceptual design. A key goal will be to attempt to demonstrate slices that span multiple technologies, e.g., a slice that runs end-to-end from sensor networks through optical networks to a virtual machine in a compute/storage cluster. This will be hard, but the payoff will be very high.

2.2 Important Areas NOT Fully Addressed by Spiral 1

Readers familiar with the GENI concept will note that a number of very important aspects of the GENI design are *not* primary goals of Spiral 1. In most cases, these areas are being explored by individual projects within Spiral 1, and will almost certainly arise as central goals of subsequent spirals. Examples of these areas not fully addressed by Spiral 1 include:

- User opt-in
- Easy-to-use researcher interfaces
- Instrumentation and measurement
- Operations and management
- Full range of desired technologies
- Large-scale experimentation

Clearly these are important aspects of the envisioned GENI design, and we expect that the individual projects addressing these areas in Spiral 1 will provide useful illumination to ongoing discussions and analysis. However, we do not expect that the integrated prototype systems arising from Spiral 1will fully incorporate these inputs; "end-to-end" integration that incorporates these inputs will be addressed in later spirals.

2.3 How can you participate in Spiral 1?

GENI is being designed and prototyped by the research community as a whole, via open and transparent processes conducted through email lists, wikis, and public meetings. We strongly encourage your participation in this process, particularly in combined academic/industrial teams.

Since GENI Spiral 1 is the very start of the prototyping process, at the time of writing there is nothing "up and running" that you can join. However, we expect that there will be running prototypes in 6-12 months, after which time it will be considerably easier to determine how you might participate in the subsequent spirals!

Until that time, here is GPO guidance on how you might participate in Spiral 1:

- **General interest** – Browse the geni.net website, learn more about GENI's goals and concepts, and drill down to individual research teams to find specific details of Spiral 1 status.

- **Interested in participating in GENI design and planning** – Join the GENI Working Groups (via geni.net) to participate in design discussions.

- **System builders** – If you have existing infrastructure that you would like to fold into the evolving GENI suite, please contact Aaron Falk at the GPO. This may be possible, especially if it is readily compatible with one of the existing Spiral 1 "clusters" (see next chapter). If you wish to build new prototypes and incorporate them, please select one of the Spiral 1 clusters to serve as your control framework. (The GPO does not plan to fund any more alternative control frameworks at this time.) If you need funding for your prototypes, you may wish to write a proposal for any of the forthcoming GPO solicitations; details will be made public through the geni.net website. Note, however, that most projects funded under these later GPO solicitations will not join the GENI effort until Spiral 2.

- **Experimenters** – If you wish to run research experiments on the GENI suite of infrastructure, please contact Aaron Falk at the GPO. It may be possible to run certain experiments even very early in Spiral 1, and the GPO is interested in early experience of researchers who are attempting to perform experiments. Please also contact Ellen Zegura of the Network Science and Engineering Council, who is leading the effort to draft the community's research agenda; that will ensure that your interests are adequately represented in the agenda.

- **Infrastructure operators** – If you operate infrastructure that could be involved in early GENI spirals, and are interested in participating, please contact Heidi Picher Dempsey at the GPO. Infrastructure of particular interest includes campus networks, regional optical networks, large-scale computing / storage clusters, metropolitan wireless networks, and sensor systems. We are very interested in gaining experience by attempting to incorporate existing infrastructure into the GENI suite and perform trial operations as early as possible. We believe that GENI prototyping can often be performed on existing, in-use infrastructure with minimal impact to ongoing operations.

3 GENI Conceptual Design

To understand how the various projects will fit together, it is useful to briefly review the elements of the GENI conceptual design. This topic is explored in more detail in the *GENI System Overview* (recently revised), but we include an abbreviated introduction here for clarity.

It is important to note that this conceptual design is still very high-level and provisional, and may change considerably as we all gain experience through Spiral 1. Indeed, exploratory prototyping (via a series of spirals) is intended to help drive the GENI design process forward. As the community gains experience with these prototypes, both in building them and in attempting to operate them, this design will become far more concrete. By the *end* of the prototyping stage, we should have a very good design; but right now it's still a little too early.

3.1 Principal Entities in the Conceptual Design

As shown in Figure 3-1, the principal entities in the GENI conceptual design are:

- One or more c**learinghouses**, which include **registries** for principals, slices and components.

- **Aggregates** or **components,** where an aggregate comprises multiple individual components. The GENI control framework utilizes an **aggregate manager** (or component manager for solo components). Example aggregates include compute clusters, backbone networks, campus networks, sensor grids, etc. Resources on components are allocated to researchers by way of the GENI control framework. Individual components (aggregated or not) may be shared, for example using virtualization, and are expected to be deeply programmable, to permit configuration by researchers. The use of a common control framework will allow components owned and operated by different organizations to **federate**, allowing access by researchers but retaining some oversight and control. For example, Component Z in the figure is an example of a federated component owned by the DOE.

- GENI-affiliated **research organizations**, who vouch for **researchers.** Researchers may have local **experiment tools**, and optional local principal registries.

- GENI-affiliated **experiment support services**, including as examples: **storage services** for researchers to archive code, configurations and experiment results; **measurement services**, to make, gather, and archive experiment measurements; and **GENI-Internet gateways**, to permit a controlled exchange of traffic with the Internet. We expect a wide range of experiment support services to be developed by the GENI community.

- **End-Users**, who connect via the Internet, or a native-GENI access network, to join a GENI experiment. Additionally, they may contribute resources to GENI such as access to their computers, handsets, or network bandwidth.

- GENI **Administration and Operations Organizations**, including a **Help Desk** for researchers.

Several logical planes connect these entities. These planes may share networking resources but will have different capacity, connectivity, and access control needs.

Experiment Plane, for data and internal control flows directly associated with a slice, e.g., from one programmable host to another programmable host, via one programmable network routing node and two optical networks.

Measurement Plane, for collecting and moving data associated with a slice, to permit a full understanding of the environment and the results of an experiment, and to allow for later analysis.

Control Plane, to allow researchers and their proxies to set up and control GENI slices.

Operations and Management Plane, for O&M data and control flows. This plane may include dedicated capacity or privileged access so that an operator can diagnose and bypass failures.

Researchers use experiment control tools to setup an experiment “in” a slice that spans an interconnected set of “slivers” on multiple components (and other types of platforms), in diverse locations. Each researcher remotely discovers, reserves, configures, programs, debugs, operates, manages, and teardowns the “slivers” that are required for their experiment, across multiple components of the GENI suite. Virtualized components can provide resources for multiple experiments at the same time, but keep the experiments isolated from one another.

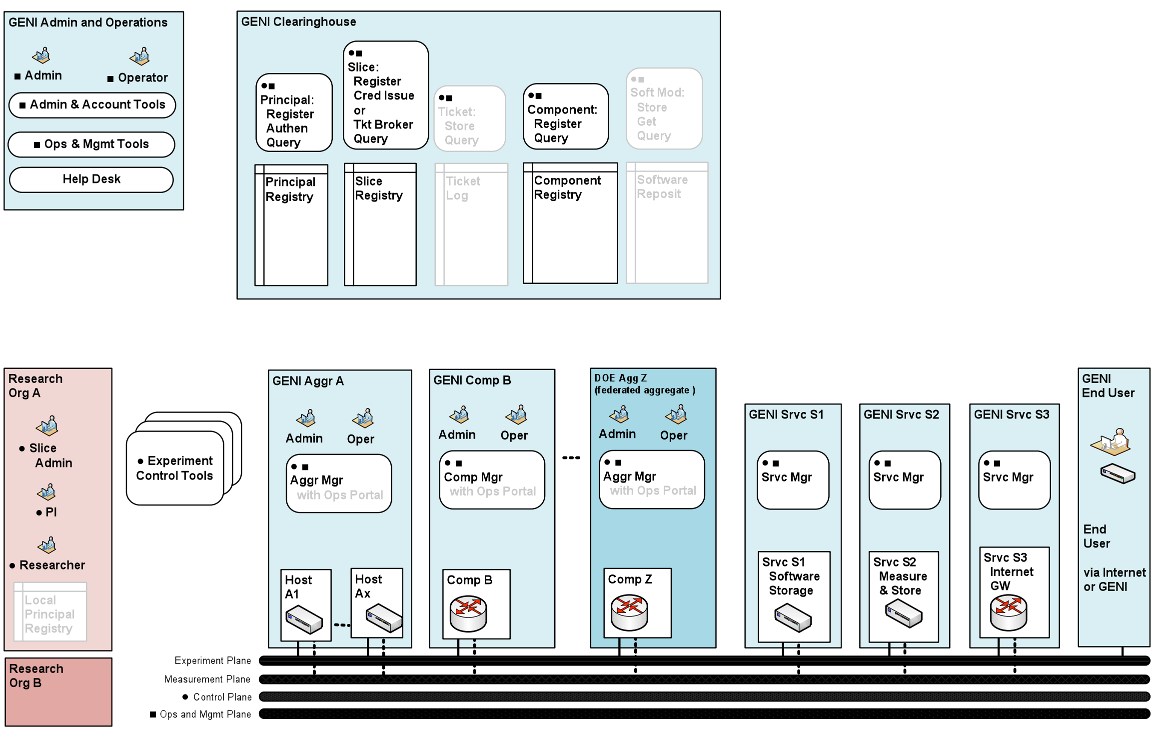

Figure 3-1. GENI System Decomposition Overview

3.2 What is Really Happening in Spiral 1?

As introduced in Chapter 2, GENI Spiral 1 has two key goals: demonstrate *control frameworks* that can manage a wide variety of envisioned technologies; and demonstrate *end-to-end slicing* across a range of technologies.

These two goals correspond directly to critical entities and interfaces shown in the system decomposition diagram above.

Integrating control frameworks "vertically" with aggregates. Spiral 1 contains five competing control frameworks (DETER, PlanetLab, ProtoGENI, ORCA, and ORBIT) chosen through an open, competitive solicitation. Each contains *some* but not *all* of the functionality envisioned for a GENI control plane. Their goals will be to evolve their individual designs, and the conceptual design of GENI as a whole, to a point where full clearinghouse functionality can be demonstrated. This will involve integrating control frameworks with a variety of aggregates, also chosen by the GPO through open, competitive solicitation. These aggregates were chosen to reflect the range of technologies currently envisioned in GENI's conceptual design. Additional aggregates may join Spiral 1 while it is in progress, for example through industry collaboration or externally funded projects joining the integration effort.

Integrating the experiment plane "horizontally" across aggregates. Slices are, in essence, virtual topologies that link together resources within different aggregates. There are many, many different ways to create virtual topologies with modern networking technology, including IP Virtual Private Networks, Ethernet VLANs, MPLS, etc. Since one intended use of the GENI suite is experimentation with non-IP data transport, we need to create mechanisms for creating virtual topologies that can transport arbitrary packet formats. The GPO has selected two mechanisms for trial use in Spiral 1: IP tunnels and Ethernet VLANs. After these are demonstrated and shaken down in Spiral 1, we can begin to explore additional mechanisms of interest such as direct optical-layer connectivity.

3.3 Federation is Fundamental

GENI's conceptual design is organized as a *federation* of autonomously owned and operated systems. This is an extremely important point, and fundamental to both its design and its intended operation. GENI is not currently conceived of as a single, monolithic system owned and operated by a single administration. Quite the contrary: it is conceived as being composed of a number of quite different systems, owned by different entities, that are "glued together" to form an over-arching ensemble. This approach closely mirrors that of the Internet, which is a federation of many autonomous systems, each with its own independent owners and operators.

Spiral 1 will try out early forms of federation, because this is such an important construct in GENI's conceptual design. As will be seen, Spiral 1 includes a number of competing control frameworks which include primitive clearinghouses; each has its own ideas on how federation should work. As we gain experience with the various approaches, the community can begin to decide which mechanisms work best, but we do not expect compatible mechanisms in Spiral 1. (Until we gain experience, it is still too early to decide what works best.)

Spiral 1 aggregates are all independent entities, which will then be joined into "clusters" organized by control framework. Examples include existing sensor fields, campus networks, compute clusters, regional networks, etc. We expect that all of these existing aggregates will continue to have their own, independent existence and management and, in many cases, uses unrelated to GENI, including production uses. A key goal of Spiral 1 is to attempt to federate them into larger, end-to-end systems as envisioned in GENI's conceptual design. This federation will be capable of supporting experiments that span the aggregates in the cluster. Note that in Spiral 1, some aggregates may be implemented in largely manual ways, with a combination of GENI programmable and procedure-based steps for enabling experiment planes.

3.4 To Learn More about GENI's Conceptual Design

Please consult the *GENI System Overview* but also remember that GENI is being designed by the community. If you wish to participate in the design, sign up for a GENI Working Group through geni.net.

4 Spiral 1 Technical Goals

As part of the GPO's overall system engineering effort for GENI, Spiral 1 should give the GENI community a better understanding of what it takes to combine and operate many GENI prototypes in a way that allows real users to exercise GENI functions end-to-end over live networks. The integration effort also combines with working group efforts to better define GENI risks and requirements. To these ends, Spiral 1 will accomplish the following technical goals:

1. Integrate control frameworks with multiple types of aggregates that will support GENI functions for geographically dispersed users and projects.
2. Integrate the GENI experiment plane to support data transfers on end-to-end slices between multiple project sites. The experiment plane is expected to support both IP and non-IP protocols across varied substrates.
    a. Integrate end-to-end "native mode" GENI connections, which are capable of supporting experimental protocols (including non-IP protocols) between Spiral 1 endpoints.
    b. Integrate IP connectivity between GENI Spiral 1 sites and the rest of the Internet where needed. This connectivity supports early integration and prepares for opt-in connections from existing IP networks and users. (We do not expect a significant number of end user opt-in experiments in Spiral 1, however.)
3. Integrate and interconnect programmable GENI nodes in multiple substrates. Spiral 1 will deploy on two national backbones, several regional optical networks, parts of many campus networks, and over several wireless infrastructures.
4. Demonstrate very early versions of GENI instrumentation, measurement, and data sharing functions that will support GENI functions for early experiments in the Spiral 1 environment.
5. Integrate operational infrastructures (academic and commercial) into Spiral 1. This work should provide realistic deployment scenarios for GENI, and provide exposure to the integration challenges of large-scale production environments.
6. Toward the end of Spiral 1, support some live experiments by users outside the Spiral 1 development teams. These experiments will be suitable only for early adopters. They will not provide all the features of a full-fledged research environment for general access to GENI, but they will provide a valuable indicator of how well GENI prototypes can serve experimenters.
7. Define and integrate basic Operations and Management functions and procedures needed to support Spiral 1 environments. This goal includes security for operations.

5 Spiral 1 Control Frameworks & their clusters

A primary goal for GENI Spiral 1 is to develop and operate multiple competing approaches to the GENI control framework. Towards that end, most GENI projects have been grouped into one of five control framework clusters. Each cluster will implement key control framework functions and will be capable of supporting experiments. In general, each cluster consists of one prototype clearinghouse plus some number of prototype aggregates that it will control.

A single interoperable control framework will not be available in Spiral 1. In fact, we expect that control frameworks will implement the required functions in different ways. This will provide an opportunity to make design decisions on this important topic informed by implementation and operational experience. Over time, member projects may switch clusters, for example if another cluster will provide easier integration. Clusters may share technology and merge if they desire.

5.1 Roles of Control Frameworks in Spiral 1 Integration

The prototype control frameworks play several roles in Spiral 1 integration, each of which allows the community to gain valuable experience in important issues influencing GENI design, as well as the beginnings of technology that can be used for early research experimentation.

Operational clearinghouses. Provide an operational clearinghouse for the projects in the control framework group. This clearinghouse supports GENI functions that allow researchers participating in Spiral 1 to use slices of components and aggregates in the control framework group. An example Spiral 1 control framework function is a registry of GENI principal experimenters.

Reference software implementations. Develop and make available to the GENI community reference implementations of software for the clearinghouse and component/aggregate manager software. These implementations will be revised and improved in multiple releases based on deployment and integration experience throughout Spiral 1. Many projects participating in a control framework cluster are also actively involved in developing or improving parts of the clearinghouse and aggregate/component manager software that are key to their projects. Projects in a control framework will collaborate with each other and with the GPO to make end-to-end experiments using this software in their control framework group successful by the end of the year.

Early Operations and Management experience. Provide Spiral 1 Operations and Management (O&M) and security functions for their cluster, and work with other projects that are developing GENI-wide security and operations architecture and implementations. Functions that are common across GENI require support from each control framework and the projects in that control framework cluster.

Tool interfaces. Provide programmable interfaces for GENI tools. All control frameworks will support software interfaces that help researchers find and use GENI resources. Several Spiral 1 projects are developing software to support configuration, downloading, tracking, user opt-in, and data collection for experiments and slices. This kind of software will eventually be the face of GENI for many researchers. In Spiral 1, projects in a control framework will agree on programmable interfaces and techniques for accessing them that will support software integration into Spiral 1 end-to-end experiments. The control framework projects will implement the control framework half of the interfaces, and other Spiral 1 projects will implement the researcher's software half. Some control framework projects will also implement their own researcher software. Ideally, some software interfaces will be common across multiple control frameworks, laying the groundwork for later GENI-wide integration.

The GPO will work with the projects to provide additional system engineering for successful end-to-end Spiral 1 experiments where needed, arrange demonstrations at GENI Engineering Conferences and encourage external early adopter researchers to participate in Spiral 1 experiments.

5.2 Overview of Spiral 1 Control Frameworks

Spiral 1 control framework clusters have different emphases. Some are more established and concentrating on expanding their base and integrating new approaches, technologies, and projects into their framework. Some are investigating characteristics of control frameworks for newer substrates in depth. Some are investigating alternative architectures in particular environments.

The five clusters currently being organized for Spiral 1 are:

A. "DETER" control framework from USC/ISI, a single project emphasizing issues around federation, trust, and security.

B. "PlanetLab" control framework, built around the PlanetLab project at Princeton, emphasizing development of control framework reference implementations and integrating a range of component technologies and tools.

C. "ProtoGENI" control framework, built around the Emulab project at the University of Utah, emphasizing network control and measurement and integrated experiment environments.

D. "ORCA" control framework from Duke University and RENCI, a cluster emphasizing development of resource allocation strategies and integration of sensor networks.

E. "ORBIT" control framework from Rutgers University, emphasizing wireless networks.

In the following sections we use the control framework clustering to introduce most of the Spiral 1 projects. Later sections introduce prototypes in Spiral 1 that have not been assigned to a cluster. Four projects are expected to study and then "pick one" of the control frameworks/clusters. Another four projects are expected to interact with "all" of the control frameworks/clusters. Finally, two analysis projects are introduced.

It is important to note that besides developing a working control plane, GENI components will also require experiment and O&M plane integration. (Only a very small amount of measurement plane work is funded in Spiral 1.) These topics are addressed in more detail in Sections 6, 7, and 8.

5.3 Cluster A: DETER Control Framework

Cluster A, as shown in Figure 5-1, utilizes the DETER control framework from USC/ISI, and currently consists of one project. This one-project cluster will form a self-contained "mini-GENI", capable of supporting experiments at the end of Spiral 1, but is otherwise isolated from the other clusters. In particular, it will be able to demonstrate both federated networks and coordinated network provisioning by the end of Spiral 1.

[**DETER**]. "Trial Integration Environment based on DETER (TIED)". PI is John Wroclawski at USC/ISI. The scope of work on this project is to develop and evangelize a control framework that particularly emphasizes usability across different communities, through federation, rich trust/security models, and similar enabling mechanisms. Priority activities that contribute to this scope include the following items: 1) Develop and deploy TIED component manager packages and clearinghouse packages. 2) Operate prototype TIED clearinghouse. (The clearinghouse currently includes no other GENI-funded projects besides those included in the original TIED proposal, but that could change over the course of the project's three years.) 3) Make reference clearinghouse and component manager implementations available via download to GENI prototype developers to use in their own aggregate or campus infrastructures. Provide limited integration and development support for those users so that reference implementations can be deployed at multiple GENI locations. 4) Provide GENI user access to DETER testbed. (Although DETER already supports access to its testbed for many different users, this goal emphasizes that access to the testbed should use GENI primitive building blocks from GENI architecture to find and obtain resources, and should allow for users outside the currently-deployed DETER community to access the testbed.)

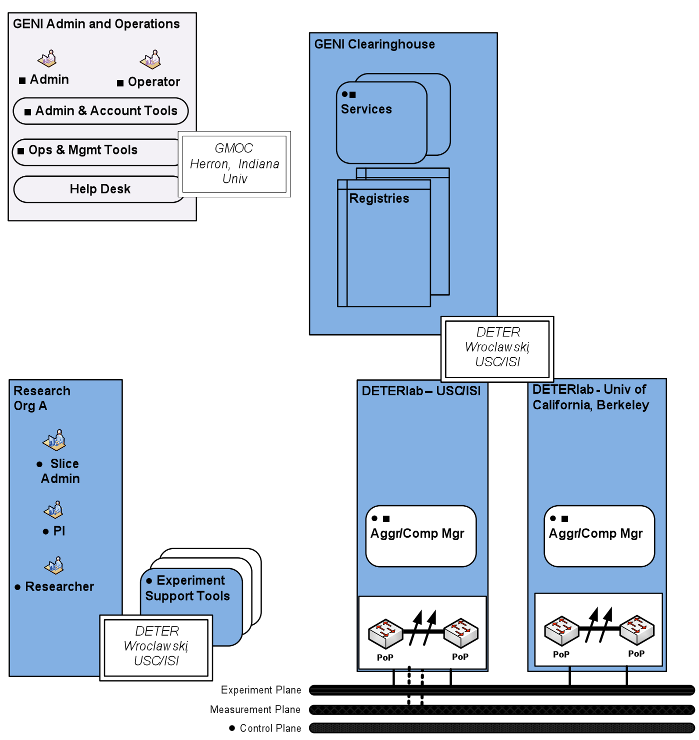

Figure 5-1. Cluster A utilizing DETER control framework

5.4 Cluster B: PlanetLab Control Framework

Cluster B, as shown in Figure 5-2, utilizes the PlanetLab control framework from Princeton, and currently includes seven projects:

[**PlanetLab**]. "Prototyping and Validating the GENI Control Framework". PI is Larry Peterson at Princeton. The scope of work on this project is to prototype the control framework that logically stitches GENI components and user-level services into a coherent infrastructure; integrates a representative set of components and autonomous organizations into a coherent, operational whole; integrates edge clusters, high-performance backbone nodes, enterprise-level nodes, and edge-sitting wireless nodes; and federates across multiple independently controlled facilities, including those managed by international and corporate partners. This effort will culminate in a running system that can be accessed by the network research community. Specific development goals include creating and deploying component manager packages and clearinghouse packages; operating a prototype clearinghouse; making reference clearinghouse and component manager implementations available via download to GENI prototype developers to use in their own aggregate or campus infrastructures; providing limited integration and development support for those users so that reference implementations can be deployed at multiple GENI locations; and providing GENI user access to PlanetLab (800 nodes, 400 sites).

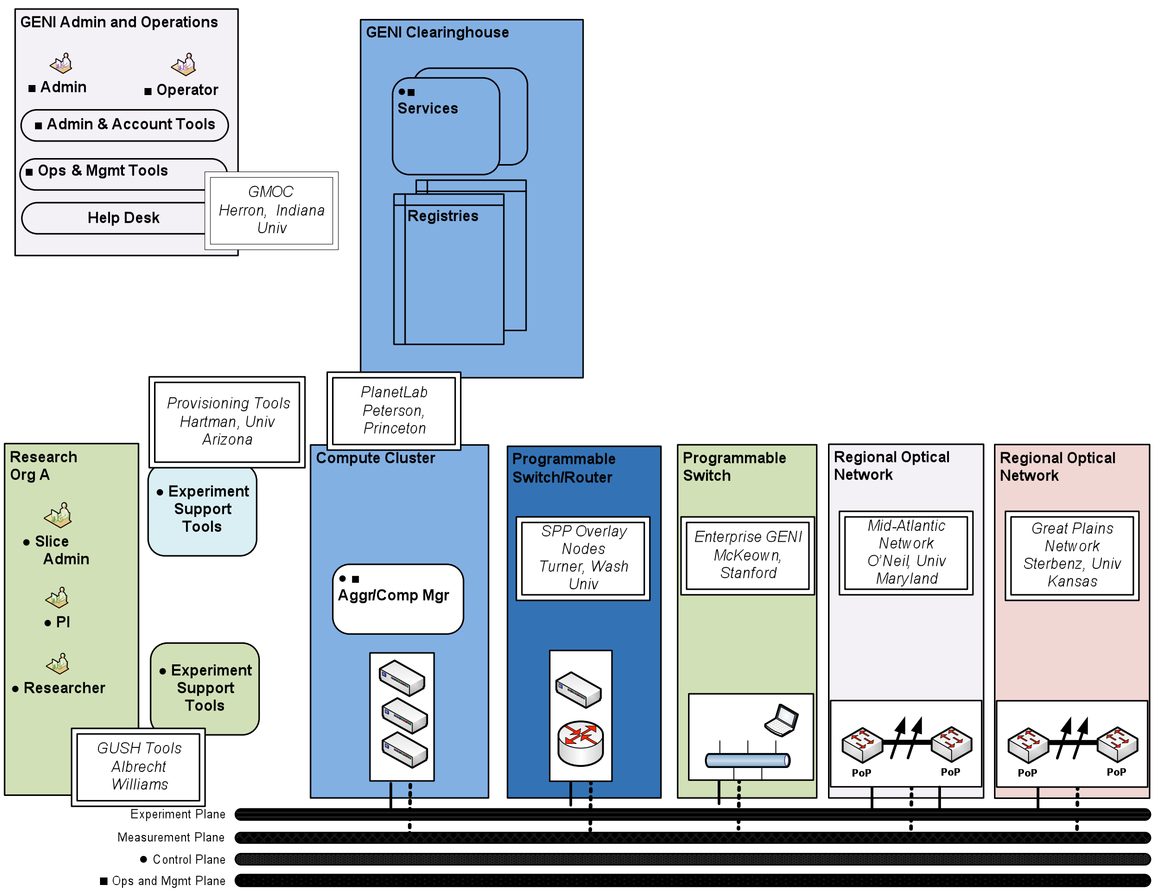

Figure 5-2. Cluster B utilizing PlanetLab control framework

[**Enterprise GENI**]. "Enterprise GENI: Prototype, Demonstrate and Create Kits for Replication". PI is Nick McKeown at Stanford. The scope of work on this project is to illustrate how GENI can be deployed on local networks, such as campus and enterprise networks, and to develop a kit that allows the work demonstrated in this project to be easily replicated elsewhere. Priority activities that contribute to this scope include the following items: 1) Deploy Enterprise GENI technology in a campus (wireline and wireless); 2) Integrate an OpenFlow network with a GENI control framework in an Aggregate Component Manager; 3) Provide access to Enterprise GENI testbeds for GENI users; 4) Define an Enterprise GENI deployment kit for research and potential commercial transition.

[**Gush Tools**]. "GENI Experiment Control Using Gush". PIs are Jeannie Albrecht at Williams College and Amin Vahdat at Univ. of California, San Diego. The scope of work on this project is to design and implement a prototype to build Gush (the GENI User Shell), a robust experiment control and management framework for GENI. The final product of this work is expected to be a fully functional framework that supports experiment control through three user interfaces, including a graphical user interface (GUI), command line interface, and a programmatic interface. This work will include design of an API in Gush for interacting with GENI Clearinghouses. Gush will integrate with GENI Clearinghouse prototypes provided by the control framework developers to test the Gush API and the use of slice interaction functions. Initial work will be with the PlanetLab control framework using XML-RPC communication with the PlanetLab Central Database (PLC). Development will focus on getting the Gush command line and programmatic interfaces working before moving on to the graphical interface, with an emphasis on detailed error reporting that will simplify debugging.

[**Provisioning Service**]."A Provisioning Service for Long-Term GENI Experiments". PI is John Hartman at Univ of Arizona. The scope of work on this project is to prototype a provisioning service that provides the infrastructure required to develop, deploy, monitor, and maintain long-term and short-term experiments on GENI. Priority activities that contribute to this scope include the following items: 1) Develop a GENI-specific provisioning service that manages software deployment for slices and also interfaces with GENI clearinghouses. Make the service available to projects beginning in Spiral 1 for at least one clearinghouse, and expanding availability in subsequent spirals. 2) Provide configuration management and resource management for longer-term experiments where software and components can change over the lifetime of the experiment. 3) Provide other researcher helper tools such as monitoring that make it easier to manage experiments.

[Mid-Atlantic Network] PI's are Peter O'Neil, Chris Tracy, and Jarda Flidr at University of Maryland. This project will provide access to an operational, regional, multi-wavelength optical network. Key contributions include: Extending DRAGON's open-source GMPLS-based control plane implementation to include edge compute resources and support network virtualization (viewing DRAGON as an aggregate/component manager); 2) Leading the integration of PlanetLab control framework within Cluster B onto the DRAGON test-bed, a physical DWDM and Layer 2 network deployment of open-source GMPLS control plane software development and the deployment of that control plane software over other networks; 3) Enabling backbone connections to resources of substrate components in Cluster B participants across Internet2 in support of end-to-end VLAN connections into the DRAGON test-bed; 4) Making integrated (VLAN connections and control framework) DRAGON infrastructure available to external researchers by the end of Spiral 1; 5) Representing/offering developed DRAGON technology to the various control frameworks selected in Spiral 1 through active participation in GECs and the appropriate working groups.

[**Great Plains Network**]. "GpENI: Great Plains Environment for Network Innovation". PI is James Sterbenz at Univ of Kansas. This project will provide access to a regional optical network with sliceable optical and router nodes, plus programmable clusters. Key contributions to Spiral 1 include: 1) Lead the integration of the Princeton control framework onto the GpENI testbed; 2) Enable backbone connection (Internet2/NLR) supporting end-to-end VLAN connections into the GpENI testbed, subject to available connectivity; 3) Make GpENI infrastructure running PlanetLab control framework available to external researchers over VLAN connections by the end of year 1 (subject to Princeton capabilities and GENI wide-area accessibility); 4) Present GpENI integration and operational status to the various control frameworks selected in Spiral 1 through active participation in GEC meetings and the appropriate working groups.

[**SPP Overlay Nodes**]. "Prototype Deployment of Internet-Scale Overlay Hosting". PIs are Jonathan Turner and Patrick Crowley at Washington Univ. The objective of the project is to acquire, assemble, deploy and operate five high performance overlay hosting platforms, and make them available for use by the research community, as part of the emerging GENI infrastructure. These systems may be hosted in the Internet2 backbone. We will provide a control interface compatible with the emerging GENI control framework that will allow the network-scale control software provided by Princeton to configure the systems in response to requests from research users. The project will leverage and extend our Supercharged PlanetLab Platform (SPP) to provide an environment in which researchers can experiment with the kind of capabilities that will ultimately be integrated into GENI. We also plan to incorporate the netFPGA to enable experimentation with hardware packet processing, in the overlay context.

5.5 Cluster C: ProtoGENI Control Framework

Cluster C, as shown in Figure 5-3, utilizes the ProtoGENI control framework based on the Emulab implementation at the Univ of Utah, and currently includes five projects:

[**ProtoGENI**]. "End-to-end ProtoGENI". PI is Jay Lepreau at the Univ of Utah. This project includes a large-scale integration of existing and under-construction systems that provide key GENI functionality. The integration consists of four key components: a nationwide, high-speed backbone on Internet2's wave infrastructure; a set of sliceable, user programmable components embedded in this backbone, including PCs and "programmable hardware" NetFPGA cards; a set of subnets, including a wireless network, residential broadband, and programmable edge clusters, that will be connected to this backbone; and software from the University of Utah, based on an enhanced version of the Emulab testbed management software, plus additional software from PlanetLab and VINI, to manage the backbone, many of the subnets, and to provide a common point of integration between them. The primary contributions of this project to GENI Spiral 1 are the development and deployment of the ProtoGENI programmable network on Internet2; deployment and operation of a prototype clearinghouse, control framework, and tools; delivery of reference clearinghouse and component manager implementations available to GENI prototype developers to use in their own aggregate or campus infrastructures; and limited integration and development support for those users so that reference implementations can be deployed at multiple GENI locations.

[**BGP Mux**]. "Bringing Experimenters and External Connectivity to GENI". PI is Nick Feamster, at Georgia Tech. This project will (1) add facilities and functions to the VINI testbed to enable experiments to carry traffic from real users; and (2) increase the experimental use of the VINI testbed by providing a familiar experiment management facility. The deliverables for this project all comprise software for supporting external connectivity and flexible, facile experimentation on GENI substrates. The primary deliverables are a BGP session multiplexer – a software router based on the Quagga software routing suite, software support for virtual tunnel and node creation, and integration of the above functionality with clearinghouse services developed as part of the ProtoGENI project. In particular, this project contributes to GENI design and prototyping through BGP mux development integration with ISPs; tunnel & topology establishment & management; ProtoGENI clearinghouse integration; and support for isolation & resource swapout.

[**CMU Testbeds**]. “Prototype Support for Heterogeneous Testbed Resources: Integrating Cluster, Broadband and Wireless Emulation Nodes into the ProtoGENI Framework”. PI is David Andersen at Carnegie Mellon Univ. This project will build upon CMU’s existing cluster, neighborhood wireless/broad-band, and wireless emulation testbeds to concretely identify—and build prototypes of—the authentication, resource arbitration, and node management primitives needed to coherently deal with this very diverse set of resources. The project will integrate these testbeds with the ProtoGENI effort from the University of Utah, which is itself based upon that group’s Emulab software. The primary contributions of this work towards GENI Spiral 1 are the integration of HOMENET, CMU wireless emulator, and CMULab into the ProtoGENI control framework (includes federation & Internet2connectivity); extension of HOMENET capabilities to support node/experiment management & isolation; definition/refinement of control framework elements such as RSpecs; and expansion of HOMENET user opt-in control.

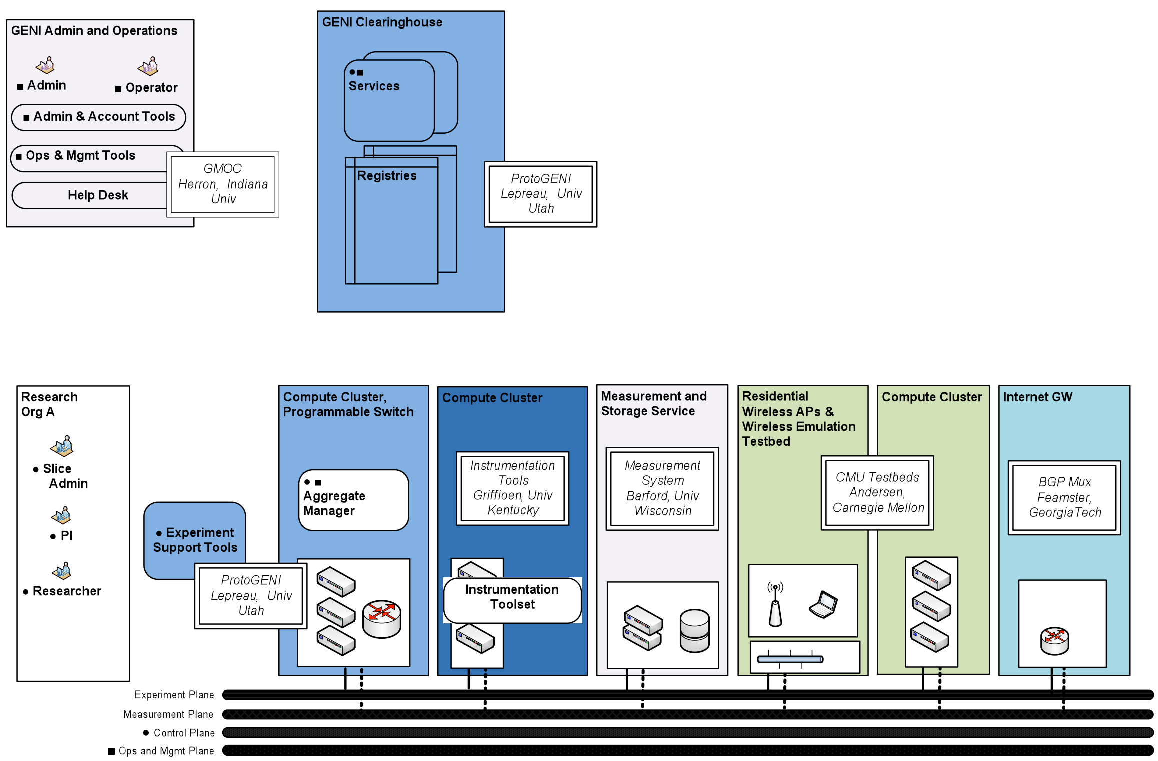

Figure 5-3. Cluster C utilizing ProtoGENI Control Framework

[**Instrumentation Tools**].“Instrumentation Tools for a GENI Prototype”. PI is James Griffioen at Univ of Kentucky. This project will provide measurement and monitoring tools for substrate components, and will begin by integrating them into a host cluster based on Emulab hosts. The scope of work on this project is to create a GENI-enabled testbed based on the existing University of Kentucky Edulab, and to implement and to deploy instrumentation capabilities that will enable GENI users to better understand the runtime behavior of their experiments. Priority activities that contribute to this scope include the following items: 1) Provide an early operational federated testbed with administrative support and active student use integrated with a GENI control framework, allowing time for studying and improving the testbed over the period of the contract and 2) provide an implementation of instrumentation capabilities for researcher and student helper tools that give GENI users the ability to better understand the runtime behavior of their experiments.

[Measurement System].“Instrumentation and measurement for GENI”. PI is Paul Barford at Univ of Wisconsin – Madison. The scope of work on this project is to develop, test and deploy a prototype implementation of network instrumentation and measurement systems for the GENI infrastructure. Priority activities that contribute to this scope include the following items: 1) Develop an instrumentation and measurement implementation for GENI that provides an interface for researchers, as well as an interface to a GENI control framework; 2) Develop an implementation that gives GENI users access to a shared measurement and instrumentation infrastructure that is extensible to several different kinds of measurement devices; 3) Implement systems consistent with the GENI Instrumentation and Measurement Systems (GIMS) Specification, to help reduce risks in this as-yet-unimplemented area of GENI.

5.6 Cluster D: ORCA Control Framework

Cluster D, as shown in Figure 5-4, utilizes the ORCA control framework from Duke Univ/RENCI, and currently includes four projects:

[**ORCA/BEN**]. ”Deploying a Vertically Integrated GENI “Island”: a Prototype GENI Control Plane (ORCA) for a Metro-Scale Optical Testbed (BEN)”. PIs are Ilia Baldine at RENCI and Jeff Chase at Duke. The scope of work on this project is to extend ORCA (a candidate GENI control framework) to include the optical resources available in BEN. Also, make a reference implementation of ORCA available to additional GENI prototypes and assist, with limited support, in the integration of ORCA into select wireless/sensor prototypes. The team will operate a clearinghouse for the various testbeds under the ORCA control framework. Also, connect with the NLR backbone network FrameNet service to facilitate end-to-end VLAN connections into BEN. Finally, make the integrated (VLAN connections and control framework) ORCA/BEN infrastructure available to external researchers by the end of Spiral 1.

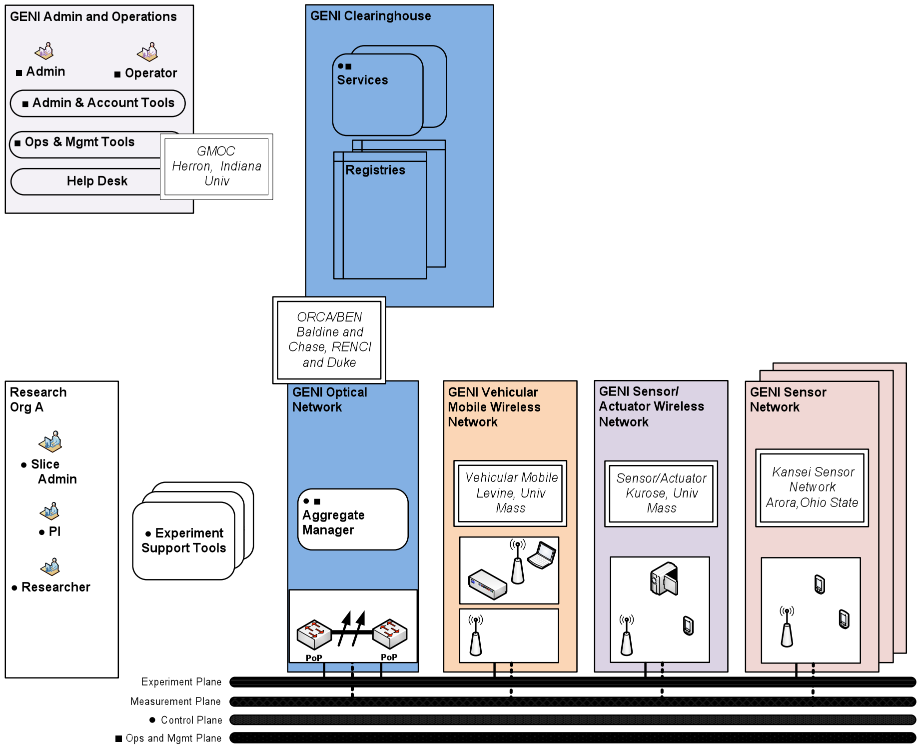

Figure 5-4. Cluster D utilizing ORCA control framework

[**Vehicular Mobile Network**]. "Slivers and slices in a Diverse, Outdoor, Mobile Network Testbed". PIs are Brian Levine and Mark Corner at Univ Massachusetts – Amherst. The scope of work on this project is to extend an outdoor, mobile network testbed to support slivering and utilize a GENI candidate control framework (ORCA). This includes: 1) A virtualized operating system on the vehicular computers using Xen, which will allow for the isolation of experiments and customization of the operating environment, and permit each experiment to begin from a known configuration. 2) Virtualized access to attached devices, including a 802.11 radio, GPS, and 900 MHz radio on each bus. 3) Standardized, general GENI mechanisms to authenticate users, install customized software and experiments, schedule DOME resources, and to log results. 4) Integration, deployment and access to GENI users.

[**Sensor/Actuator Network**]. "Sensor Virtualization and Slivering in an Outdoor Wide-Area Wireless GENI Sensor/Actuator Network Testbed". PI is Jim Kurose at Univ of Massachusetts – Amherst. The scope of work on this project is to extend an outdoor, wide-area sensor/actuator network testbed to support slivering and utilize a GENI candidate control framework (ORCA/Shirako). This includes: 1) Virtualization of the sensor/actuator system. 2) Integration with GENI-compliant Software Artifacts, including the use of Shirako software (part of the ORCA project) as the base for the control framework. 3) Making the testbed publicly available, starting in year 1, and integrating it into an environment of federated testbeds by the end of year 2. 4) Providing documentation for testbed users, administrators, and developers.

[***Kansei* Sensor Network**]. "GENI-fying and Federating Autonomous *Kansei* Wireless Sensor Networks". PI is Anish Arora at Ohio State Univ. The scope of work on this project is to adapt a large-scale prototype wireless sensor network to provide GENI-compliant interfaces and principles, to provide publically available support for programmability, virtualization, and slice-based experimentation, and to deploy three geographically dispersed sites in a federated arrangement. Also, provide periodic demonstrations, code releases and installation packages. Furthermore, provide and experiment interaction dashboard as well as a scripting environment for composing long running, complex/phased experiments. And finally, provide the Kansei Doctor, whose multi-level invariant-based detector-corrector modules will help make Kansei more self-repairing and autonomic.

5.7 Cluster E: ORBIT Control Framework

Cluster E, as shown in Figure 5-5, is focused on mobile and wireless testbeds, and uses the ORBIT control software for resource management, experiment control and measurement, to support experiments in a wireless environment. The basic ORBIT control framework software includes the Component Manager and Experiment Control Tools, but does not include a full Clearinghouse. During Spiral 1, this control framework will explore in depth how wireless technologies interact with and affect GENI's architecture and requirements. Over time, ORBIT may evolve to include additional GENI control framework structures, or perhaps merge into another control framework, bringing its unique wireless capabilities into that framework. Cluster E includes two wireless network prototypes:

[**ORBIT**]. "Control, Measurement and Resource Allocation Framework for Heterogeneous Mobile and Wireless Testbeds". PI is Marco Gruteser at Rutgers Univ. The scope of work on this project is to extend the Orbit Control, Management and Measurement Framework (OMF) to design and implement a prototype of a GENI-compliant resource management, experiment control, and measurement framework, so that it can support experiments across heterogeneous testbed resources, with a specific focus on mobile testbeds. GENI control framework functions will be added to the OMF as they become defined. Support for mobile testbeds will include the handling of disconnection, and providing temporal and spatial control. Reference implementations of the GENI-compliant resource management, experiment control, and measurement framework will be provided to another wireless project, and its testbed will be integrated into the OMF environment as a federated testbed. Both testbeds will be connected to a GENI backbone network.

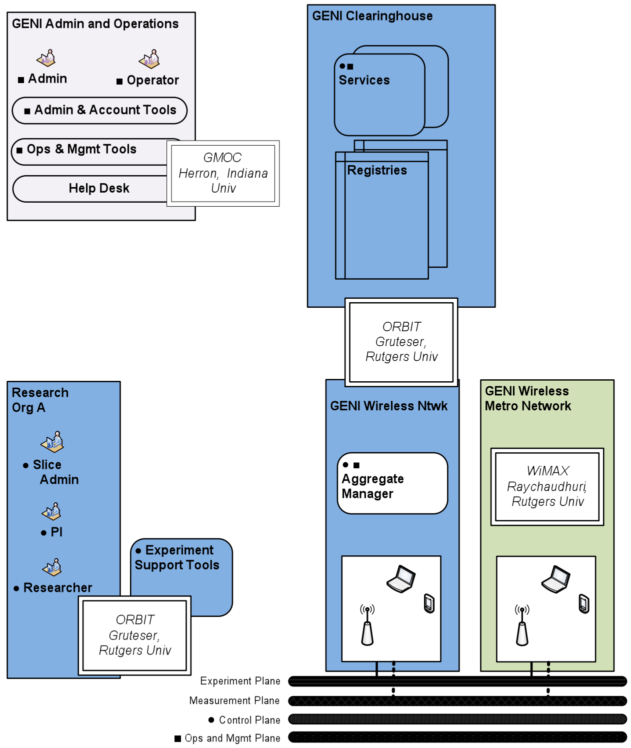

Figure 5-5. Cluster E utilizing "ORBIT" Control Framework

[**WiMAX**]. "Open Virtualized WiMAX Base Station Node for GENI Wide-Area Wireless Deployments". PI is Ray Raychaudhuri at Rutgers Univ. The scope of work on this project is to leverage a commercial IEEE 802.16e WiMAX base station product to prototype an open, programmable and virtualizable GENI base station node (GBSN) that could work over a metropolitan area and connect with off-the shelf WiMAX handsets and data cards. This includes the following steps: 1) Develop an open/virtualizable WiMAX base station with external control and data API's. 2) Import a control framework from the ORBIT project, and implement GENI-specific software on an external Linux-based PC controller for the WiMAX base station, demonstrating basic GENI compliance: virtualization, slice setup & resource management, L2/L3 programmability, and opt-in for off-the shelf terminals. 3) Integrate the GBSN with backhaul options to validate and demonstrate the total access networking solution, including VLAN connections to a GENI backbone network. 4) Demonstrate the GBSN capabilities in a phased manner, starting with controlled lab tests of each GENI feature and then migrating to a small-scale outdoor trial with off-the-shelf WiMAX terminal equipment. 5) Develop a deployment plan for multi-cell WiMAX services in GENI, including guidelines for site selection, frequency allocation, network backhaul and equipment/operating costs.

5.8 Projects to "Pick One" Control Framework Cluster

Some projects in Spiral 1 are expected to study and eventually "pick one" (or more than one) of the control frameworks/clusters for further integration. There are currently four such projects:

[**Digital Object Registry**]. PI is Larry Lannom at CNRI. The scope of work on this project is to adapt the Handle System and/or a Digital Object Registry to realize a clearinghouse registry for principals, slices, and/or components in a GENI Spiral 1 control framework (possibly using XML RPC), and capable of supporting limited operations in Year 1. Also, to analyze how the Handle System and/or a Digital Object Registry could be used to identify and register GENI software, including experimenter's tools, test images and configurations, and test results. And finally, to define the operational, scaling, security, and management requirements, plus recommended design approaches, for implementing GENI clearinghouse and software registry services.

[**Local Opt-In**]."Prototyping Techniques to Implement Opt-In". PI is Matt Mathis at Pittsburg Supercomputing Center. The scope of work on this project is to develop a prototype mechanism that allows researchers or enterprise network managers to direct campus/enterprise traffic to/from the public Internet through GENI infrastructure in a way that meets opt-in requirements for GENI. Priority activities that contribute to this scope include the following items: 1) Produce an opt-in requirements document covering this mechanism for the GENI Spiral 1 prototype environment. 2) Produce a reference design showing how a planned Spiral 1 project(s) opt-in can be implemented with Spiral 1 end-to-end connections. 3) Demonstrate how GENI could use this local opt-in mechanism to manage test and background traffic loads at GENI scales.

[**Million-Node GENI**]."A Prototype of a Million-Node GENI". PI is Thomas Anderson of Univ of Washington – Seattle. The scope of work on this project is to specify, build, and demonstrate a prototype end host deployment platform consisting of three components: a) a general-purpose yet safe execution environment for experimenter code running on end hosts, b) a light-weight, programmable and customizable proxy for end hosts for redirecting end-user traffic into the GENI infrastructure suite, and c) a clearinghouse for resources contributed by end users who have opted into the system. Specific development goals include: 1) Development of a viable end-host virtual machine; 2) Control-plane integration, including resource discovery and reservation; experiment debug and control; 3) End-user configuration and management tools; 4) Deployment strategies such as inclusion in Bit Tyrant or web plug-in; and 5) End-user policy & awareness issues and mechanisms.

[**Programmable Edge Node**]. "Design and Performance Evaluation of a Programmable Edge Node with x86 Multi-Core Processors and Network Processors". PI is Yan Luo at Univ. of Massachusetts – Lowell. This project will produce a programmable edge node using readily available and low cost technology. The key contributions of this work are: 1) Develop PEN virtual router templates, set-up scripts and traffic shaper as elements of the component manager or user help tools within a specified GENI control framework; 2) Develop measurement and diagnostic tools as elements of GIMS and user help tools within a specified GENI control framework; 3) Deploy an operational PEN in spiral-1 infrastructure under a specified control framework or identify similar platforms in Spiral 1 and assess the need to integrate/release the SW deliverables in this project with other GENI prototypes; and 4) Represent position taken on PEN architectures and design by active participation in GECs and appropriate working groups.

5.9 Projects to Contribute to All Control Framework Clusters

Some projects in Spiral 1 are expected to contribute to all of the control framework clusters. There are currently four such projects:

[**GMOC**]. "Global Research NOC at Indiana University – GENI Meta Operations Center". PI is Jon-Paul Herron at Indiana Univ. The scope of work on this project is to facilitate the sharing of operational and experimental information among GENI experimental components. This effort has both technical development and operational requirements. Technically, the GENI Meta Operations Center

(GMOC) would require a well-defined protocol to help generalize the operational details of GENI prototypes and for the providers of prototypes to send those details to an operational data repository. These requirements suggest a modular approach, with a generalized protocol rather than a restricted set of hardware and software that GENI prototype participants would be required to run. In other words, it would be largely up to the GENI Spiral 1 project investigators to decide what data to share and how to collect this data from their prototype infrastructure. The GMOC would provide the standardized format for this data and the systems required to share, monitor, display, and act on this data. In addition, the GMOC could be used to help provide a repository for data collections passing into and out of GENI prototypes for the purpose of discovering and isolating prototypes that have caused problems. This might require additional instrumentation at the connection points and substrate elements between prototypes. This would be accomplished with the help of the other prototypes that are part of GENI Spiral 1. The GMOC will work with these other projects to develop the operational data formats, processes, and systems needed for a consistent and useful suite of GENI infrastructures. During the project, participants will investigate how a Meta Operations Center might interact with various prototype participants to accomplish operations functions.

[**Security Architecture**].“GENI Security Architecture Toolkit”. PI is Stephen Schwab at SPARTA. This effort will define a GENI Security Architecture, in support of the broad goals for GENI Spirals 1 and beyond, including (a) working with teams prototyping multiple control frameworks and (b) demonstrating end-to-end slicing across a range of technologies, including Ethernet VLANs as an initial universal service offered by the GENI infrastructure suite. By interacting continuously with testbed prototyping efforts, the project will jointly refine the security requirements, reflect those requirements within the security architecture, and validate through feedback gleaned from collaborator’s rapid deployment cycles that proposed security architecture concepts are indeed aligned and addressing the needs of the GENI testbed community.

[**Optical Metrics**].“Cross-Layer Communications for Enabling GENI Clean-Slate Experimentation Across the Heterogeneous Optical Substrate”. PI is Keren Bergman at Columbia Univ. The scope of this project is to perform analysis to ensure GENI includes the technology to support cross-layer communications, specifically, the ability to incorporate a diverse set of real-time measurements in networking protocols. The project addresses the GENI challenge of architectural experimentations across diverse heterogeneous technologies by supporting real-time cross-layer communications and measurements. The objective is to develop networking capabilities within the GENI infrastructure that enable deeper exposure of cross-layer information and user access to real-time measurements.

[**Optical Access Networks**]. “An Experimental Facility for Optical Access and its Integration with Wireless Access”. PI is Chunming Qiao at SUNY Buffalo. The project will study how to make an optical edge network, such as a campus-scale optical access network based on passive optical network (PON) technologies, a part of the GENI infrastructure. In particular, it will study issues such as a) *how* to establish a campus-wide PON and, implement desired GENI functionalities (such as programmability); b) the *time* and *cost* involved; and c) expected GENI *users* and *applications*. The output of these efforts will be a white paper describing the plans to realize this infrastructure, and the expected cost, and GENI functionality and usage.

5.10 Analysis Projects

Last but not least, Spiral 1 includes two analysis projects that will provide information and guidance for the project as a whole. We expect that the results of these projects will help shape the GENI endeavor as it grows and evolves.

[**GENI at 4-year Colleges**]. "Use Case Scenarios for Promoting GENI at Four-Year Colleges and Minority Institutions". PI is Pierre Tiako at Langston Univ. This project will assess the substrate resources offered in spiral-1 and help to define potential experiment scenarios that could serve as topics of interest to four-year colleges and minority institutions. They will use the capabilities offered in the spiral-1 prototype infrastructure suite to shape and propose use-case scenarios and, within the second year, the LU team (including undergraduate research assistant students) will apply one of the use-case scenarios and actually conduct a (limited scope) experiment on the prototype infrastructure suite using one of the prototype GENI control frameworks.

[**Data Plane Measurements**]."Optical Layer Measurements for GENI Research Platform". PI is Deniz Gurkan at Univ of Houston. This project will assess the embedded measurement capabilities as well as methods to integrate external test equipment for the optical substrate resources offered in Spiral 1. Findings will be published to appropriate GENI mailing lists, wiki, and at an upcoming GEC.

6 Spiral 1 Interconnection of Aggregates

A primary goal for GENI Spiral 1 is to demonstrate "end-to-end" slices across a range of technologies. This is done by creating an experiment plane that connects multiple components across a wide range of aggregates owned and operated by different organizations.

Spiral 1will demonstrate the experiment plane connecting multiple components throughout the United States with Spiral 1 developers, integrators, and researchers. It will reach through campus and corporate networks, regional networks, backbone networks, and the commercial Internet. The data plane must be available as quickly as possible for projects to collaborate on end-to-end experiments. But it must also provide a foundation that can evolve to the experiment plane that the GENI architecture envisions: a sliceable, programmable data plane where substrate resources can be discovered and slices share the data plane but are virtually isolated from each other.

Spiral 1 integration will use a combination of existing IP and Ethernet VLAN infrastructure over multiple substrates and providers to create the first GENI experiment plane. This approach will support IP and non-IP experiments in Spiral 1, and connect GENI components that implement varying degrees of GENI programmability and isolation so they can be used together in end-to-end experiments.

We expect that additional techniques will be added in subsequent spirals, e.g., to enable experimental connectivity directly over optical layers.

6.1 Layer 3 (IP) Connectivity

IP connectivity to all GENI components and end hosts is the first type of data service available in Spiral 1. IP connectivity is used for all control plane exchanges, and is also sufficient for many GENI experiments. We will leverage existing Internet connectivity for this service, and work with projects, campus IT groups, and regional network providers to address any special experiment routing or performance needs. It is reasonable to assume that both IPv4 and IPv6 protocols will be used during Spiral 1, but most projects are currently using IPv4. Note that general IP connectivity also supports the ability to create host-to-host IP tunnels across the experiment plane, which may be important for some GENI experiments.

6.2 Layer 2 (Ethernet VLAN) Connectivity

In order to support non-IP experiments in a controlled manner, Spiral 1 must provide Layer Two connectivity between all locations that provide substrates to each control framework cluster.

Where feasible, we will support Layer 2 connectivity between clusters as well, in order to prepare for later spirals that emphasize those connections. Because Ethernet frames are supported by nearly all existing infrastructures, Spiral 1 will use Ethernet frames forwarded over multiple networks to create virtual Ethernet topologies between locations. Ideally, each connection would be a full Ethernet emulation on which the control framework could allocate its own VLANs. In Spiral 1, this may be feasible in some parts of the experiment plane (for example in a programmable backbone VLAN), but is not likely to be available end-to-end.

Layer 2 in National Backbones. Internet2 and National Lambda Rail (NLR) have both donated backbone capacity that can be used to provide Layer 2 connectivity in the GENI experiment plane backbone. NLR will provide a complete VLAN service based on Cisco equipment for Spiral 1, and Internet 2 will provide connections to a 10 Gbps optical wave through Infinera transport equipment (additional Ethernet switches will be required to create VLANs.)

Using 10 GbE and 1 GbE interfaces, we can construct VLANS in both backbones that can reach regional optical networks whose members are providing GENI experimental substrates. In some cases these regional networks are also active control framework project members. These regional networks are already working with the GPO to determine the best way to connect their members to GENI Layer 2 and Layer 3 services. Of course the solutions will vary between regions. In some cases it may be possible to create similar Layer 2 Ethernet VLANS that reach campus and corporate networks. In other cases, we may use fixed or dynamic IP tunnels to connect at Layer 2 endpoints. In some cases, only IP connectivity may be available, and routing tables or other network engineering techniques can be used to direct traffic to the desired backbone VLAN access points.

Layer 2 in Campus Networks. Campuses and corporate networks use many different types of infrastructures to connect project locations where GENI substrates may be located to the regional optical networks and the commercial Internet. Local networks use border routers, firewalls, and other devices to protect their networks and isolate production traffic from experimental infrastructure. The GPO is working with CIOs and GENI project leads to determine the best way to connect each GENI local network to the rest of the GENI infrastructure. The Enterprise GENI project represents one solution for extending a programmable GENI Layer 2 VLAN across campus infrastructure, and there are others. Tunneling and IP routing approaches like those used in the regional networks may also provide solutions for campus infrastructures where a complete Layer 2 VLAN is not feasible.

6.3 Heterogeneous Experiment Planes

Note that the GENI design concept does not call for a single, ubiquitous form of interconnectivity. Quite the contrary: the experiment plane may vary from one experiment to the next, depending on the particular sites, resources, and substrates involved in the experiment. This design supports a wide range of experimental interests, and also allows easy technological transitions as new types of connectivity become available and as the old ones become obsolete.

In Spiral 1 we will concentrate on providing appropriate connectivity for IP and non-IP experiments, and ensuring that projects working together in a common control framework can also use a common backbone VLAN framework, if desired, even though their local and regional connections will vary. Our ultimate GENI goal is to make it possible for all parts of the experiment plane, including the campus, regional, and backbone components, to be sliceable, programmable, discoverable, and virtually isolated, even though in Spiral 1 most parts will not be.

7 Spiral 1 Measurement Plane

Although Spiral 1 will be developing technologies useful for GENI instrumentation and measurement, an integrated “end to end” measurement capability is not planned. Future GENI spirals are expected to focus on these areas, as well as archives and perhaps analysis tools.

8 Spiral 1 Operations and Management

Spiral 1 projects that operate clearinghouses will also provide O&M and security functions for the GENI community. However, this is only part of the larger O&M picture, which has already begun, and will surely evolve as we start to gain operational experience with GENI prototypes.

GENI working groups such as the OMIS group have been working on longer-term requirements and use cases for Operations, Management, and Security functions. This work will continue, and will include a GENI Concept of Operations document that will help shape the O&M framework for Spiral 1 and subsequent spirals. Working group products are available on the GENI wiki (groups.geni.net) and GENI website (www.geni.net).

Two GENI Spiral 1 projects (GMOC and Security Architecture) are focusing on cross-project Spiral 1 security and operations solutions that are the first steps towards longer-term solutions. The projects will develop and integrate solutions in concert with the five control framework clearinghouse developments during Spiral 1. An example O&M function that will be needed for Spiral 1 and is also part of longer-term operations is a function to provide emergency shutdown of slices when they are not behaving normally.

The O&M and security Spiral 1 effort has both technical development, procedural, and operational requirements. Spiral 1 must provide ways for operational and project contacts to find and reach each other, exchange data, record problems and solutions (particularly those that will be of interest to other projects), report current status, and track progress against integration milestones. The GPO and the GMOC and Security Architecture projects will work together to provide procedures, documentation, systems and software to share, monitor, display and act on O&M and operational security information in concert with what the operational clearinghouses do. A prototype GENI Meta Operations Center that supports data sharing between the 5 control frameworks and 29 projects will be operating towards the end of Spiral 1 Integration.

Initially all O&M functions will use general IP connectivity in Spiral 1. It may also be possible to create O&M slices in the GENI experiment plane to support particular functions, such as data collection, if necessary, but that will probably not be needed until later spirals. GENI O&M will also coordinate with O&M organizations in other networks (for example backbones, regionals, and commercial ISPs) as needed to share data and facilitate Spiral 1 integration and operations.

9 Appendices

9.1 Acronyms

CIO	Chief Information Officer
GENI	Global Environment for Network Innovations
GIMS	GENI Instrument and Measurement System
GPO	GENI Project Office
NOC	Network Operations Center
O&M	Operations and Management
TBD	To be determined
TBR	To be reviewed
TBS	To be specified

9.2 Key GENI Terms

Term	Explanation
Aggregate	An *aggregate* is an object representing a group of components, where a given component can belong to zero, one, or more aggregates. Aggregates can be hierarchical, meaning that an aggregate can contain either components or other aggregates. Aggregates provide a way for users, developers, or administrators to view a collection of GENI nodes together with some software-defined behavior as a single identifiable unit. Generally aggregates export at least a component interface, i.e., they can be addressed as a component, although aggregates may export other interfaces, as well. Aggregates also may include (controllable) instrumentation and make measurements available. This document makes broad use of aggregates for operations and management. Internally, these aggregates may use any O&M systems they find useful.
Clearinghouse	A *clearinghouse* is a, mostly operational, grouping of a) architectural elements including trust anchors for Management Authorities and Slice Authorities and b) services including user, slice and component registries, a portal for resource discovery, a portal for managing GENI-wide policies, and services needed for operations and management. They are grouped together because it is expected that the GENI project will need to provide this set of capabilities to bootstrap the facility and, in general, are not exclusive of other instances of similar functions. There will be multiple clearinghouses that will federate. The GENI project will operate the NSF-sponsored clearinghouse. One application of 'federation' is as the interface between clearinghouses.
Components	*Components* are the primary building block of the architecture. For example, a component might correspond to an edge computer, a customizable router, or a programmable access point. A component encapsulates a collection of resources, including physical resources (e.g., CPU, memory, disk, bandwidth) logical resources (e.g., file descriptors, port numbers), and synthetic resources (e.g., packet forwarding fast paths). These resources can be contained in a single physical device or distributed across a set of devices, depending on the nature of the component.

Term	Explanation
Experiment	An *experiment* is a researcher-defined use of a slice; we say an experiment runs in a slice. Experiments are not slices. Many different experiments can run in a particular slice concurrently or over time.
Federation	Resource *federation* permits the interconnection of independently owned and autonomously administered facilities in a way that permits owners to declare resource allocation and usage policies for substrate facilities under their control, operators to manage the network substrate, and researchers to create and populate slices, allocate resources to them, and run experiment-specific software in them.
Management Authority	A *management authority* (MA) is responsible for some subset of substrate components: providing operational stability for those components, ensuring the components behave according to acceptable use policies, and executing the resource allocation wishes of the component owner. (Note that management authorities potentially conflate owners and operators. In some cases, an MA will correspond to a single organization in which case the owner and operator are likely the same. In other cases, the owner and operator are distinct, with the former establishing a "management agreement" with the latter.)
Owner	GENI includes *owners* of parts of the network substrate, who are therefore responsible for the externally visible behavior of their equipment, and who establish the high-level policies for how their portion of the substrate is utilized.
Portals	A *portal* denotes the interface—graphical, programmatic, or both—that defines an "entry point" through which users access GENI. A portal is likely implemented by a combination of services. Different user communities can define portals tailored to the needs of that community, with each portal defining a different model for slice behavior, or support a different experimental modality. For example, one portal might create and schedule slices on behalf of researchers running short-term controlled experiments, while another might acquire resources needed by slices running long-term services. Yet another portal might be tailored for operators that are responsible for keeping GENI components up and running.
Principal	*A principal* is an actor in GENI such as a researcher or operator.
Resource	*Resources* are abstractions of the sharable features of a component that are allocated by a component manager and described by an RSpec. Resources are divided into computation, communication, measurement, and storage. Resources can be contained in a single physical device or distributed across a set of devices, depending on the nature of the component.
Slices	From a researcher's perspective, a *slice* is a substrate-wide network of computing and communication resources capable of running an experiment or a wide-area network service. From an operator's perspective, slices are the primary abstraction for accounting and accountability—resources are acquired and consumed by slices, and external program behavior is traceable to a slice, respectively. A slice is the basis for resource revocation (i.e., shutdown). A slice is defined by a set of slivers spanning a set of network components, plus an associated set of users that are allowed to access those slivers for the purpose of running an experiment on the substrate. That is, a slice has a name, which is bound to a set of users associated with the slice and a (possibly empty) set of slivers.

Term	Explanation
Slivers	It must be possible to share component resources among multiple users. This can be done by a combination of virtualizing the component (where each user acquires a virtual copy of the component's resources), or by partitioning the component into distinct resource sets (where each user acquires a distinct partition of the component's resources). In both cases, we say the user is granted a *sliver* of the component. Each component must include hardware or software mechanisms that isolate slivers from each other, making it appropriate to view a sliver as a "resource container."
Substrate	GENI provides a set of physical facilities (e.g., routers, processors, links, wireless devices), which we refer to as the *substrate*. The design of this substrate is concerned with ensuring that physical resources, layout, and interconnection topology are sufficient to support GENI's research objectives.
User Opt-In	An important feature of GENI is to permit experiments to have access to end-user traffic and behaviors. For examples, end-users may access an experimental service, use experimental access technologies, or allow experimental code to run on their computer or handset. GENI will provide tools to allow users to learn about an experiment's risks and to make an explicit choice ("*opt-in*") to participate.