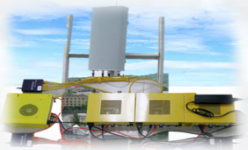
geni
Exploring Networks of the Future



GENI

Exploring Networks of the Future

Vicraj Thomas

www.geni.net

Sponsored by the National Science Foundation

Outline

GENI – Exploring future internets at scale

The GENI Concept

Building GENI

Experimental and Classroom use of GENI

What's next for GENI?

GENI: An experimenter's view

Global networks are creating extremely important new challenges

Science Issues

We cannot currently understand or predict the behavior of complex, large-scale networks

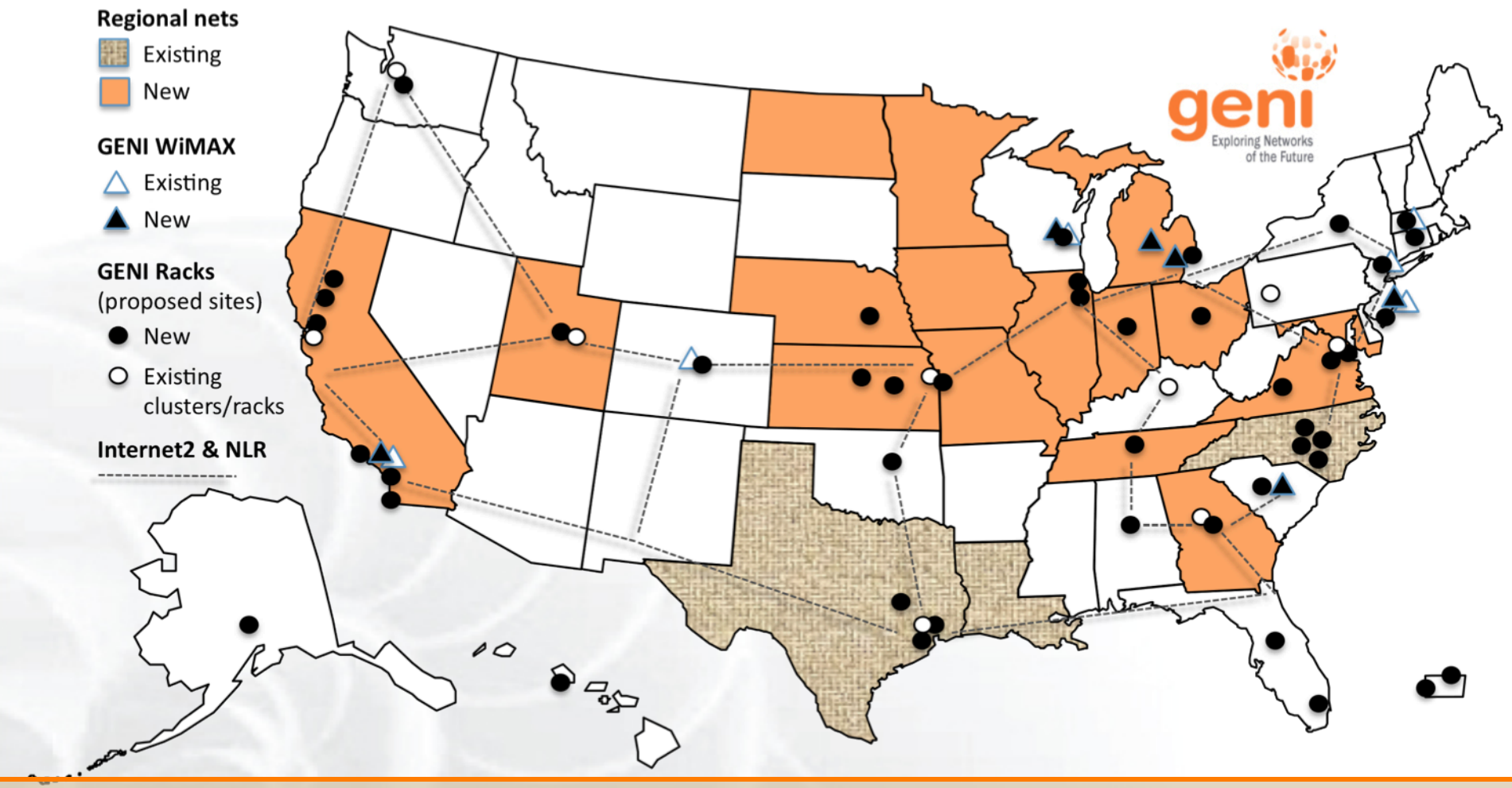
Innovation Issues

Substantial barriers to at-scale experimentation with new architectures, services, and technologies

Society Issues

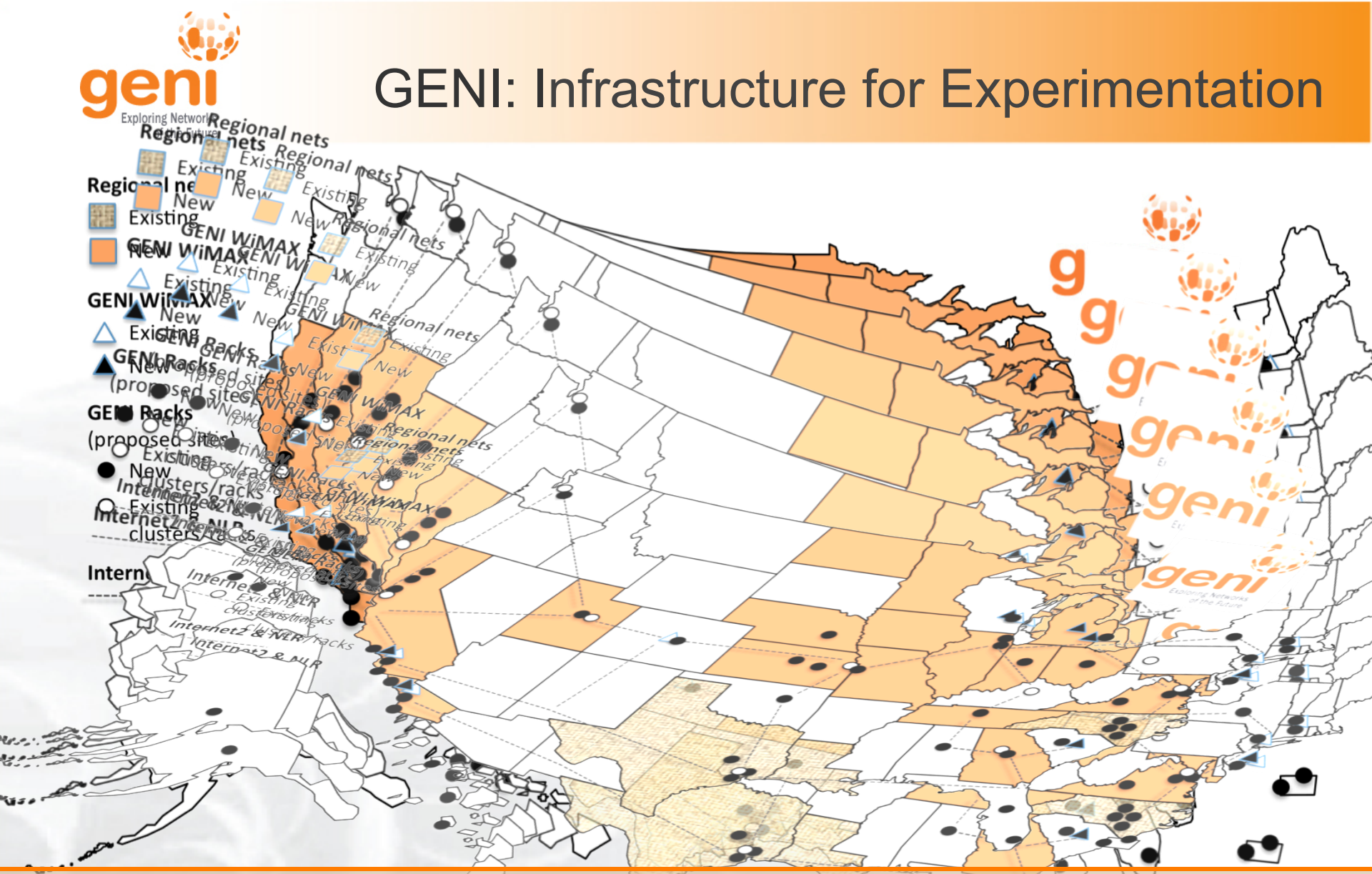
We increasingly rely on the Internet but are unsure we can trust its security, privacy or resilience

GENI: Infrastructure for Experimentation



GENI provides compute resources that can be connected in experimenter specified Layer 2 topologies.

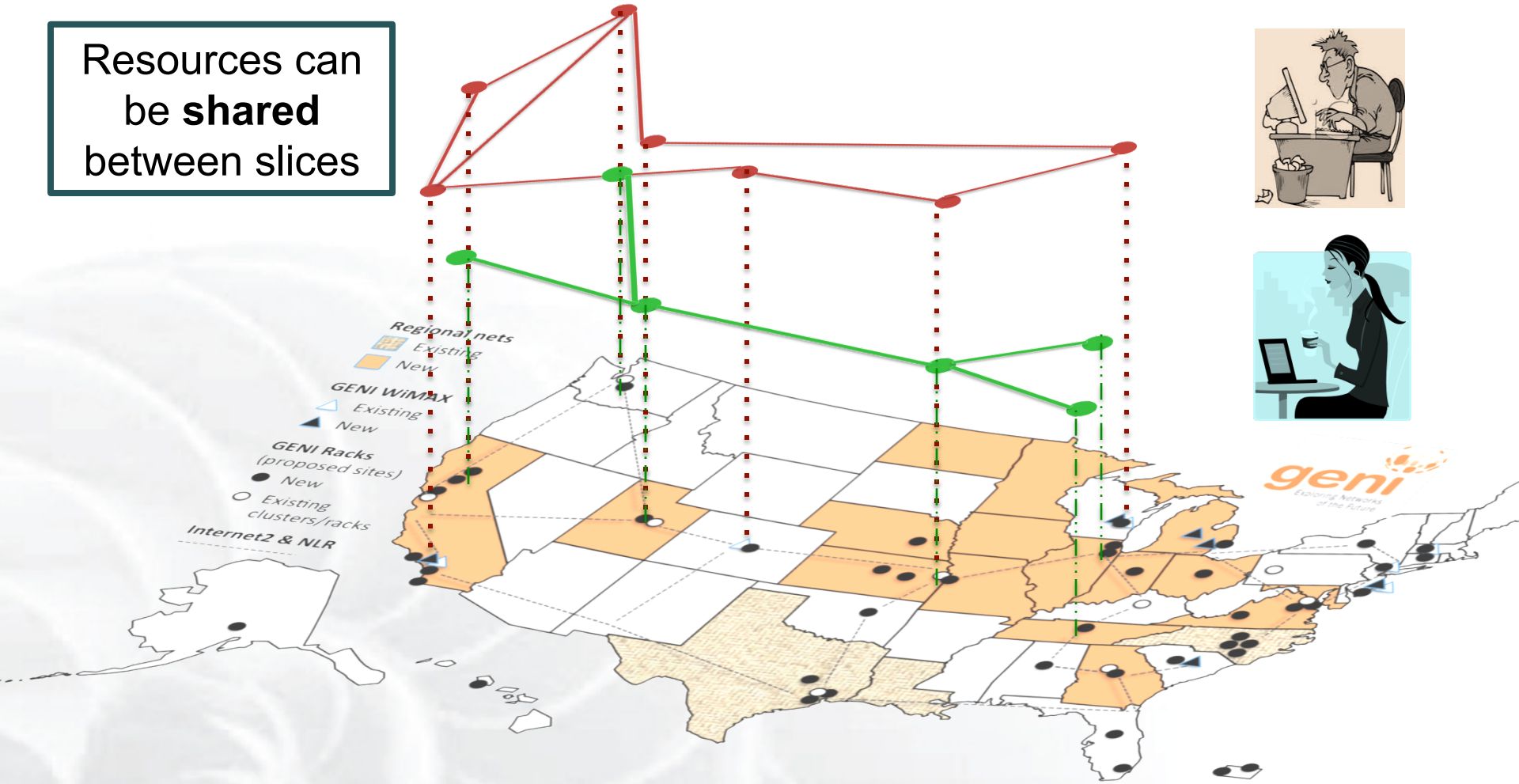
GENI: Infrastructure for Experimentation



GENI provides compute resources that can be connected in experimenter specified Layer 2 topologies.

Multiple GENI Experiments run Concurrently

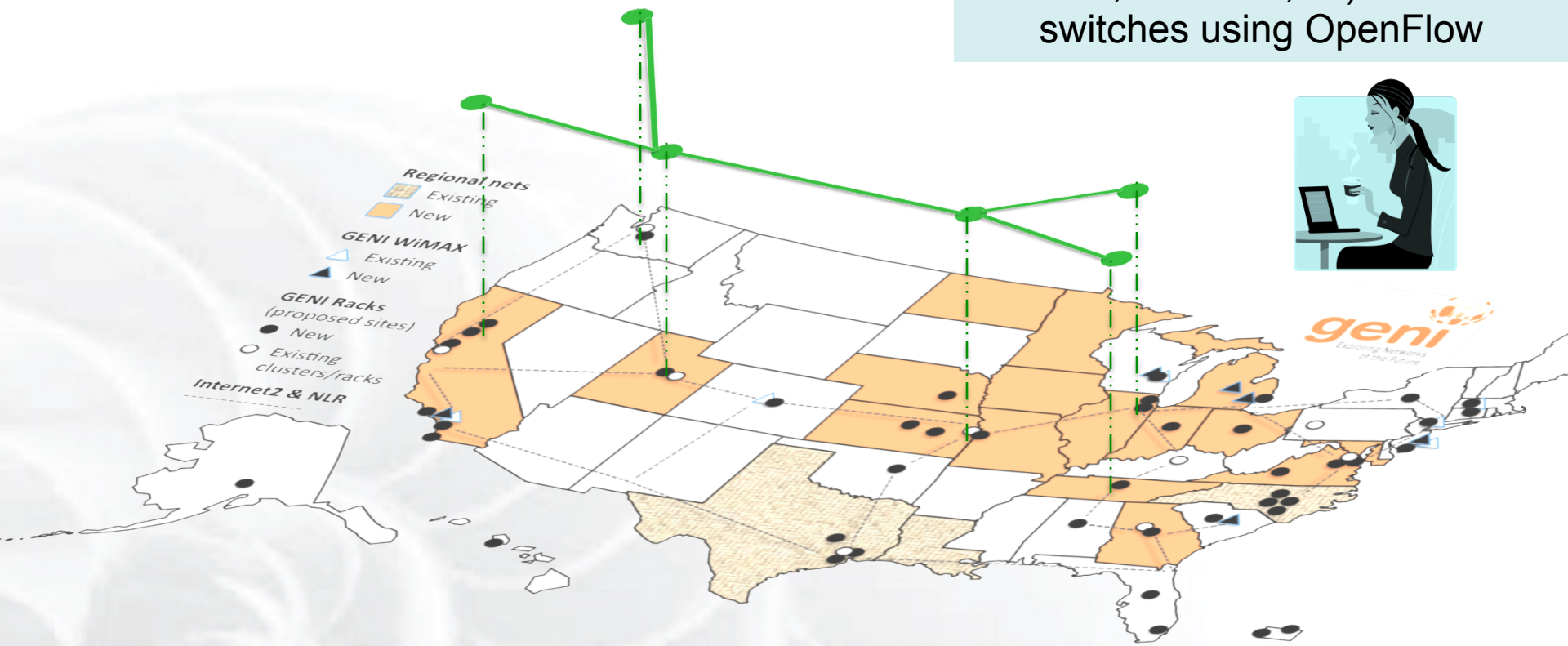
Resources can be **shared** between slices



Experiments live in **isolated** "slices"

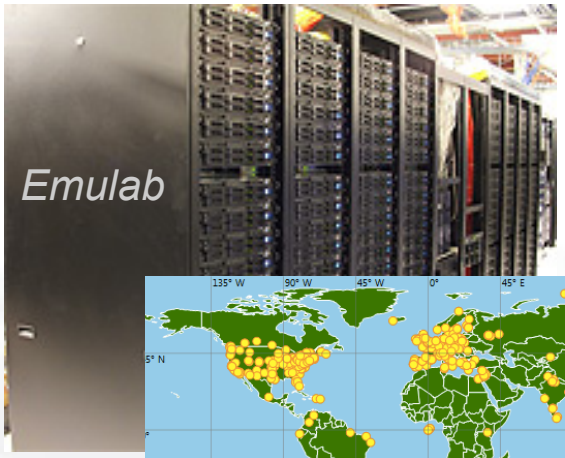
GENI is “Deeply Programmable”

I install software I want throughout my network slice (into routers, switches, …) or control switches using OpenFlow



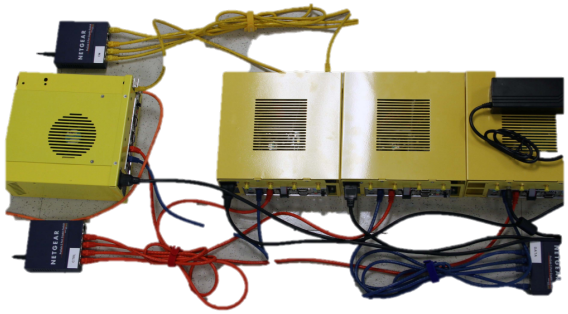
Experimenters can set up custom topologies, protocols and switching of flows

GENI Compute Resources

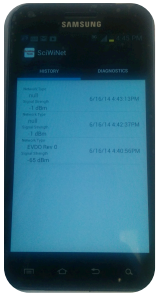


Existing Testbeds

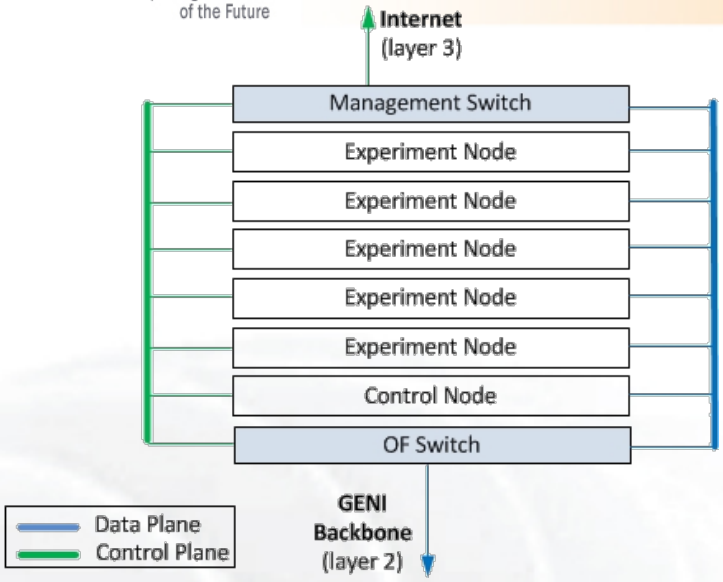
GENI Racks



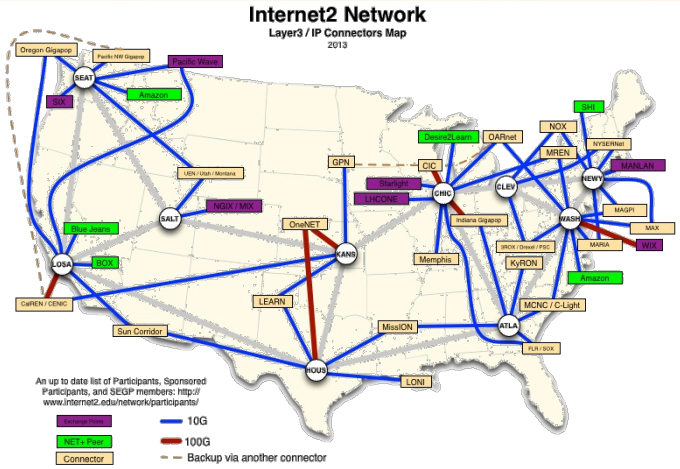
GENI Wireless compute nodes



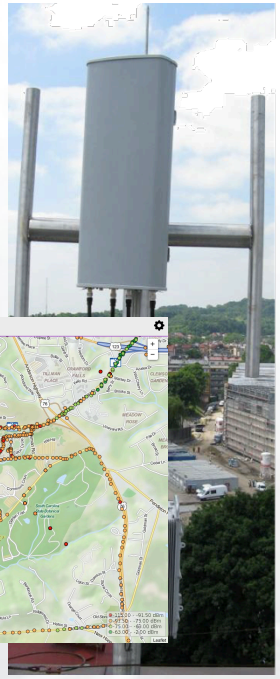
GENI Networking Resources

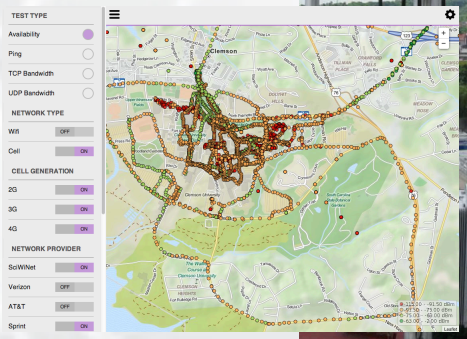


Networking within a Rack



National Research Backbones
(e.g. Internet2)





4G/3G
GENI network

WiMAX Base Stations

Regional Networks
(e.g. CENIC)

Outline

GENI – Exploring future internets at scale

The GENI Concept

Building GENI

Experimental and Classroom use of GENI

What's next for GENI?

GENI: An experimenter's view

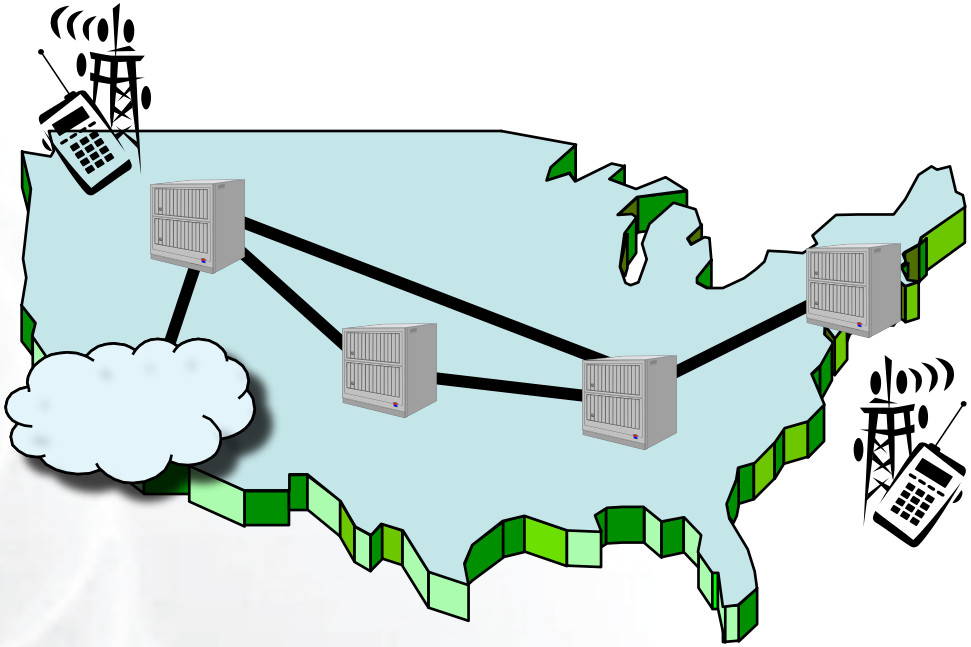
A bright idea

"I have a great idea."

"That will never work."

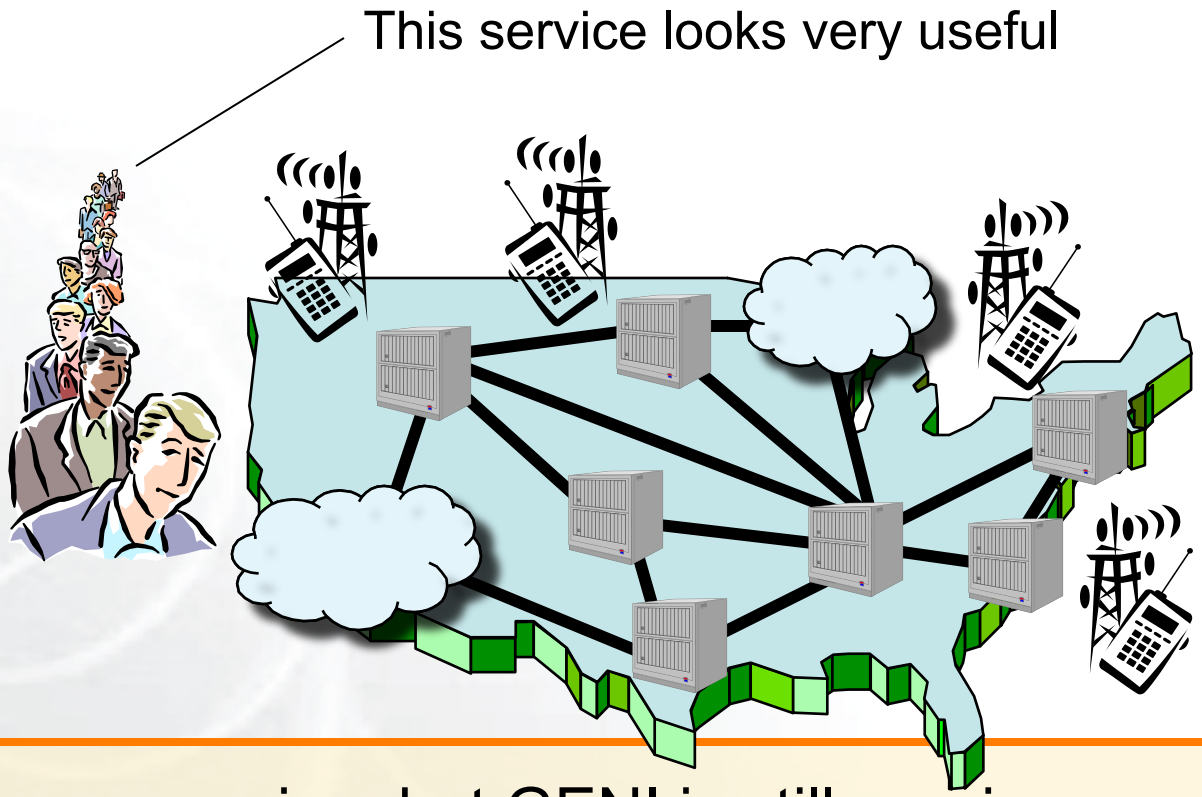
Let's try it out!

My new architecture worked great in the lab, so now I'm going to try a larger experiment for a few months.



He uses a modest slice of GENI, sharing its infrastructure with many other concurrent experiments.

It turns into a really good idea

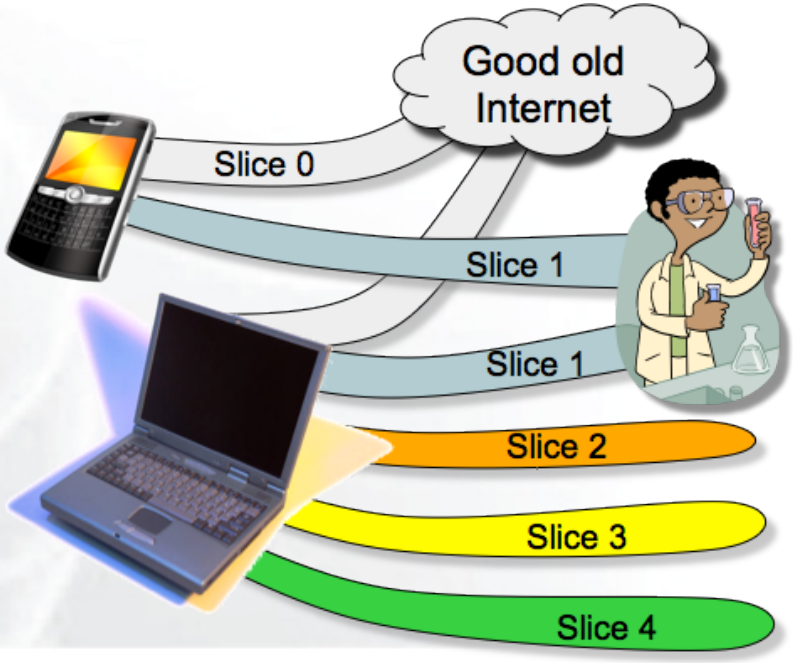


His slice of GENI keeps growing, but GENI is still running many other concurrent experiments.

Attracts real users

"Looks like an app to me."

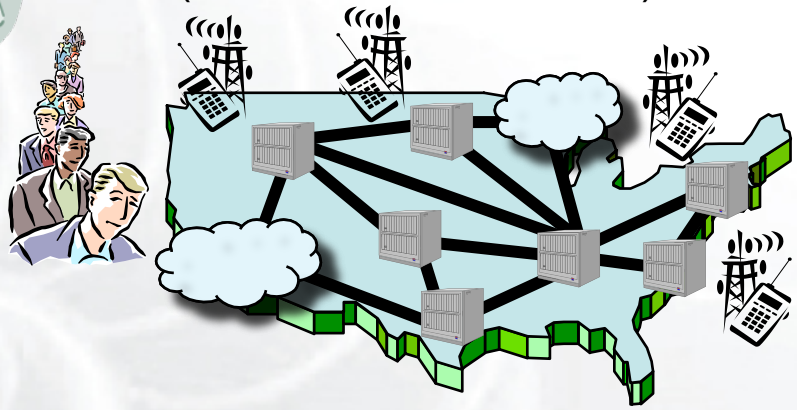
"It's my very own GENI slice."



“Boy did I learn a lot!”

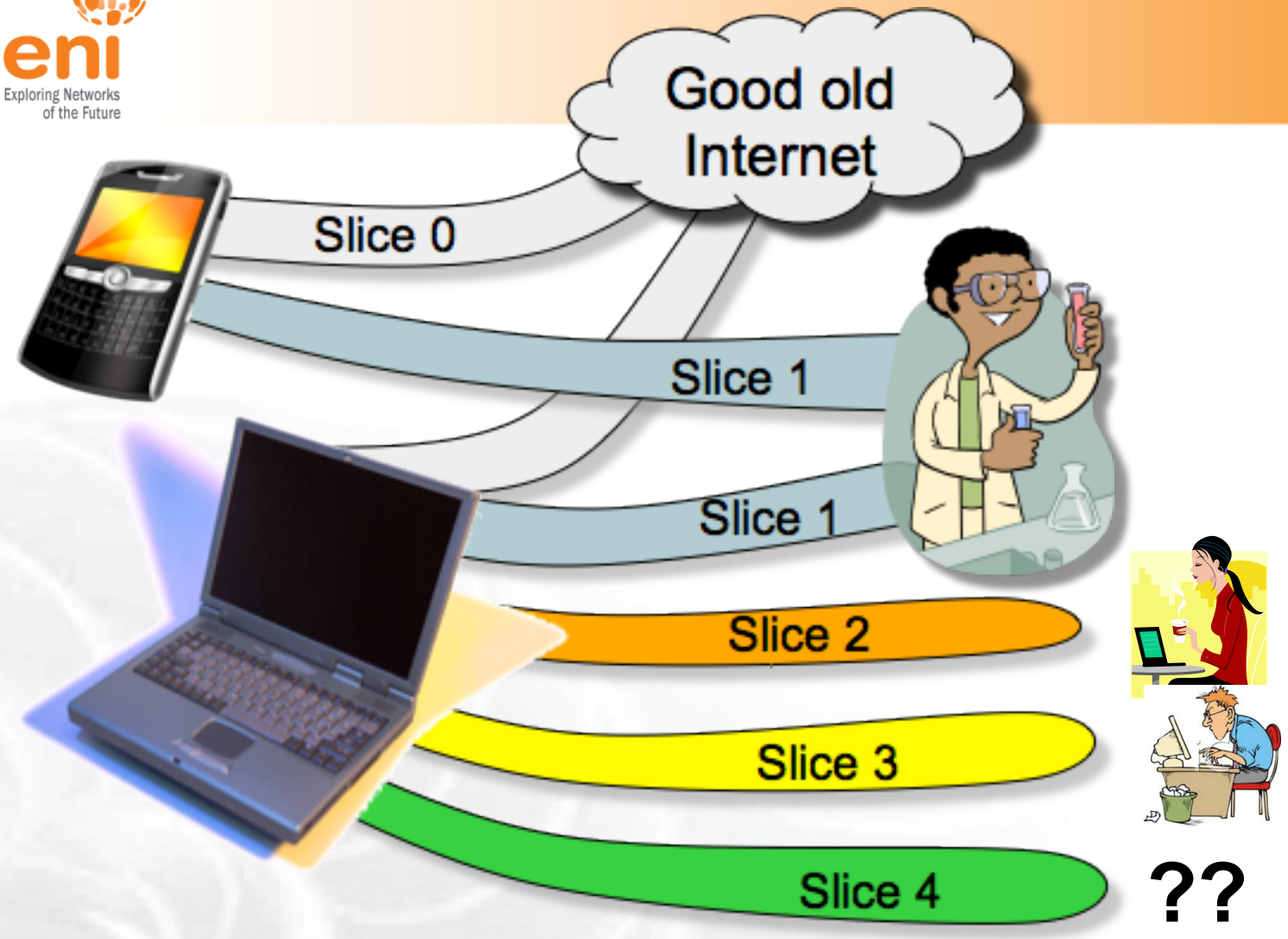
“What a cool service.”

(I wonder how it works.)



“I always said it was a great idea.”

(But way too conservative.)

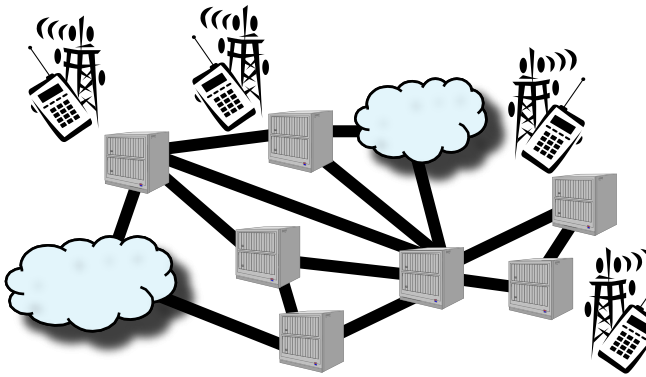


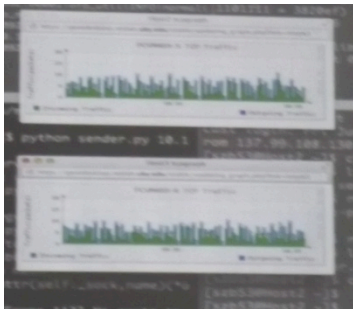
If **you** have a great idea, check out the
NSF CISE research programs for current opportunities.

Moral of this story

GENI is meant to enable . . .

- At-scale experiments
- Internet-incompatible experiments
- Both repeatable and “in the wild” experiments
- ‘Opt in’ for real users
- Instrumentation and measurement tools





GENI creates a huge opportunity for ambitious research!

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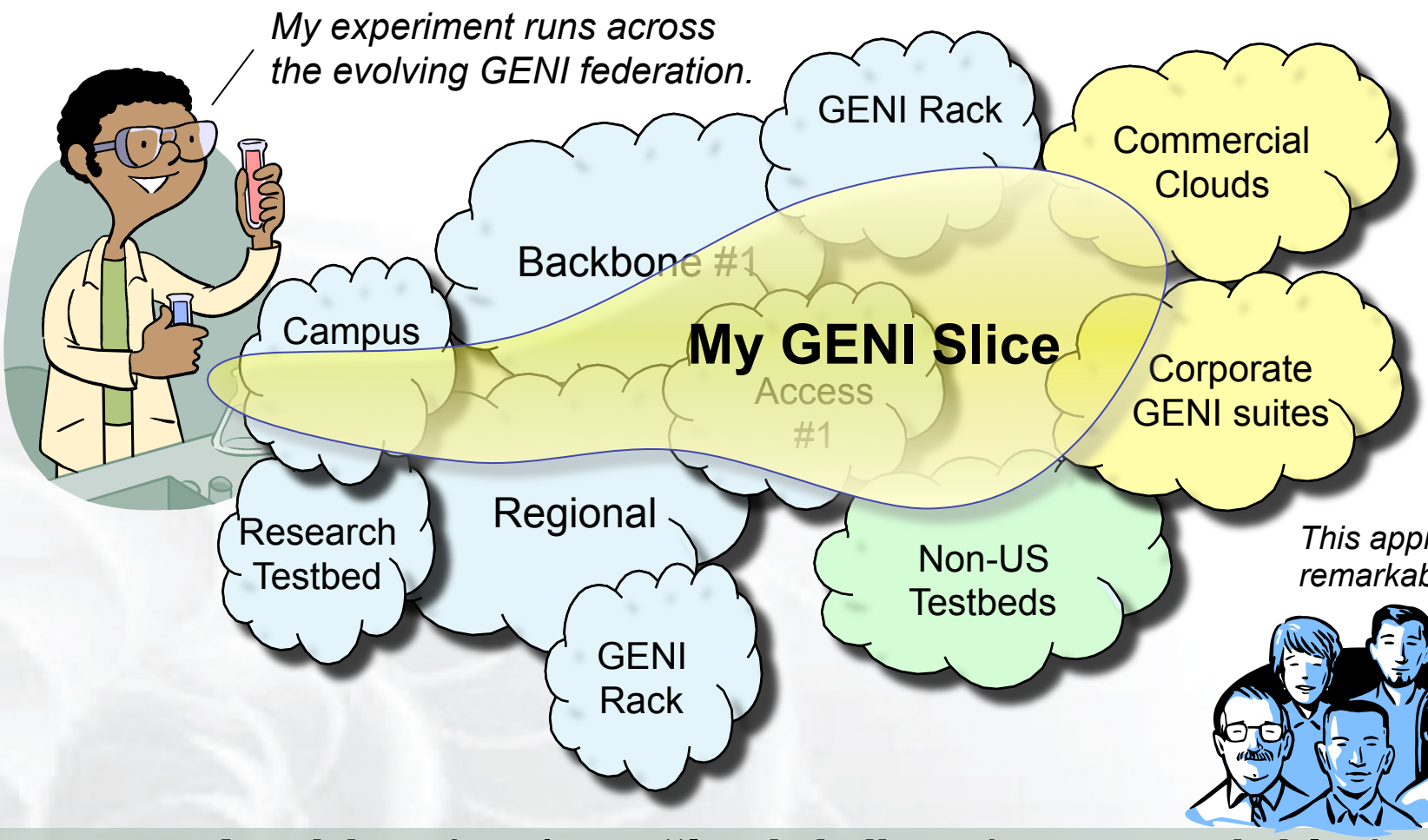
GENI: An experimenter's view

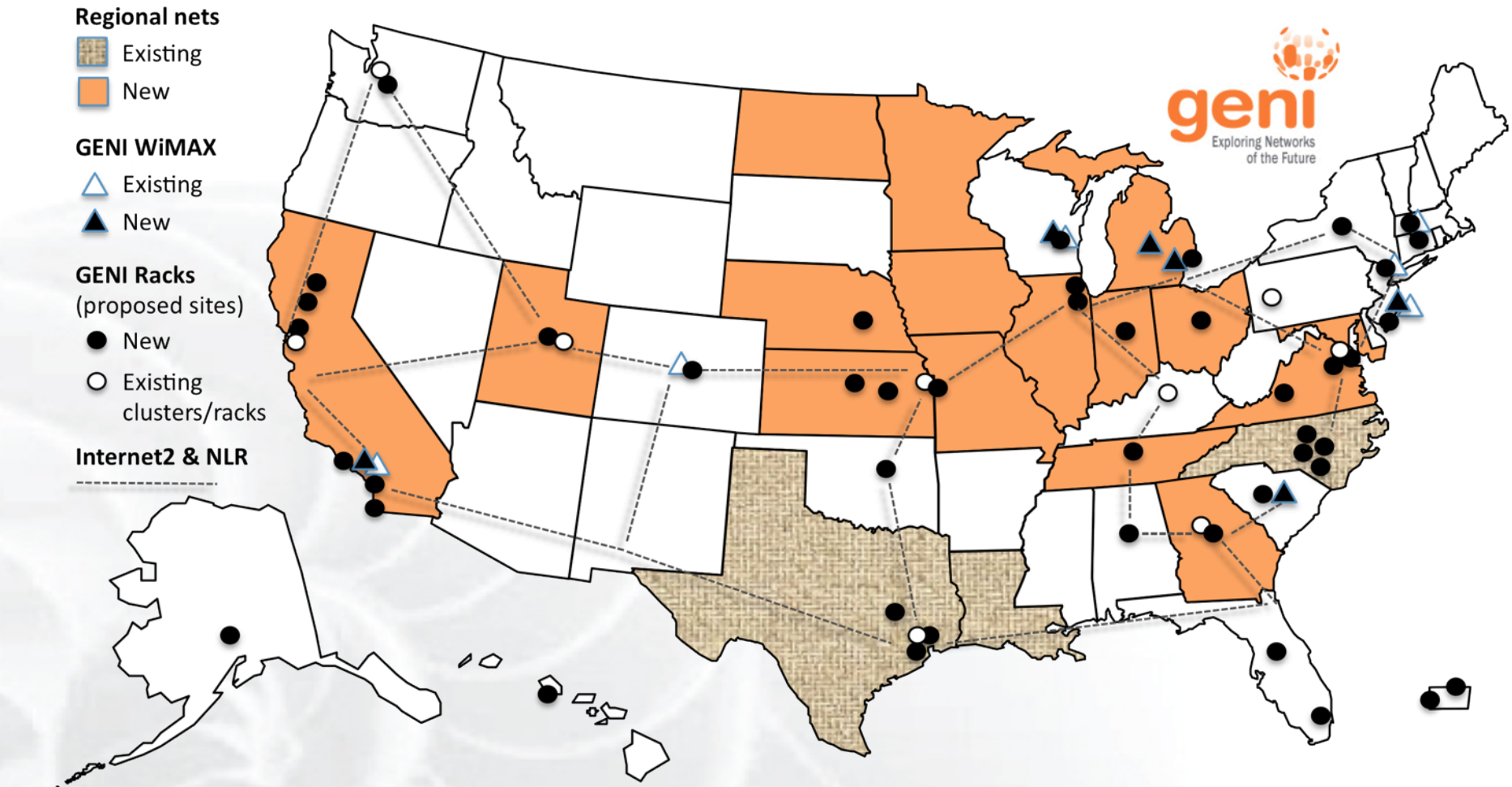
Federation

GENI grows by GENI-enabling heterogeneous infrastructure



Avoid technology **"lock in"** and **grow quickly** by incorporating existing infrastructure

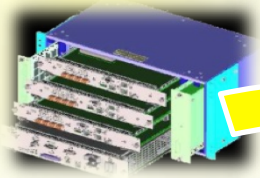
Growing GENI's footprint



Build GENI at sufficient scale

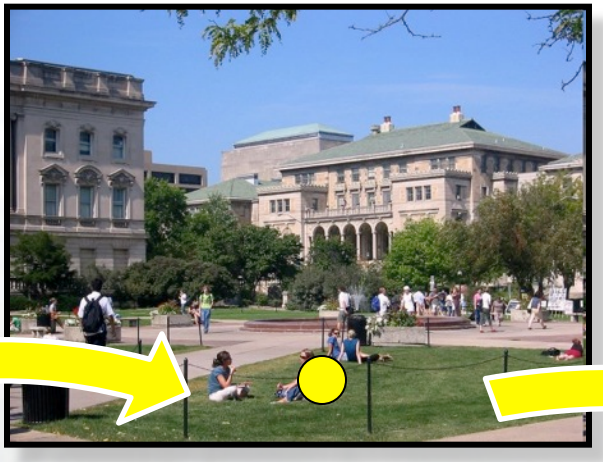
Infeasible to build a testbed as big as the Internet

HP ProCurve 5400 Switch

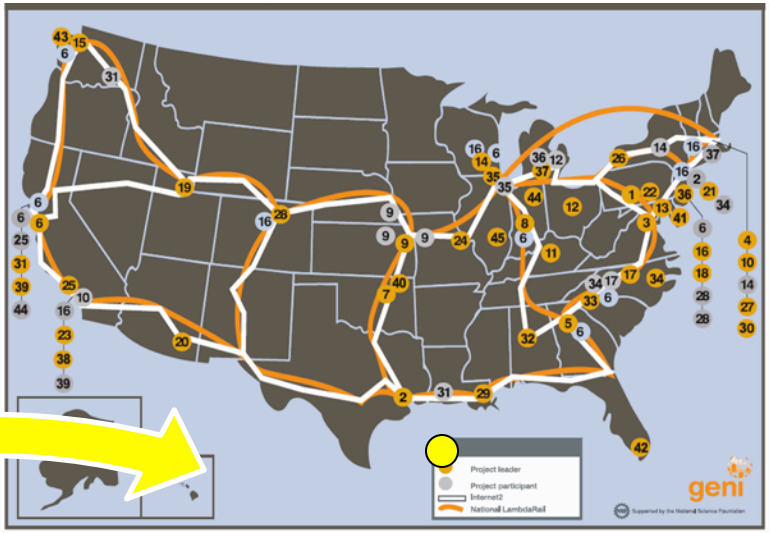


NEC WiMAX Base Station

GENI-enabled equipment



GENI-enabled campuses, students as early adopters

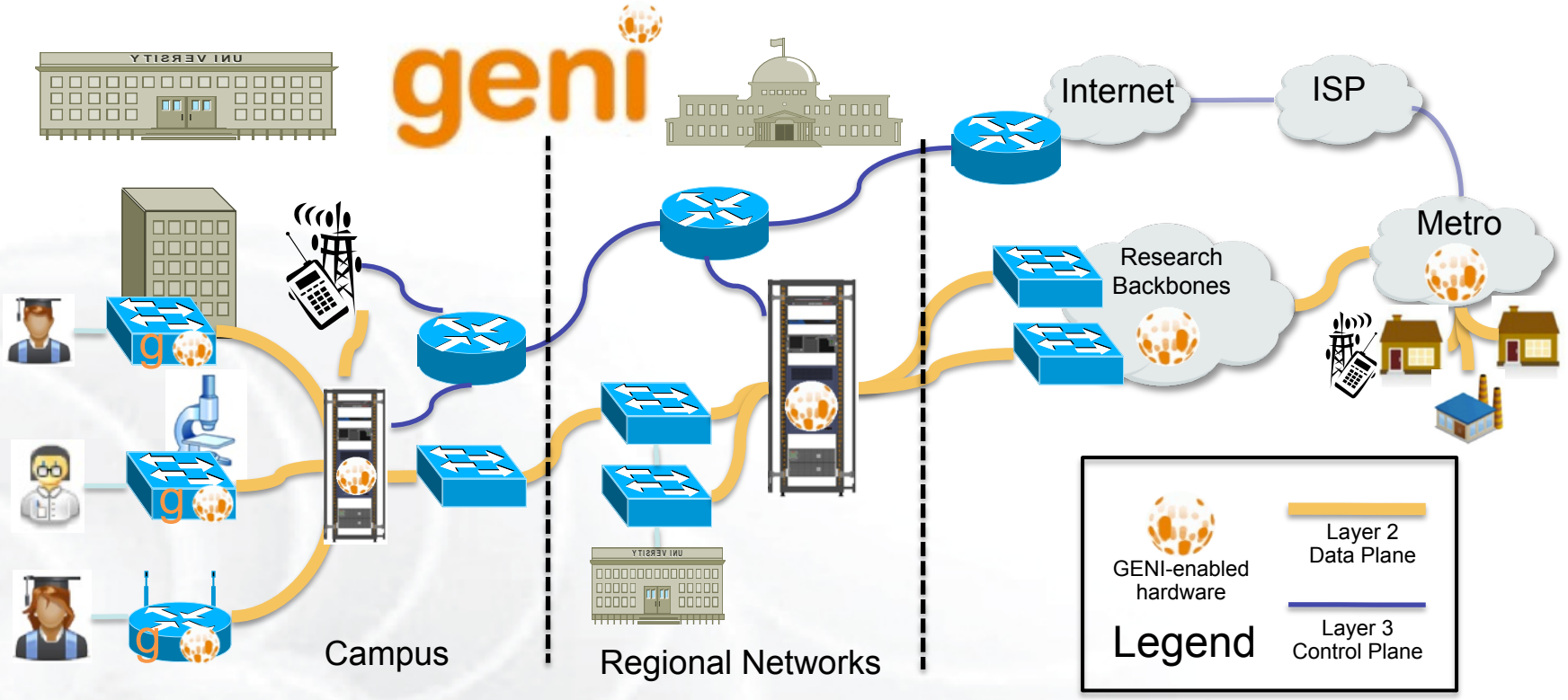


"At scale" GENI prototype

GENI-enable testbeds, commercial equipment, campuses, regional and backbone networks

Campus photo by Vonbloompasha

GENI Network Architecture



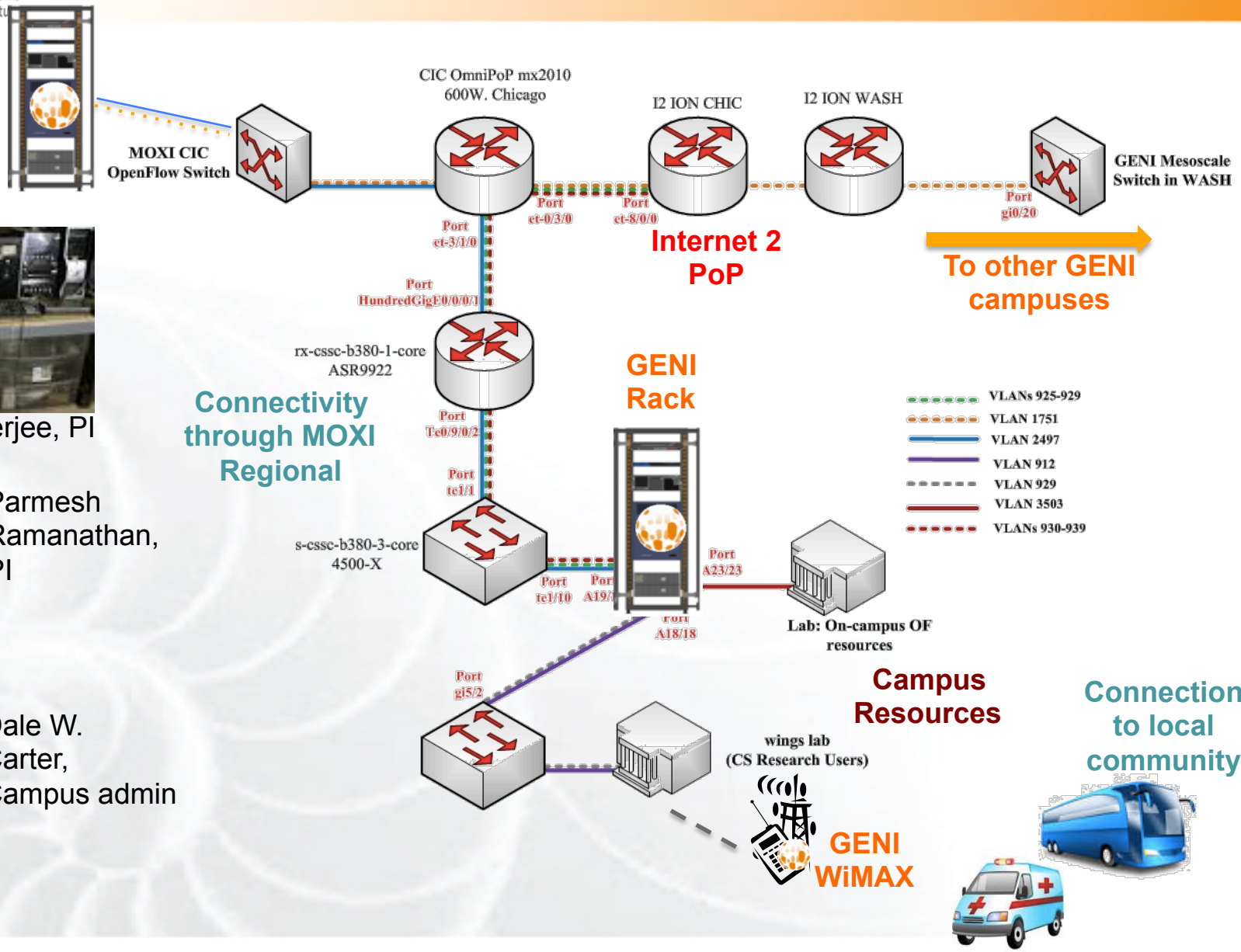
- Flexible network / cloud research infrastructure
- Also suitable for physics, genomics, other domain science
- Distributed cloud (racks) for content caching, acceleration, etc.

Wisconsin: a Great Example

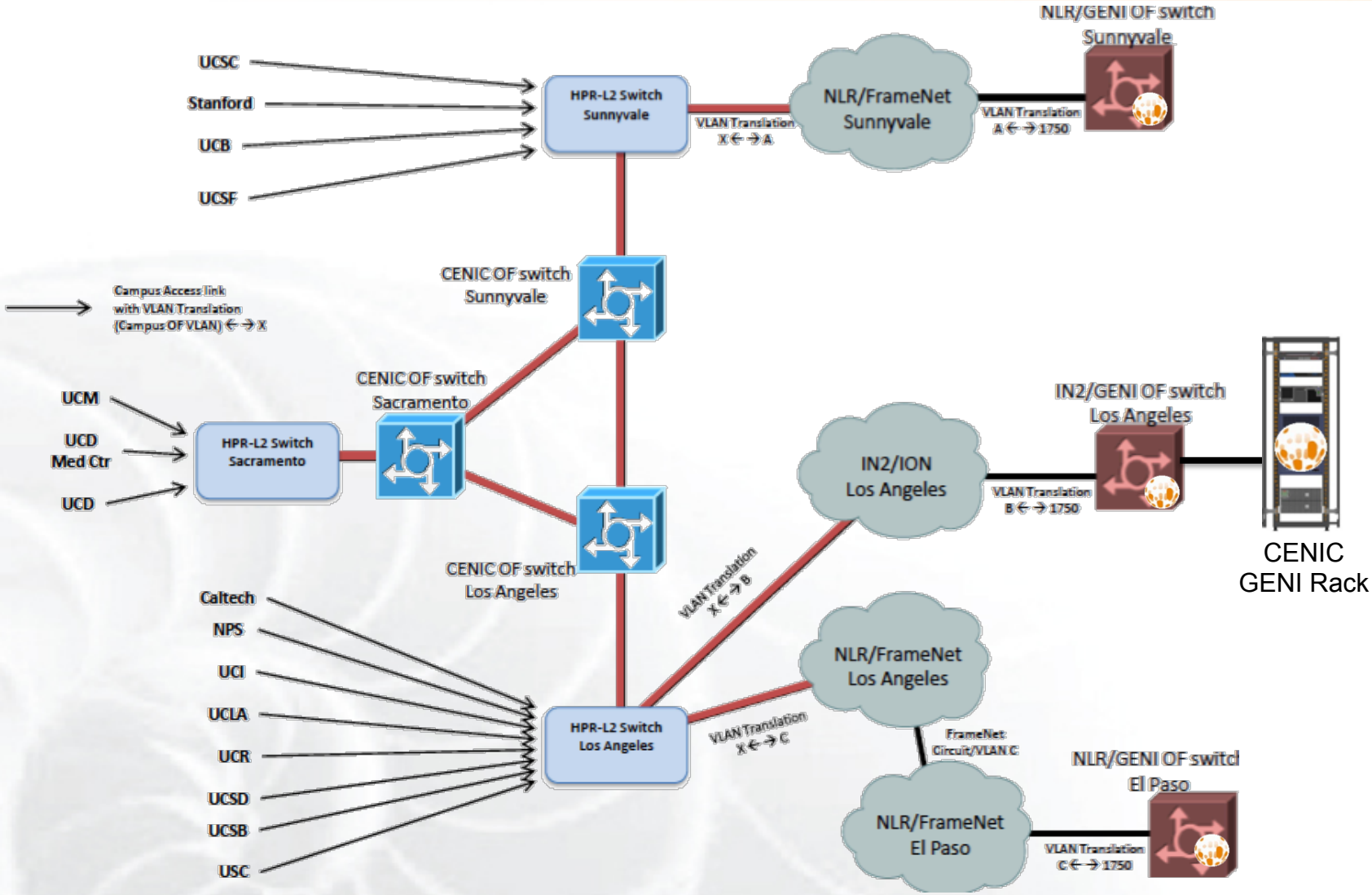
Suman Banerjee, PI

Parmesh Ramanathan, PI

Dale W. Carter, Campus admin



Example regional network
CENIC OpenFlow buildout



GENI on Internet2

- Collaboration to **implement national-scale infrastructure**
  - sliced and deeply-programmable
  - incorporating OpenFlow/SDN switches, GENI Racks, etc.
  - high-speed (10-100 Gbps)
- Internet2 provides dynamic link provisioning to GENI Experimenters (ION AM)
- In-progress migration from “prototype GENI” to AL2S production system
  - Testing GENI dynamic provision on AL2S AM
  - Testing Experimenter OpenFlow controllers on AL2S

GENI Operations session
Wed: 1:30pm – 3:30pm

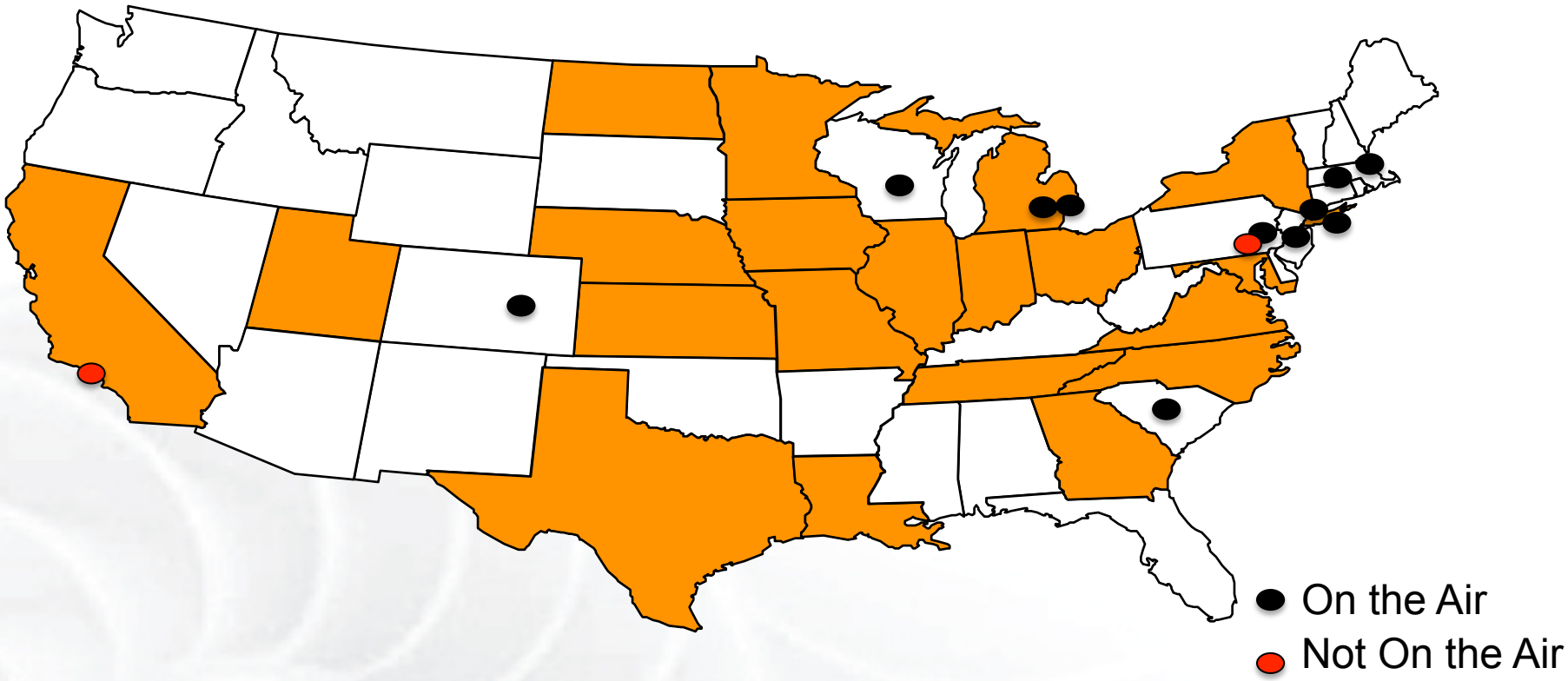
GENI WiMAX

- **Agreement with Sprint**
  - Sprint and Rutgers University have signed a **master spectrum agreement**
  - encompassing all WiMAX sites, to ensure **operation in the EBS Band**.
  - An **emergency stop procedure**, in case of interference with Sprint service, has been agreed upon.

- **SciWinet GENI Mobile Virtual Network Operator (MVNO)**
  - Partner with Sprint and Arterra (a Sprint partner) to create and operate an (**MVNO**) that serves the academic research community
  - The effort is led by Jim Martin and Ivan Seskar, to learn more: http://sciwinet.org

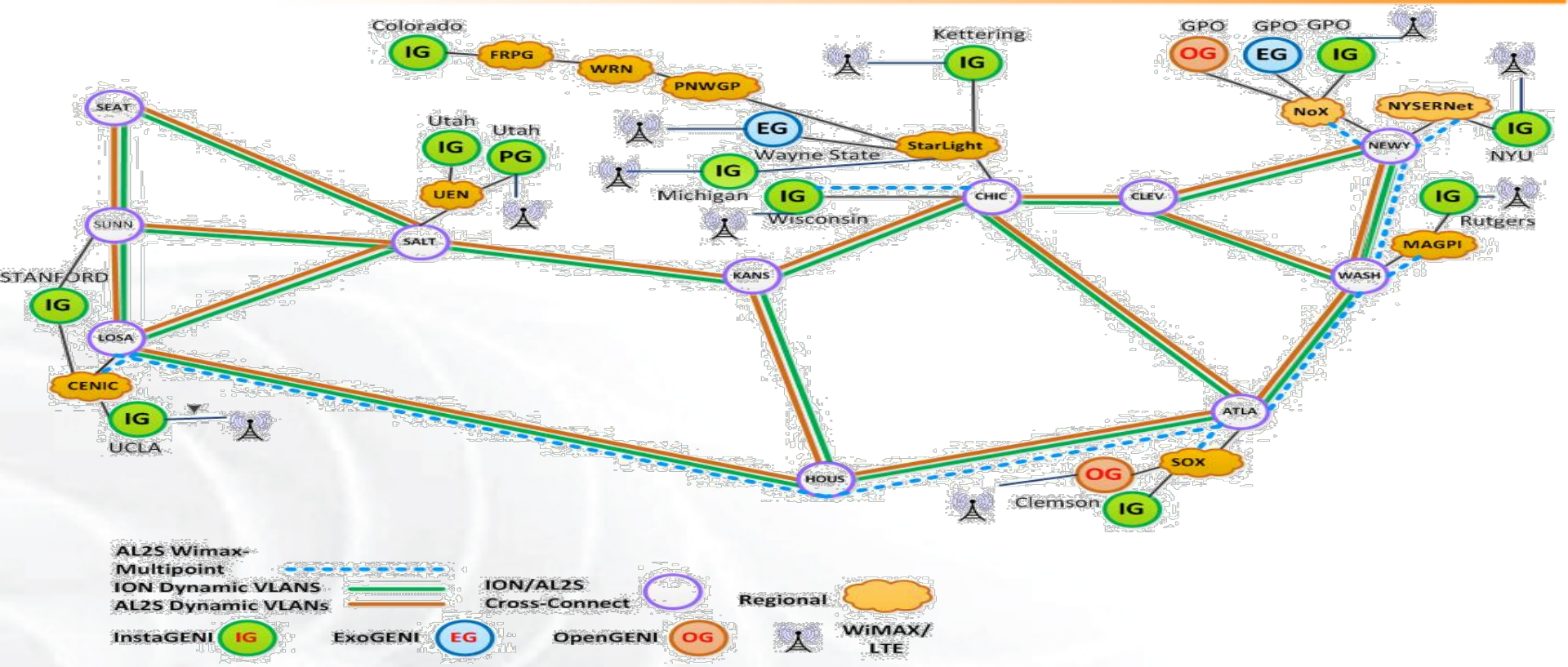
WiMAX Developers session
Wed: 11:30pm – 12:30pm

GENI WiMAX 2014



- 26 Wimax Base Stations in 13 Sites
- 90 android handsets available to experimenters
- 36 wireless (yellow) nodes
- Uniform experimenter experience using yellow nodes
- Sliced, virtualized and interconnected through Internet2

GENI WiMAX 2014



- 26 Wimax Base Stations in 13 Sites
- 90 android handsets available to experimenters
- Sliced, virtualized and interconnected through Internet2

GENI Operations

GMOC: GENI Meta-operation Center

- Keeps track of outages
- Notification system for resource reservation
- Monitors most GENI Aggregates
- Coordinates LLR Requests
  - **L**egal **L**aw Enforcement & **R**egulatory
- Handles Emergency Stop

GMOC Calendar tracks reservations/outages

For emailed notifications: experimenter-ops*

https://mail1.grnoc.iu.edu/mailman/listinfo/experimenter-ops

Creating and deploying GENI racks

Ilia Baldine
RENCI
More resources / rack, fewer racks

IBM

Rajesh Narayanan
DELL

KC Wang Clemson

Latest addition

DELL

Rick McGeer
HP Labs
Fewer resources / rack, more racks

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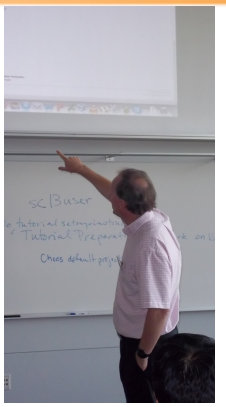
What's next for GENI?

GENI: An experimenter's view

How is GENI being Used?

Research

- Future Internet Architectures
- Software defined networking
- Large scale evaluation of protocols
- Could networking
- Domain sciences

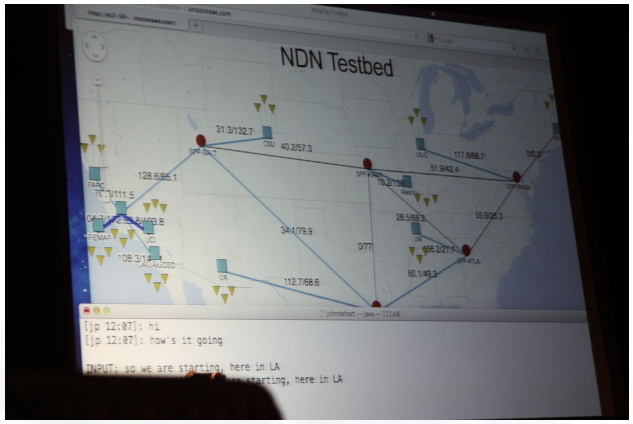


Education

- Classes in:
  - Computer Networking
  - Distributed systems
  - Cloud computing
  - Wireless Communications
- Undergraduate, graduate

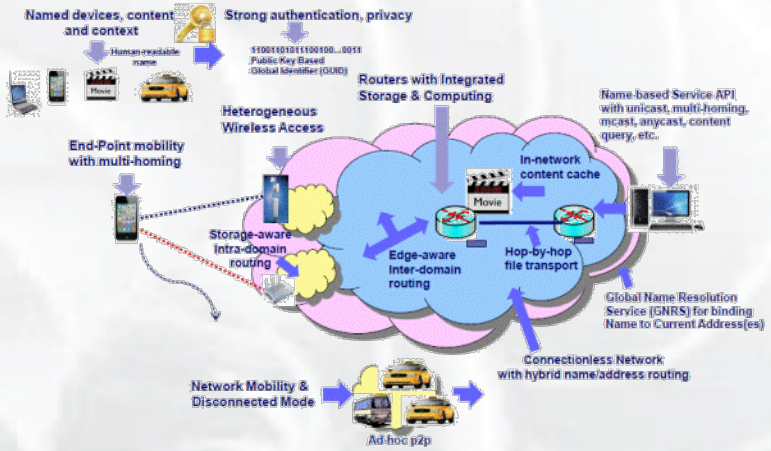
As of October 2014, GENI has over 2700 users!

Three FIA Teams have Slices on GENI

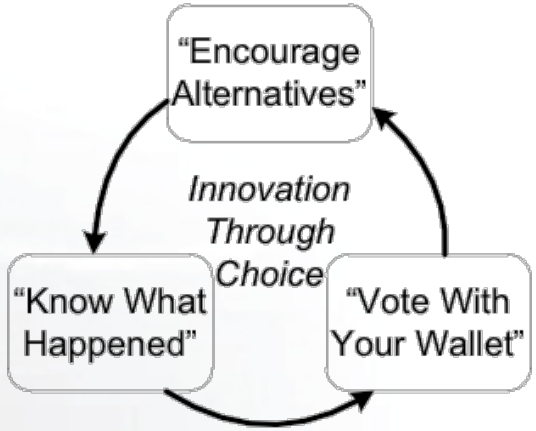


NDN (tutorial Wed @ 1.30pm)

XIA (tutorial @ today @10.30am)



MobilityFirst (tutorial today @ 3.30pm)



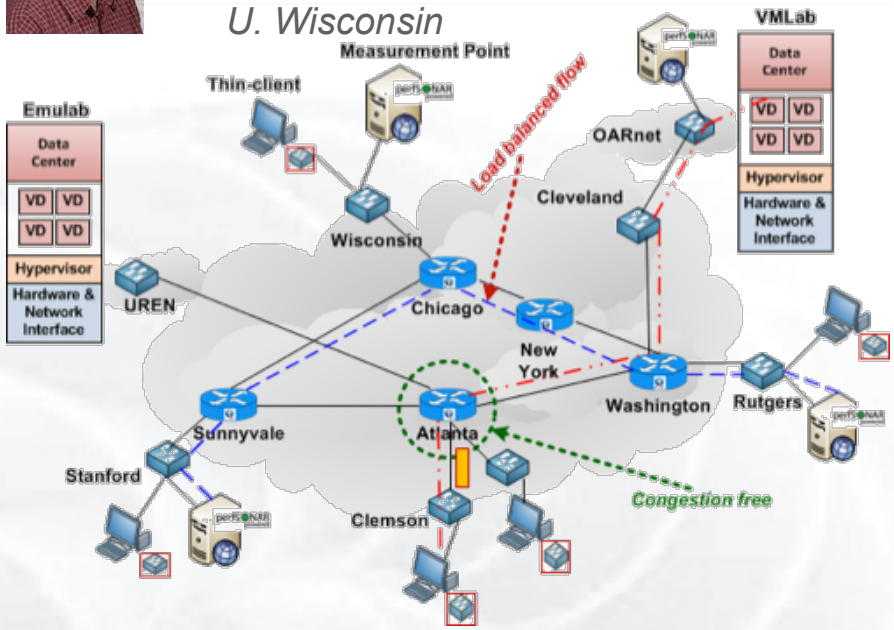
ChoiceNet (tutorial today @ 3.30pm)

GENI is the only testbed that can support these teams.

Software Defined Networking Research

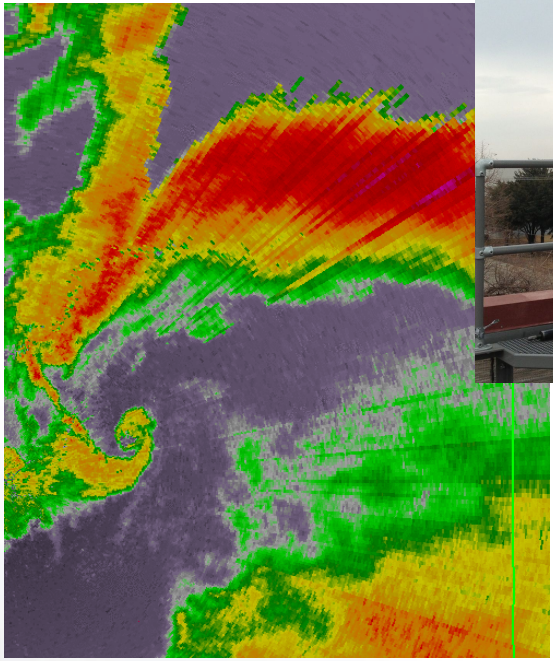
KC Wang
Clemson U.

Parmesh Ramanathan
U. Wisconsin



GENI Cinema

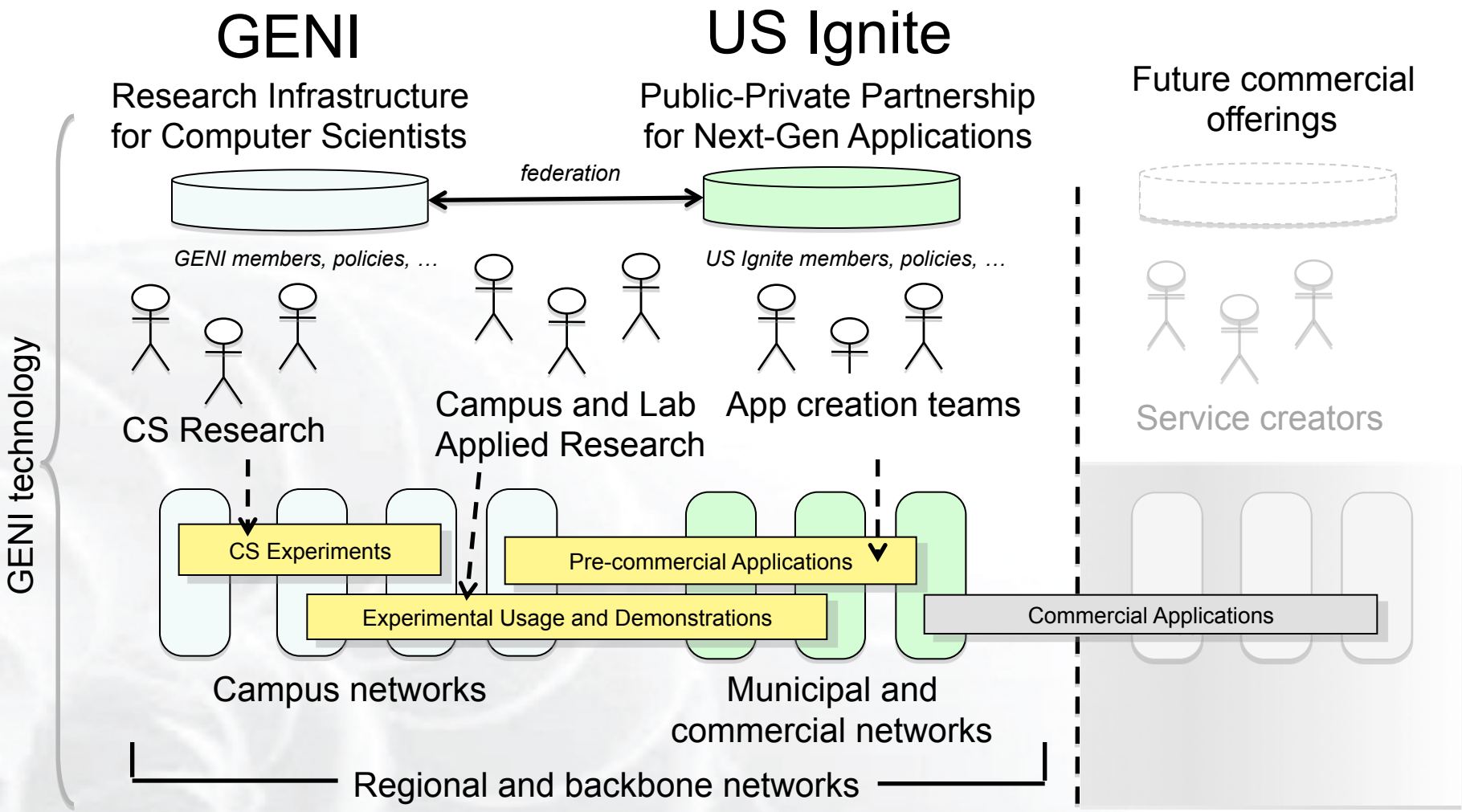
Improve in-time weather forecasting using **S**oftware **D**efined e**X**changes



Mike Zink
Umass Amherst

GENI is the largest multi-domain SDN testbed

US Ignite: Builds application of the future



US Ignite promotes advanced applications and infrastructure leveraging GENI research and technologies.

Growing use of GENI in the Classroom!

Over 50 classes have used GENI

- Undergrad level
- Graduate level
- Used Internationally

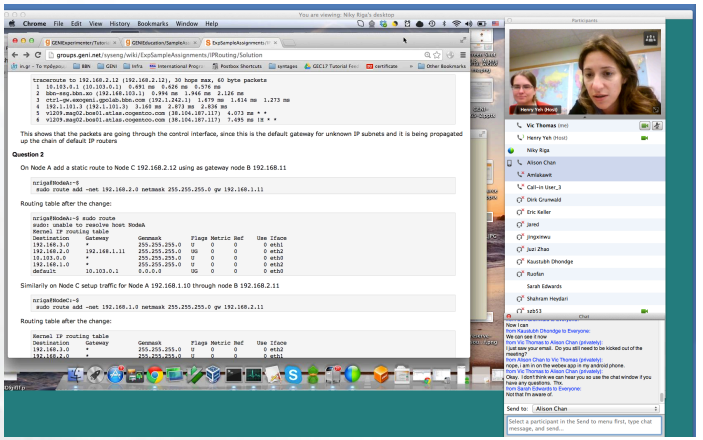
Jeannie Albrecht (Williams College) with students from her Spring 2012 Distributed Systems class

Ready-to-use tutorials assignments

- Teach how to use GENI
- Teach networking concepts
- Teach distributed computing concepts
- Teach programmable networks

Train-the-TA tutorials

- Start of each semester
- Taught over WebEx



Train-the-TA Webinar

GENI in the Classroom – A great success!

Jeannie Albrecht (Williams College) with students from her Spring 2012 Distributed Systems class

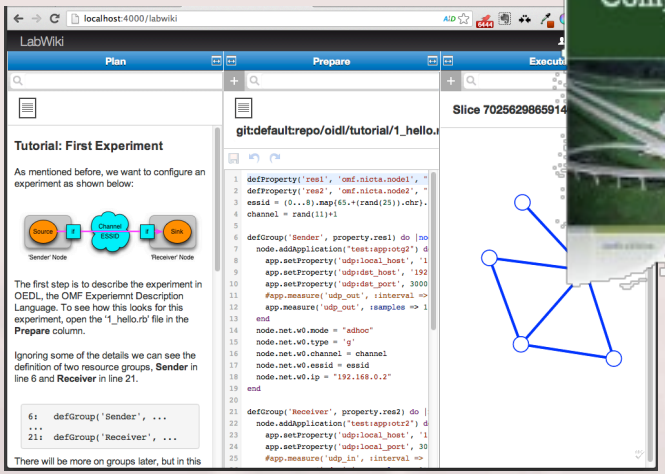
Spring 2014 (15 classes):
- Jeanne Albrecht (Williams College)
- Suman Banerjee (U. of Wisconsin)
- Baek-Young Choi (U. of Missouri-Kansas City)
- Zongming Fei (U. of Kentucky)
- Deniz Gurkan (U. of Houston)
- Thanasis Korakis (NYU Poly)
- Yaoqing Liu (Clarkson U.)
- Shivendra Panwar (NYU Poly)
- Robert Ricci (U. of Utah)
- Carolyn Sher-Decusatis (City U. of New York)
- Violet Syrotiuk (Arizona State U.)
- Bing Wang (U. of Connecticut)
- KC Wang (Clemson U.)
- *Vasillis Maglaris (NTUA Greece)*
- *Gaia Maselli (Sapienza University of Rome – Italy)*

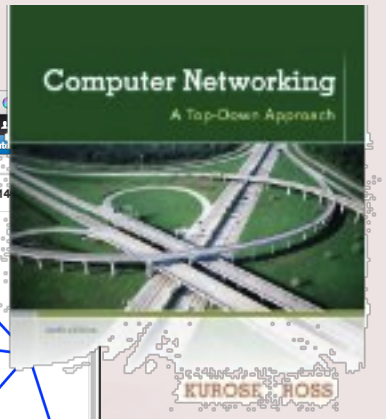
Fall 2013:
- Suman Banerjee (U. of Wisconsin)
- Prasad Calyam (U. of Missouri)
- Zongming Fei (U. of KY)
- John Geske (Kettering U.)
- Deniz Gurkan (U. of Houston)
- Christos Papadopoulos (Col. State)
- Henning Schulzrinne (Columbia U.)
- Violet Syrotiuk (Arizona State U.)
- Zhi-Li Zhang (U. of MN)

Spring 2013:
- Jay Aikat (U. of NC)
- Rudra Dutta (NCSU)
- Khaled Harfoush (NCSU)
- Jelena Marasevic (Columbia U)
- Parmesh Ramanathan (U. Wisc)
- Violet Syrotiuk (Arizona State U.)
- KC Wang (Clemson)
- Michael Zink (U. of MA)

Fall 2012:
- Rudra Dutta (NCSU)
- Zongming Fei (U. of KY)
- Fraida Fund (NY Poly)
- Kaiqi Xiong (RIT)

GENI in the Classroom – Moving Forward

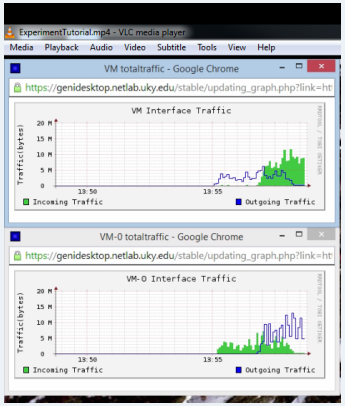




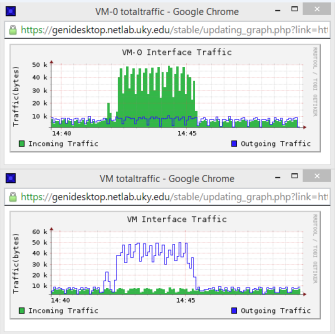
Labs on GENI for networking textbook

Mike Zink
UMass Amherst

GENI Modules to teach networking concepts

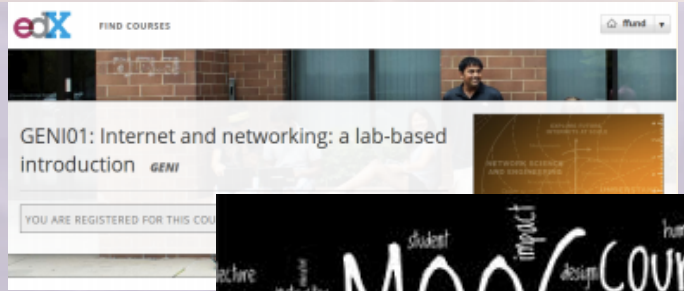


Example Demo Module



Example Assignment

Kevin Jaffay, Jay Aikat
UNC-Chapel Hill



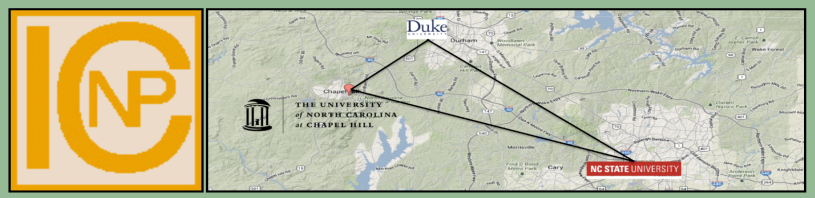
Massive Online Open Courses on GENI

Use GENI to educate the Internet users, not the Internet creators.

Shivendra Panwar, Thanasis Korakis
NYU Poly

GENI at Conferences and Workshops

The 22nd IEEE International Conference on Network Protocols



October 21-24, 2014 **The Research Triangle, North Carolina**

CNERT
Computer and Networking Experimental Research using Testbeds

October 24th 2014

- 6 long papers, 4 short
- Live demos for most papers

KEEP CONNECTED
12TH VINE
SIGCSE 2015 KANSAS CITY
KEEP COMMITTED
KEEP COMPUTING

SIGCESE 2015
March 4 – 7

GENI Pre-symposium event on Education

MORGAN STATE UNIVERSITY

Introduction to GENI Workshop
organized by
Wole Akpose & Jeannie Albrecht

Outline

GENI – Exploring future internets at scale

The GENI Concept

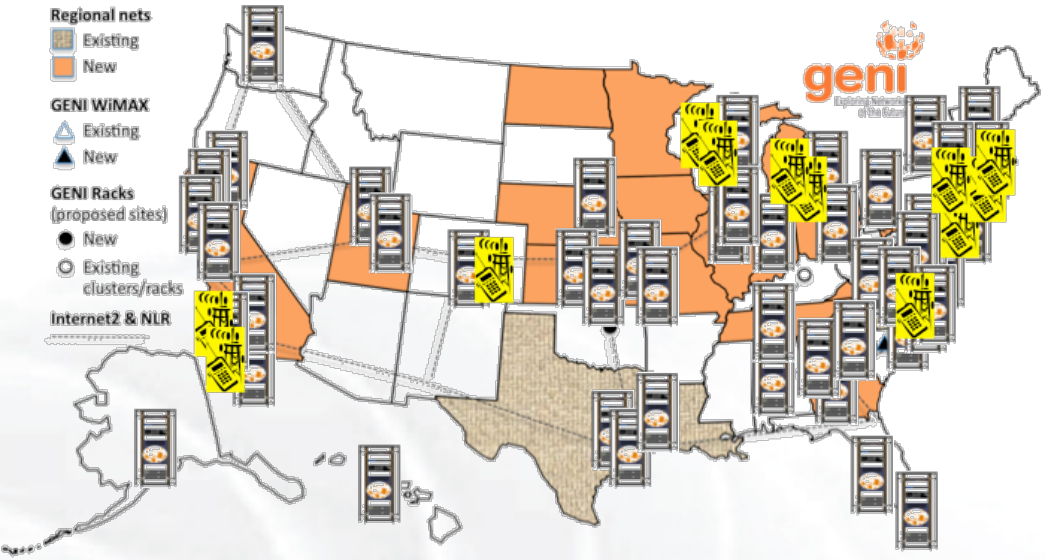
Building GENI

Experimental and Classroom use of GENI

What's next for GENI?

GENI: An experimenter's view

Interested in GENI Enabling your Campus?



"GENI-enabled" means . . .
OpenFlow + GENI racks, plus WiMAX on some campuses

Omnibond
Directed Development & Support for OrangeFS

OpenGENI vendor

MATRIX INTEGRATION
International provider of Voice & Data solutions.
"We make it work."

InstaGENI vendor

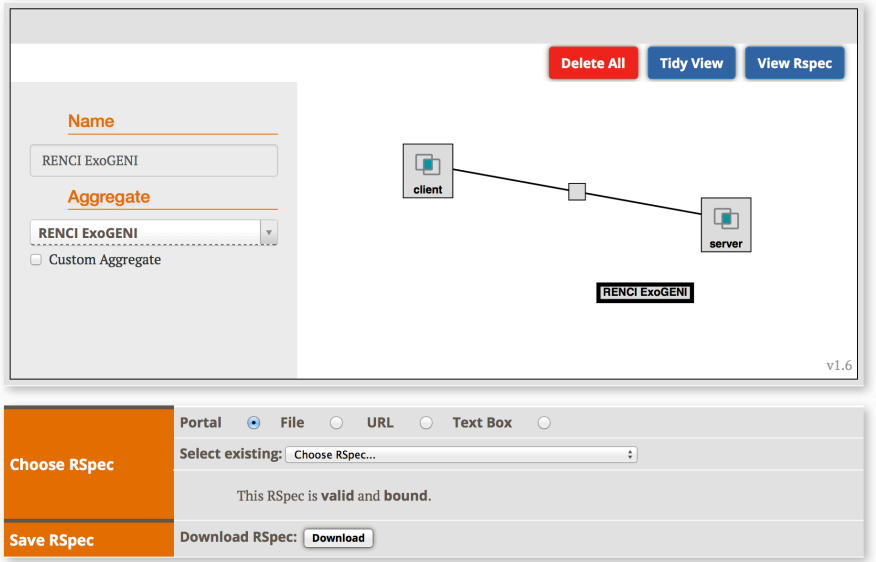
IBM

ExoGENI vendor

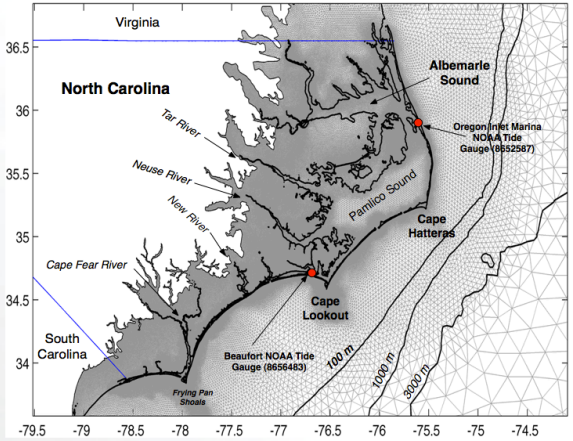
To buy a GENI Rack talk to rack vendors or GPO

Ongoing Activities

- Tools to support complex experiments
  - Setup and manage complex topologies
    - geni-lib: Tutorial on Wed @ 4pm
    - VTS: Demo at the plenary tomorrow
- New experimenter tools
  - Jacks and jFed
- New GENI-based courseware
  - GENI in Education @ 10.30am
- Shakedown Experiments
  - Run services in GENI
    - GENI Cinema, Intelligent Data Management
  - Use of GENI in other domain sciences



Jacks



Storm Surge Modeling

GENI's International Collaborations

GENI is working actively with peer efforts on five continents to define and adopt common concepts and APIs.

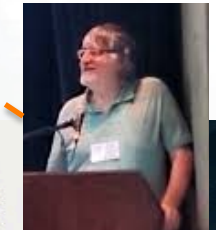
TransGeo Distributed Clouds:
Think Globally, Compute Locally

Yvonne Coady
U. Victoria
Canada

Rob Ricci
U. Utah
US

Joe Mambertti
Northwestern
US

Julio Ibarra
FIU, **US**



Michael Stanton
USP, **Brazil**

Piet Demeester
Ughent
Belgium

Rick McGeer
HP, **US**

Compute *"green index"* for cities worldwide

Paul Mueller
U. Kaiserslautern
Germany

Aki Nakao
U. Tokyo
Japan

Federation fosters International Collaborations

Outline

GENI – Exploring future internets at scale

The GENI Concept

Building GENI

Experimental and Classroom use of GENI

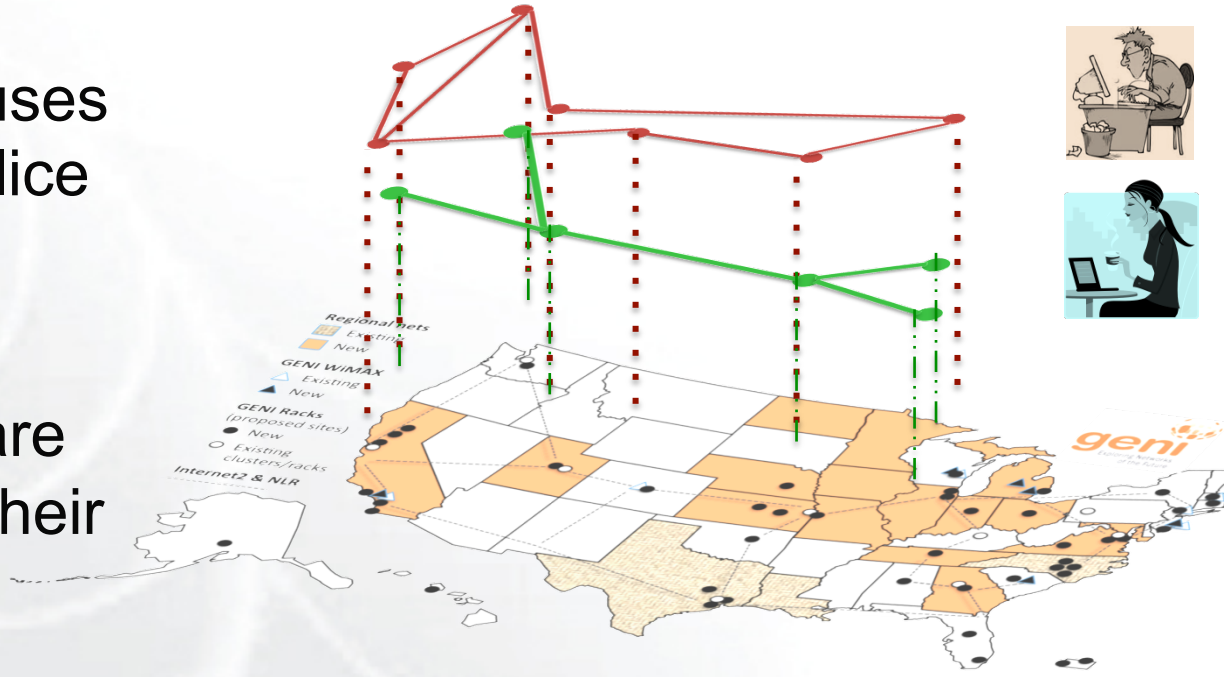
What's next for GENI?

GENI: An experimenter's view

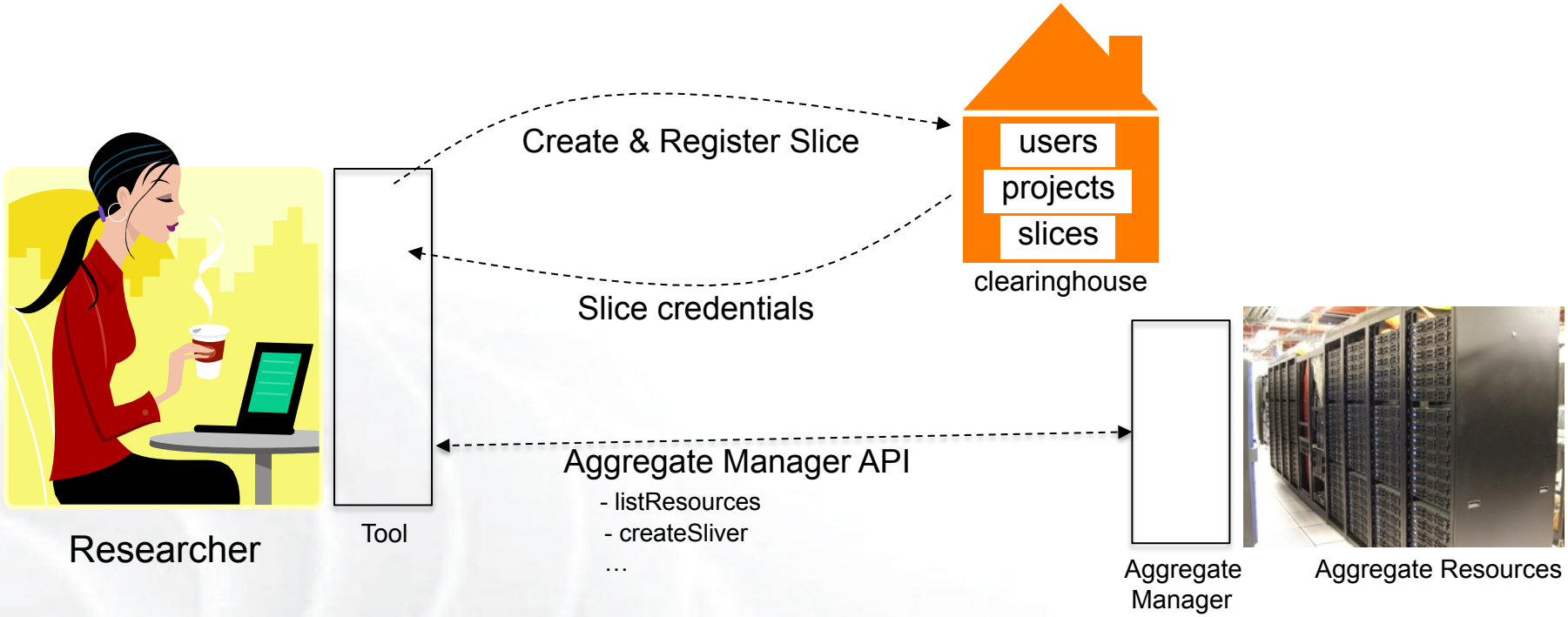
Slice

Abstraction for a collection of resources capable of running experiments

- An experiment uses resources in a slice
- Slices isolate experiments
- Experimenters are responsible for their slices



Clearinghouse and Aggregates



- Clearinghouse: Manages users, projects and slices
  - Standard credentials shared via custom API or new Common CH API
  - GENI supported accounts: GENI Portal/CH, PlanetLab CH, ProtoGENI CH
- Aggregate: Provides resources to GENI experimenters
  - Typically owned and managed by an organization
  - Speaks the GENI AM API
  - Examples: PlanetLab, Emulab, GENI Racks on various campuses

GENI User Authentication

The GENI Portal leverages InCommon for single sign-on authentication

InCommon®

Experimenters from 304 educational and research institutions have InCommon accounts

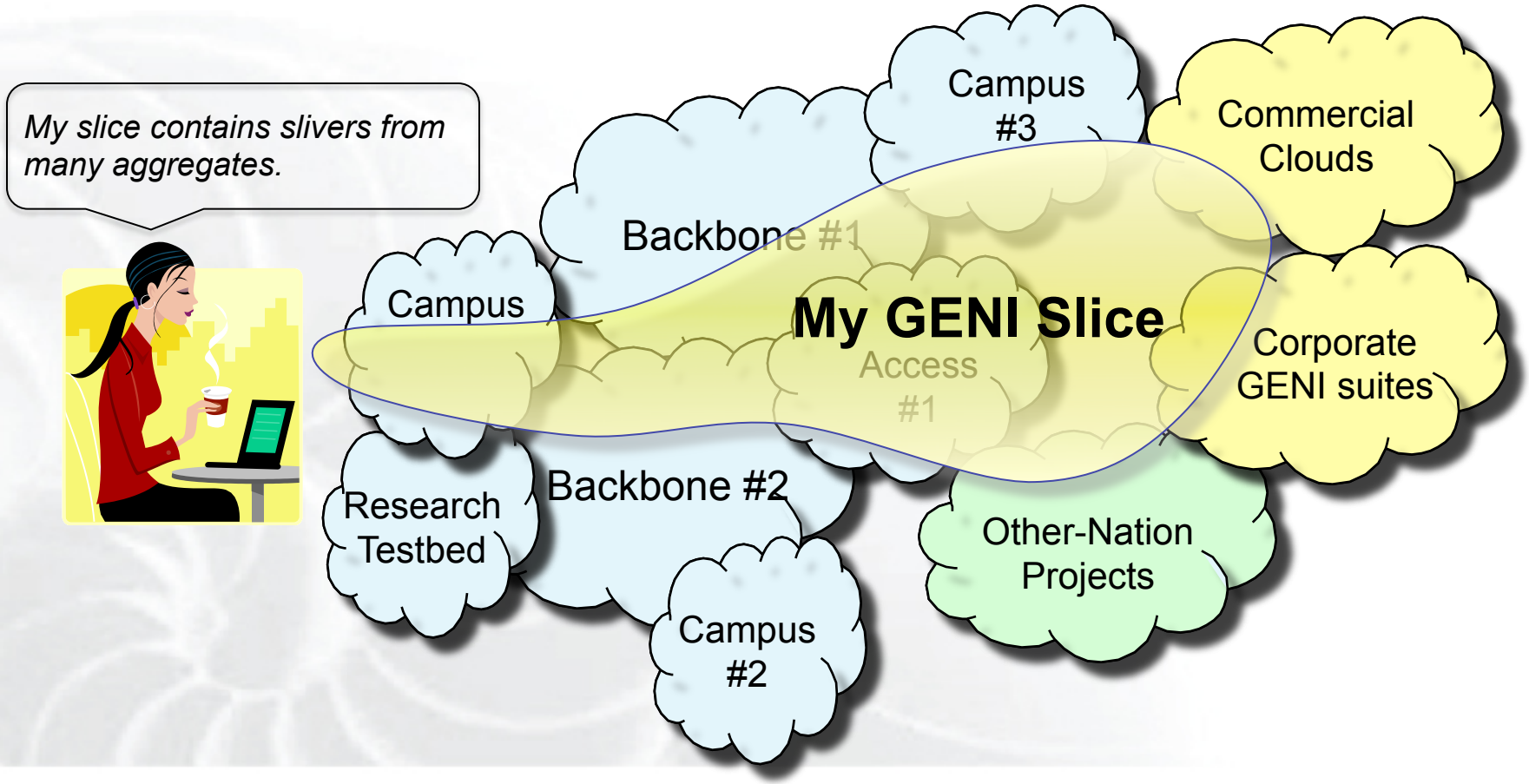
For many experimenters:

- no new passwords
- familiar login screens

GENI Project Office runs a federated IdP to **provide accounts** for non-federated organizations.

GENI: Terms and Definitions

- Sliver: One or more resources provided by an aggregate
  - E.g. Bare machines, virtual machines, VLANs



RSpecs

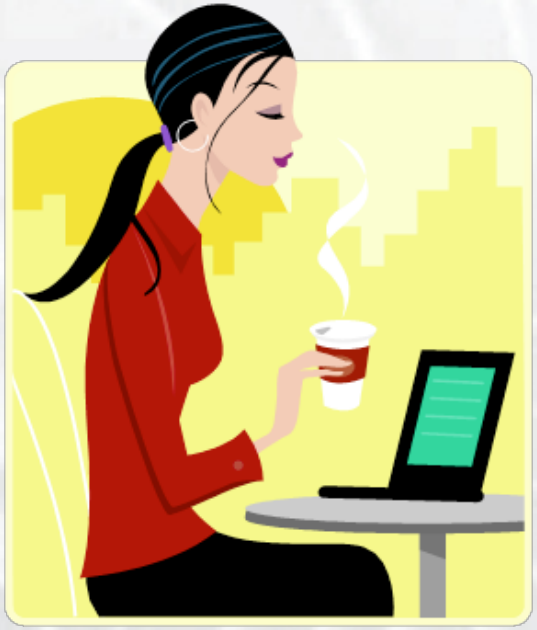
- RSpecs: Lingua franca for describing and requesting resources
  - "Machine language" for negotiating resources between experiment and aggregate
  - Experimenter tools eliminate the need for most experimenters to write or read RSpec

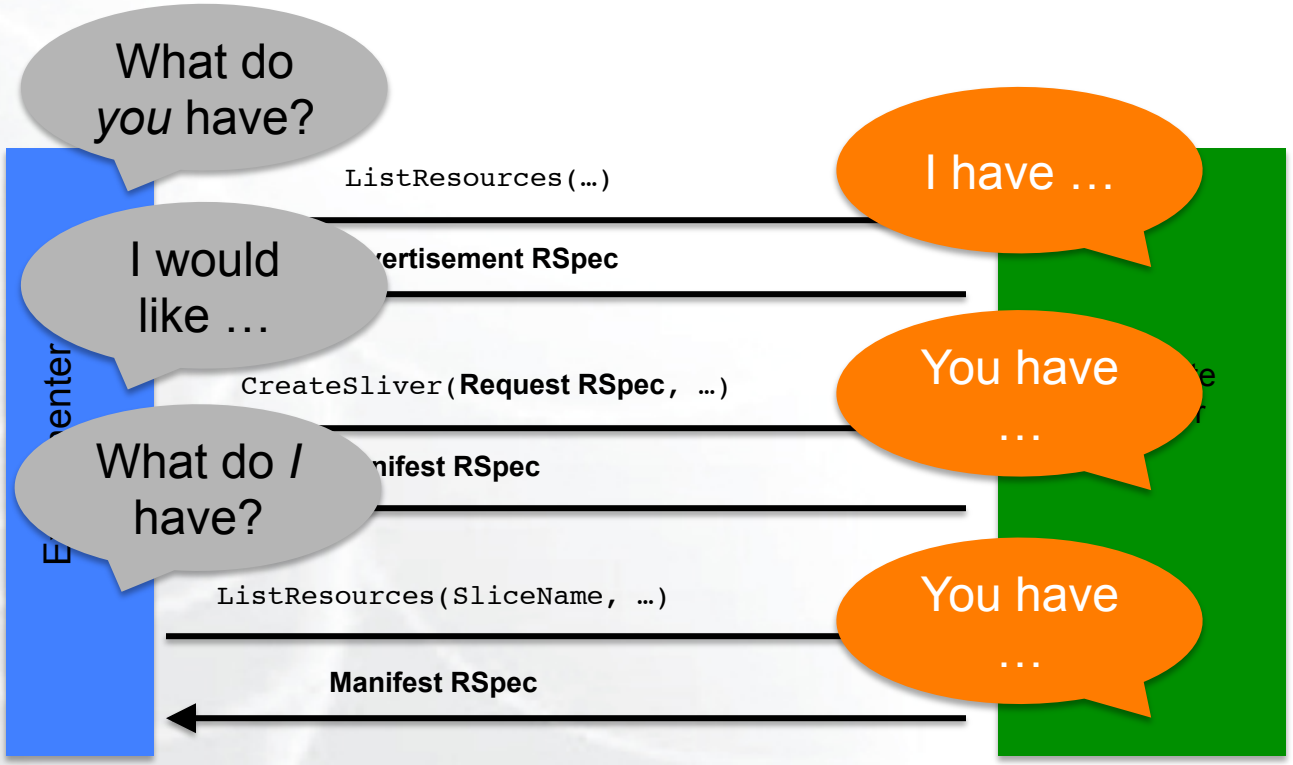
```
<?xml version="1.0" encoding="UTF-8"?>
<rspec xmlns="http://www.protogeni.net/resources/rspec/2"
       xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
       xsi:schemaLocation="http://www.protogeni.net/resources/rspec/2
                           http://www.protogeni.net/resources/rspec/2/request.xsd"
       type="request" >
  <node client_id="my-node"
        exclusive="true">
    <sliver_type name="raw-pc" />
  </node>
</rspec>
```

RSpec for requesting a single node

Reserving Resources using RSpecs and the AM API

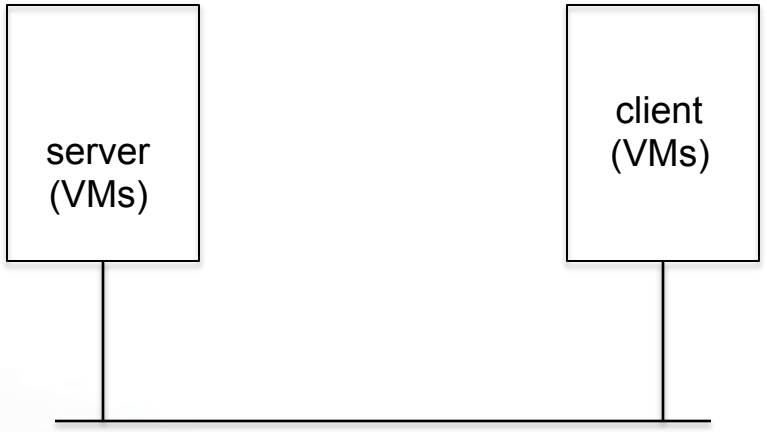
- Experimenter tools and aggregates talk to each other using resource specifications (RSpecs) and the GENI Aggregate Manager API (GENI AM API)
- Advertisement RSpec: What does an aggregate have?
- Request RSpec: What does the experimenter want?
- Manifest RSpec: What does the experimenter have?





Putting it all Together: Demo

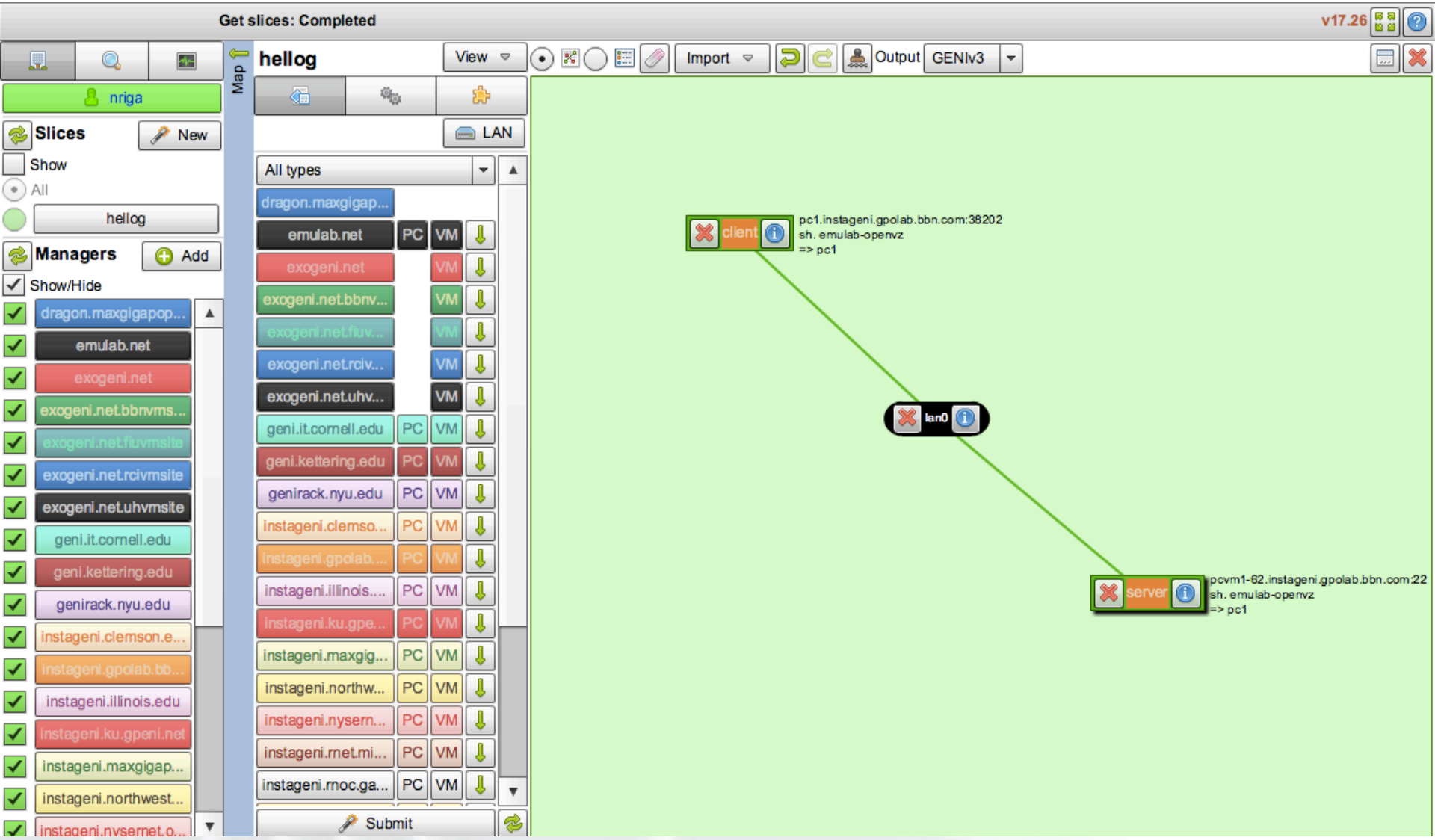
- Demo
  - Login to the GENI Portal
  - Create a slice
  - Create a sliver at one aggregate
    - Two computers (VMs), connected by a LAN
  - Install and run software on the machines
  - View output of software
  - Delete sliver
- Experimenter tool: Jacks



Start Demo

- Login to GENI Experimenter Portal
- Create slice
- Launch Flack
- Draw topology
- Create sliver
- Verify sliver creation was successful

The Demo Experiment in Flack



The Request Rspec

```
<rspec type="request" xsi:schemaLocation="http://www.geni.net/resources/rspec/3 http://www.geni.net/resources/rspec/3/request.xsd"
      xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance" xmlns="http://www.geni.net/resources/rspec/3">
  <node client_id="server" component_manager_id="urn:publicid:IDN+emulab.net+authority+cm" exclusive="true">
     <sliver_type name="raw-pc">
        <disk_image name="urn:publicid:IDN+emulab.net+image+emulab-ops//FEDORA10-STD"/>
     </sliver_type>
     <services>
         <execute command="sudo /local/install-script.sh" shell="sh"/>
         <install install_path="/local" url="http://www.gpolab.bbn.com/experiment-support/HelloGENI//hellogeni-install.tar.gz"/>
      </services>
    <interface client_id="server:if0" />
  </node>
     <node client_id="client" component_manager_id="urn:publicid:IDN+emulab.net+authority+cm" exclusive="false">
     <sliver_type name="emulab-openvz"/>
     <services>
         <execute command="sudo /local/install-script.sh" shell="sh"/>
         <install install_path="/local" url="http://www.gpolab.bbn.com/experiment-support/HelloGENI//hellogeni-install.tar.gz"/>
     </services>
     <interface client_id="client:if0" />
  </node>
  <link client_id="Lan">
     <component_manager name="urn:publicid:IDN+emulab.net+authority+cm"/>
         <interface_ref client_id="server:if0"/>
         <interface_ref client_id="client:if0"/>
        <property source_id="server:if0" dest_id="client:if0"/>
        <property source_id="client:if0" dest_id="server:if0"/>
  </link>
</rspec>
```

The Manifest Rspec

```
<rspec type="manifest"  …>
  <node client_id="server" component_manager_id="urn:publicid:IDN+emulab.net+authority+cm" exclusive="true"
        component_id="urn:publicid:IDN+emulab.net+node+pc554" sliver_id="urn:publicid:IDN+emulab.net+sliver+95506">
      <sliver_type name="raw-pc">
        <disk_image name="urn:publicid:IDN+emulab.net+image+emulab-ops//FEDORA10-STD"/>
      </sliver_type>
      <services>
         <execute command="sudo /local/install-script.sh" shell="sh"/>
         <install install_path="/local" url="http://www.gpolab.bbn.com/experiment-support/HelloGENI//hellogeni-install.tar.gz"/>
         <login authentication="ssh-keys" hostname="pc554.emulab.net" port="22" username="vthomas"/>
      </services>
      <interface client_id="server:if0" component_id="urn:publicid:IDN+emulab.net+interface+pc554:eth2" sliver_id="urn:publicid:IDN
+emulab.net+sliver+95509" mac_address="0024e87a46fb">
         <ip address="10.10.1.1" type="ipv4"/>
      </interface>
  </node>
  <node client_id="client" component_manager_id="urn:publicid:IDN+emulab.net+authority+cm" exclusive="false"
         component_id="urn:publicid:IDN+emulab.net+node+pc533" sliver_id="urn:publicid:IDN+emulab.net+sliver+95505">
      <sliver_type name="emulab-openvz"/>
      <services>
         <execute command="sudo /local/install-script.sh" shell="sh"/>
         <install install_path="/local" url="http://www.gpolab.bbn.com/experiment-support/HelloGENI//hellogeni-install.tar.gz"/>
         <login authentication="ssh-keys" hostname="pc533.emulab.net" port="37178" username="vthomas"/>
      </services>
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+emulab.net+sliver+95510" mac_address="0262331adfd4">
         <ip address="10.10.1.2" type="ipv4"/>
      </interface>
  </node>
  <link client_id="Lan" sliver_id="urn:publicid:IDN+emulab.net+sliver+95508" vlantag="310">
      <interface_ref client_id="server:if0" component_id="urn:publicid:IDN+emulab.net+interface+pc554:eth2" sliver_id="urn:publicid:IDN
+emulab.net+sliver+95509"/>
      <interface_ref client_id="client:if0" component_id="urn:publicid:IDN+emulab.net+interface+pc533:eth2" sliver_id="urn:publicid:IDN
+emulab.net+sliver+95510"/>
      <property source_id="server:if0" dest_id="client:if0"/> <property source_id="client:if0" dest_id="server:if0"/>
```

Do Try This at Home!

- Tutorials on the GENI wiki
  - Look for the

icon on the GENI wiki and then click on

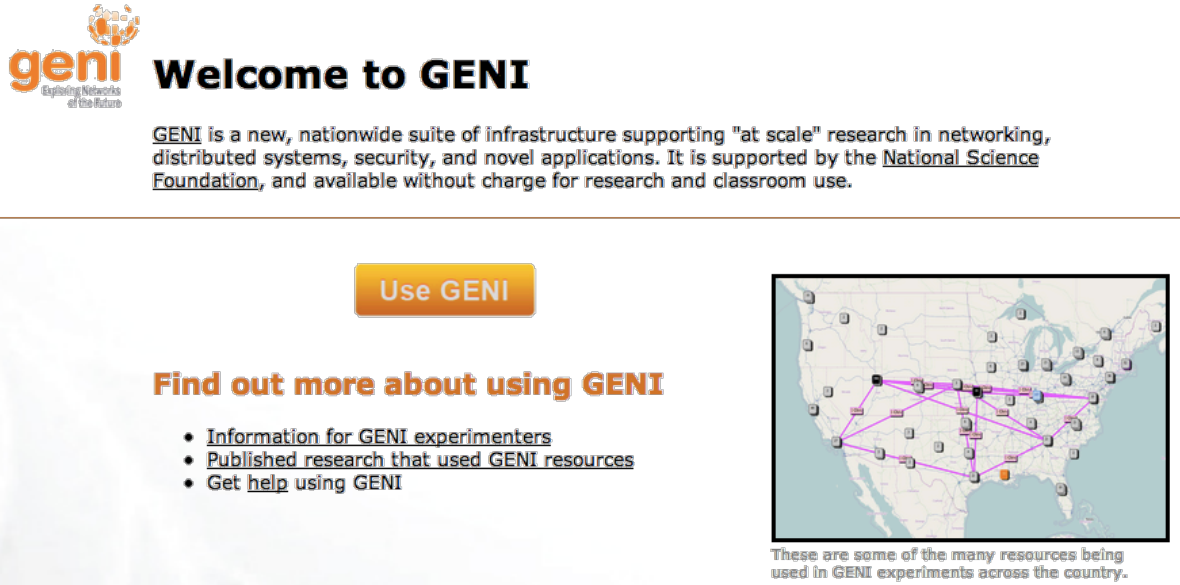
for tutorials
- Participate in the hands-on tutorials at the GEC
- Get a GENI account today!

Get a GENI Account Today!

At the GEC:

- **Registration Desk**
- **Experimenter drop-in**

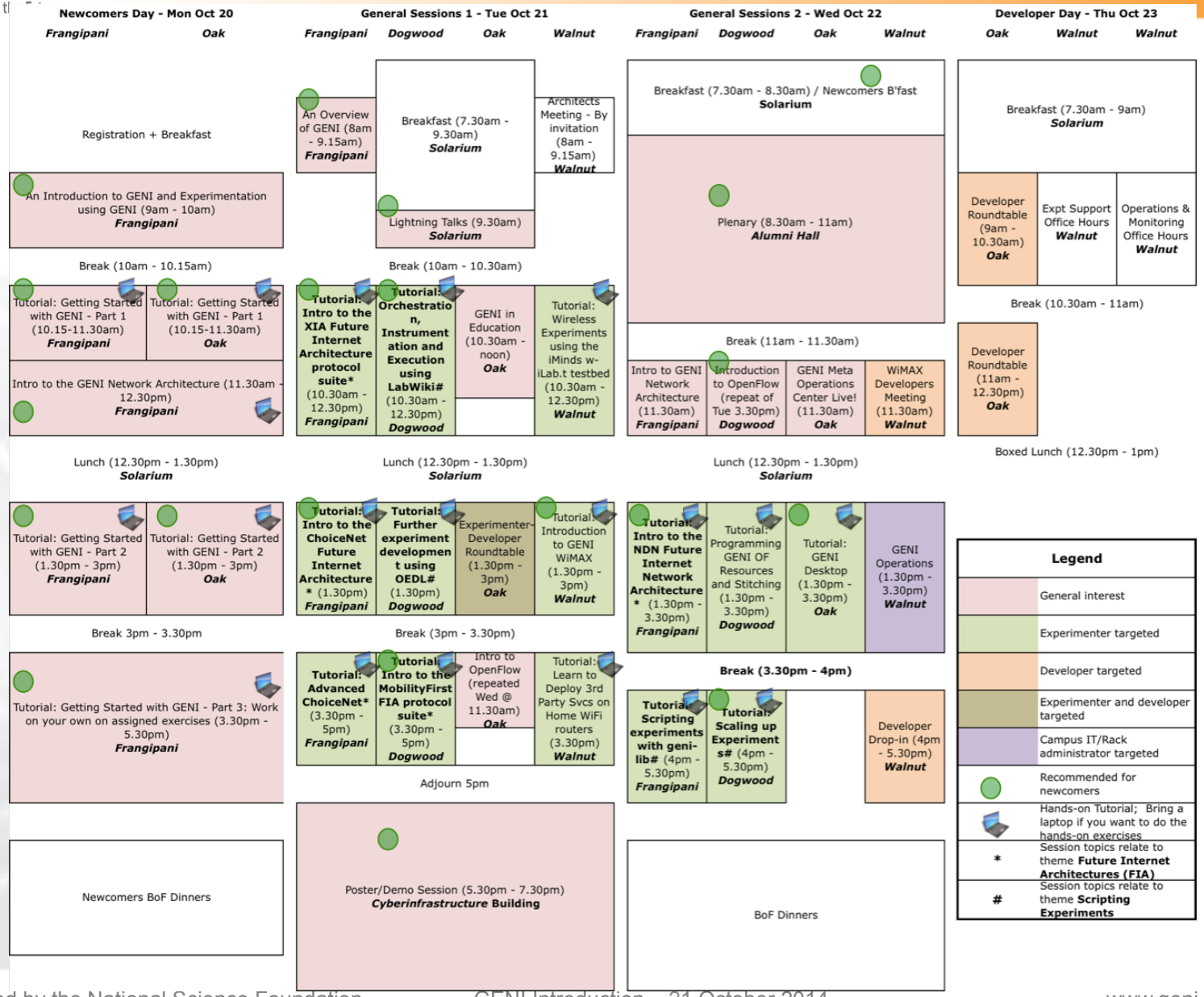
Email: help@geni.net



Online: https://portal.geni.net

Students need a professor to create a GENI project

GEC21 Agenda: Suggestions for Newcomes



GENI Engineering Conferences
We welcome your participation in GENI

- **22nd meeting, open to all:**
  March 23-26, 2015**, Washington, DC**
  - Planning & discussion for experimenters, software, infrastructure
  - Tutorials and workshops
  - **Travel grants** to US academics for participant diversity

QUESTIONS?