GENI

Exploring Networks of the Future

Now going live across the US!

GENI Project Office
July 2011
www.geni.net

Sponsored by the National Science Foundation

Outline

- GENI – Exploring future internets at scale
- Introducing GENI: an example
- GENI's growing suite of infrastructure
- Experiments going live across the US!
- What's next for GENI?
- GENI and U.S. Ignite
- How can you participate?
- Suggested GEC11 sessions for newcomers

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

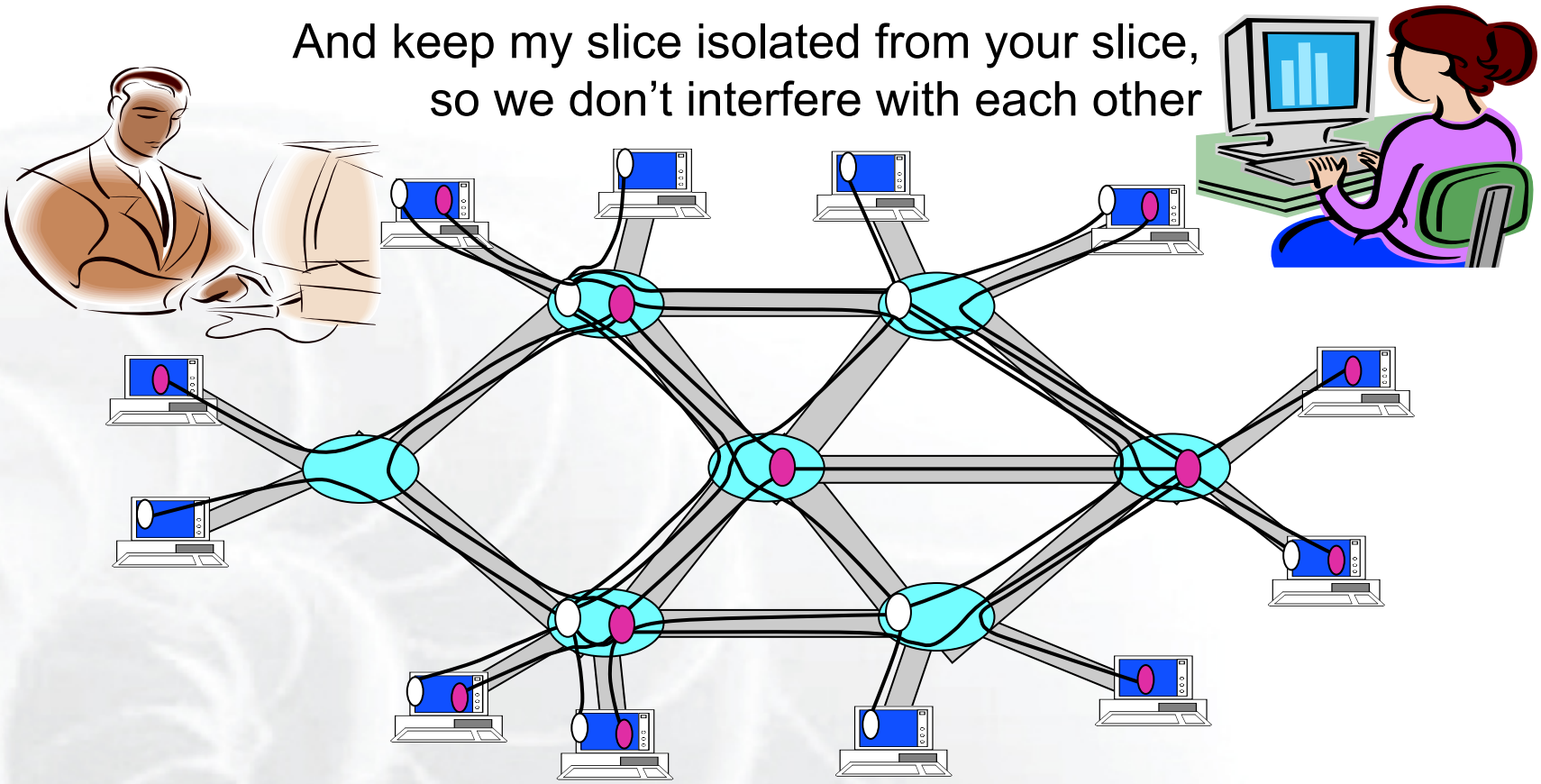
What is GENI?

- GENI is a virtual laboratory for **exploring future internets at scale**, now rapidly taking shape in prototype form across the United States
- GENI opens up huge new opportunities
  - **Leading-edge research** in next-generation internets
  - **Rapid innovation** in novel, large-scale applications
- Key GENI concept: slices & deep programmability
  - Internet: open innovation in application programs
  - GENI: open innovation deep into the network

Revolutionary GENI Idea
Slices and Deep Programmability

Install the software I want *throughout* my network slice (into firewalls, routers, clouds, …)

And keep my slice isolated from your slice, so we don't interfere with each other



We can run many different "future internets" in parallel

GENI is now going live across the US

GENI-enabling testbeds, campuses, and backbones

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A bright idea

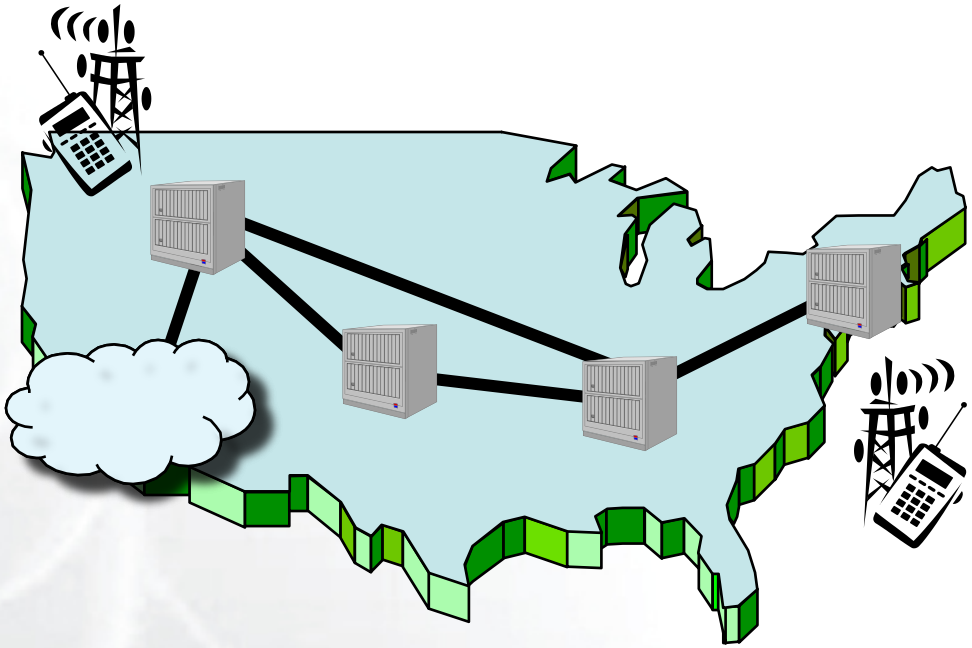
I have a great idea! The original Internet architecture was designed to connect one computer to another – but a better architecture would be fundamentally based on PEOPLE and CONTENT!

That will never work! It won't scale! What about security? It's impossible to implement or operate! Show me!

Trying it out

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

And so he poured his experimental software into clouds, distributed clusters, bulk data transfer devices ('routers'), and wireless access devices throughout the GENI suite, and started taking measurements . . .



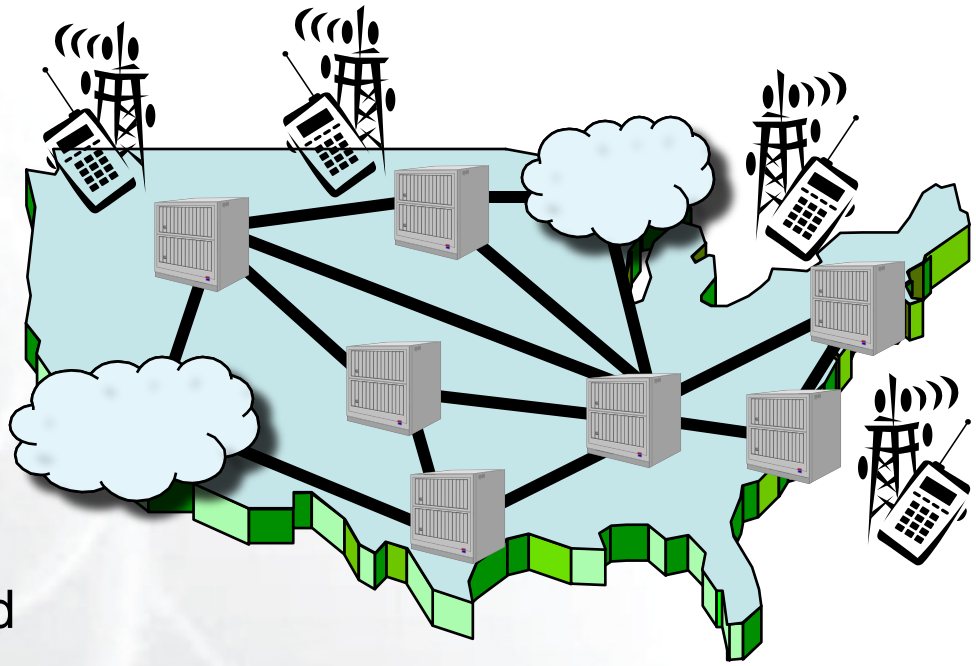
He uses a modest slice of GENI, sharing its infrastructure with many other concurrent experiments.

It turns into a really good idea

Boy did I learn a lot! I've published papers, the architecture has evolved in major ways, and I'm even attracting real users!

Location-based social networks are really cool!

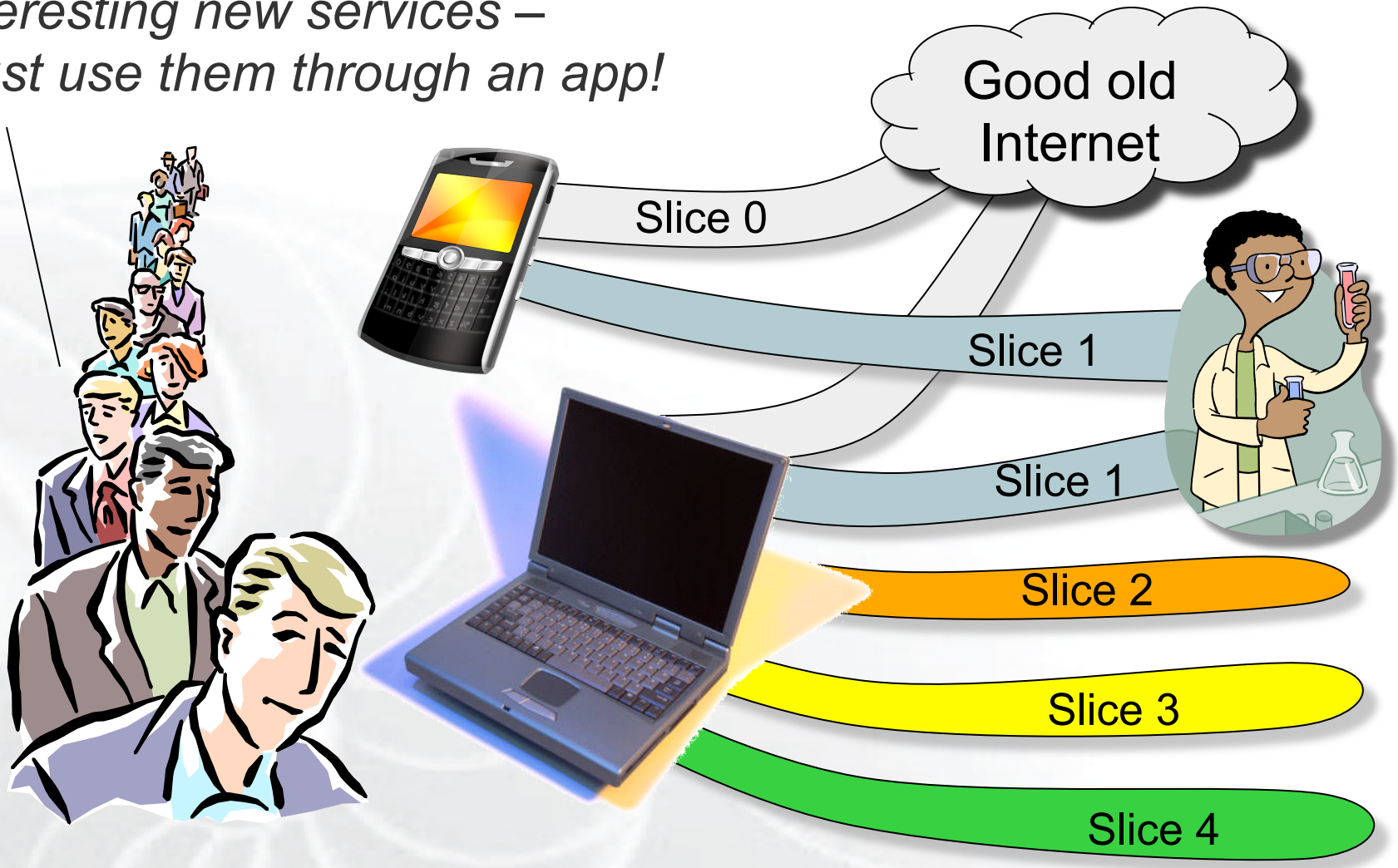
His experiment grew larger and continued to evolve as more and more real users opted in . . .



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

The (opt-in) user's view

Interesting new services –
I just use them through an app!



Experiment turns into reality

My experiment was a real success, and my architecture turned out to be mostly compatible with today's Internet after all – so I'm taking it off GENI and spinning it out as a real company.

I always said it was a good idea, but way too conservative.

Meanwhile . . .

I have a great idea! If the Internet were augmented with a scalable control plane and realtime measurement tools, it could be 100x as robust as it is today . . . !

And I have a great concept for incorporating live sensor feeds into our daily lives !

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**, which may or may not be compatible with today's Internet
  - **Both repeatable and "in the wild" experiments**
  - '**Opt in' for real users** into long-running experiments
  - Excellent **instrumentation and measurement** tools
  - **Large-scale growth for successful experiments**, so good ideas can be shaken down at scale

GENI creates a huge opportunity for ambitious research!

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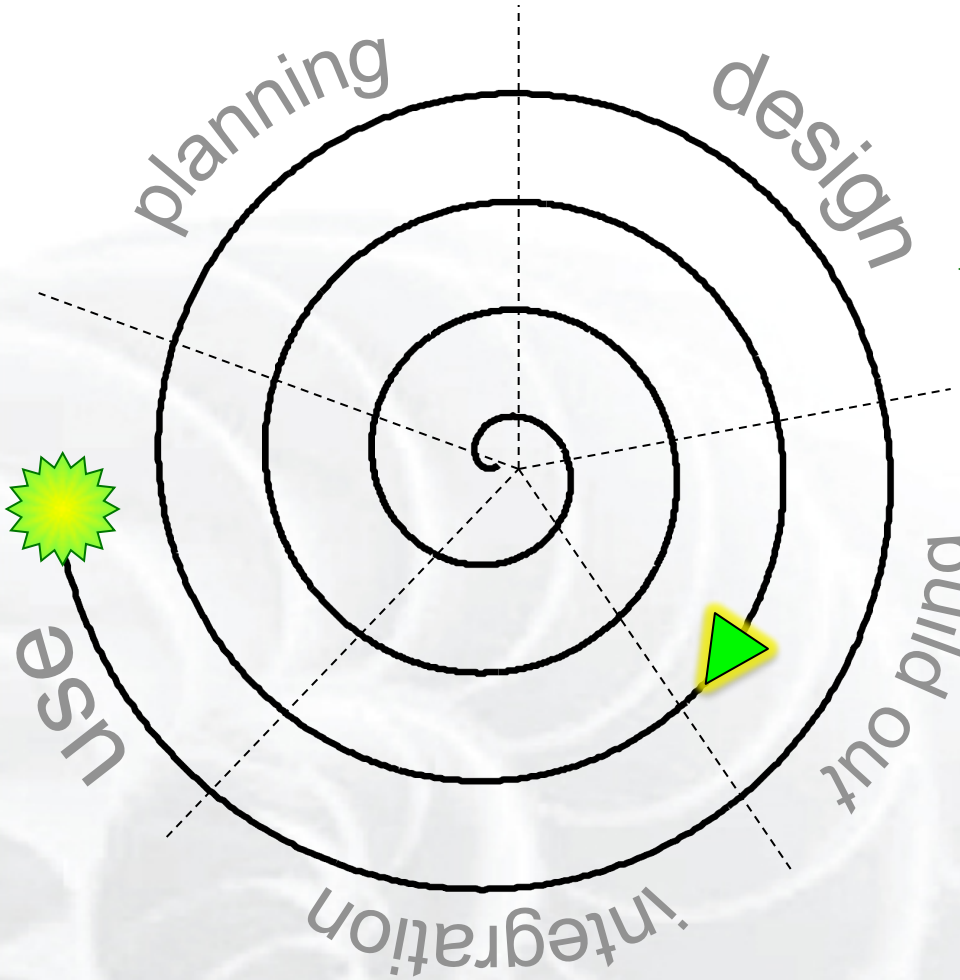
Spiral Development

GENI grows through a well-structured, adaptive process



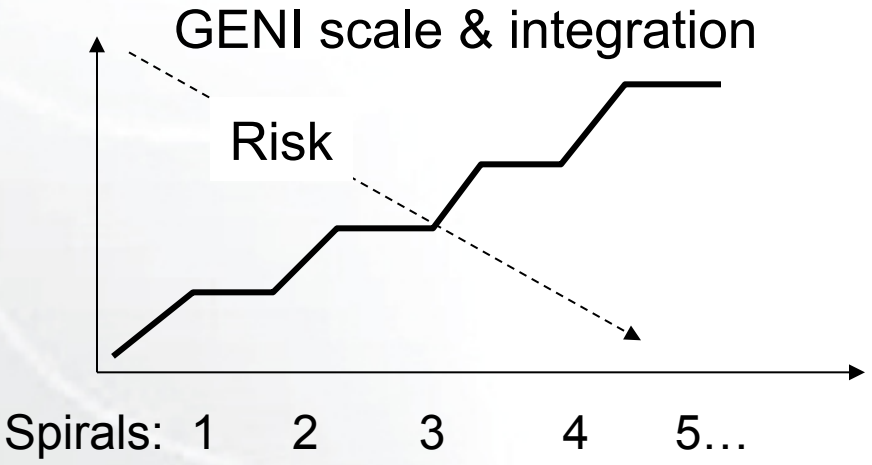
GENI Prototyping Plan

GENI Spiral 3

Early experiments, meso-scale build, interoperable control frameworks, ongoing integration, system designs for security and instrumentation, starting up operations.

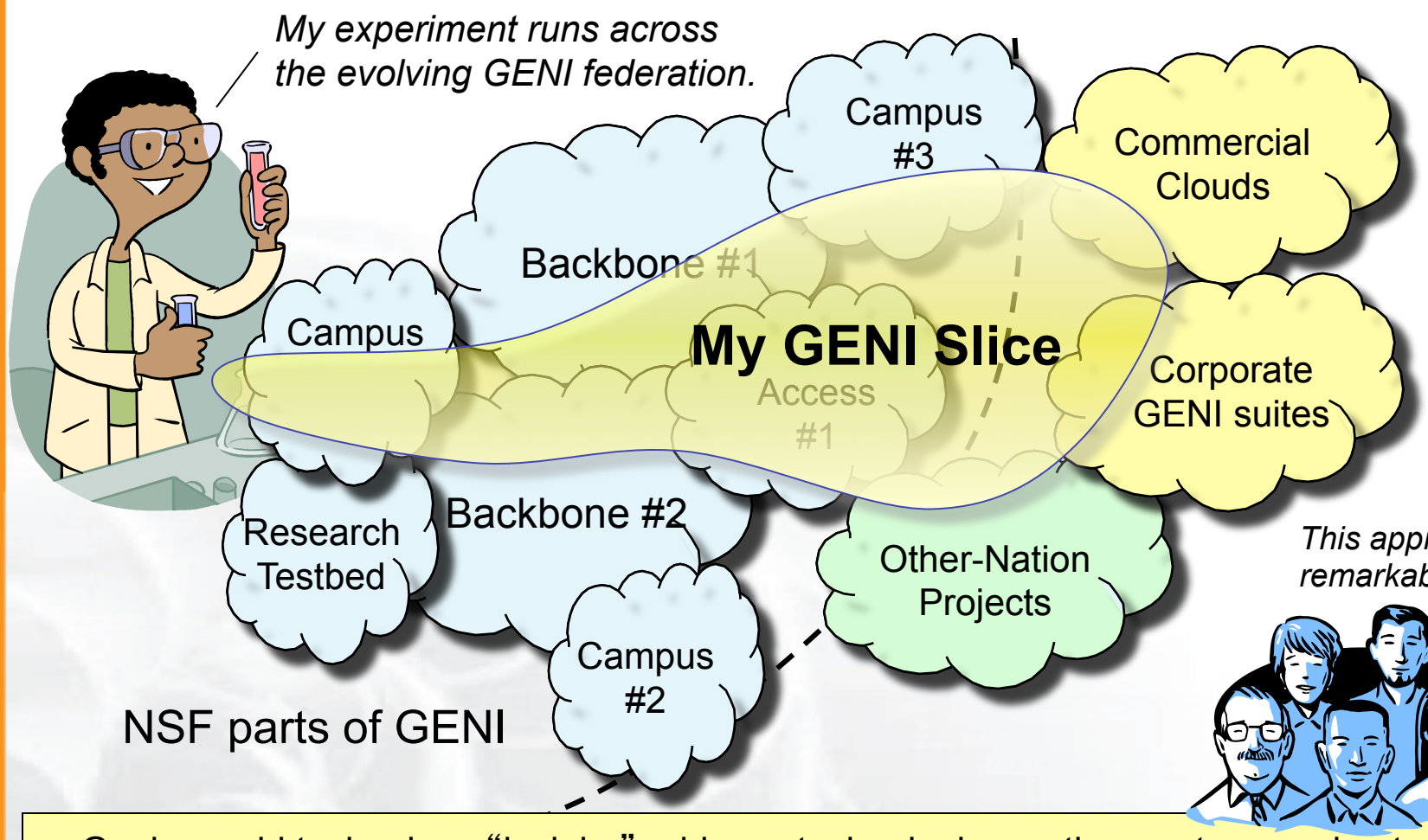
Envisioned **ultimate goal**

Large-scale distributed computing resources, high-speed backbone nodes, nationwide optical networks, wireless & sensor nets, etc.



Federation

GENI grows by "GENI-enabling" heterogeneous infrastructure

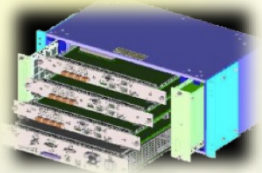


Goals: avoid technology "lock in," add new technologies as they mature, and potentially grow quickly by incorporating existing infrastructure into the overall "GENI ecosystem"

Enabling “at scale” experiments

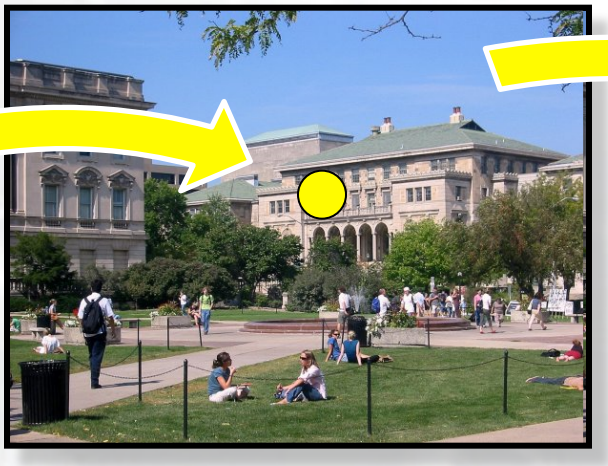
- **How can we afford / build GENI at sufficient scale?**
  - Clearly infeasible to build research testbed “as big as the Internet”
  - Therefore we are “GENI-enabling” testbeds, commercial equipment, campuses, regional and backbone networks
  - **Students are early adopters / participants in at-scale experiments**
  - Key strategy for building an at-scale suite of infrastructure

HP ProCurve 5400 Switch

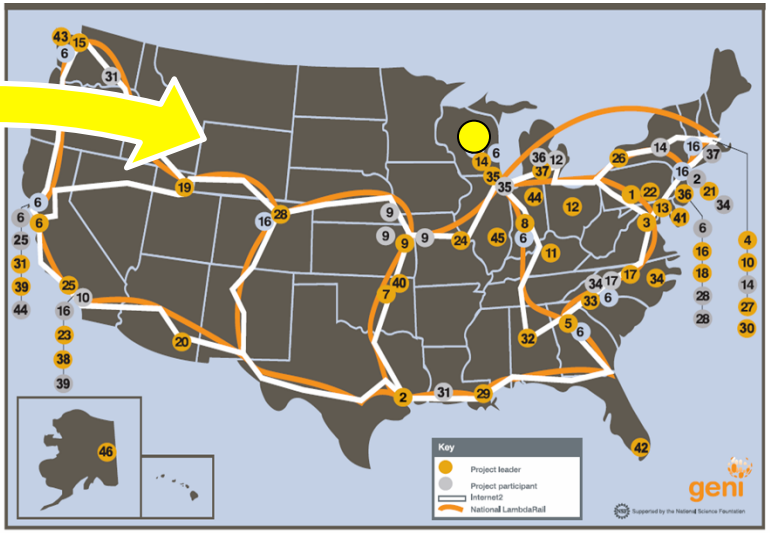


NEC WiMAX Base Station

GENI-enabled equipment



GENI-enabled campuses, students as early adopters



“At scale” GENI prototype

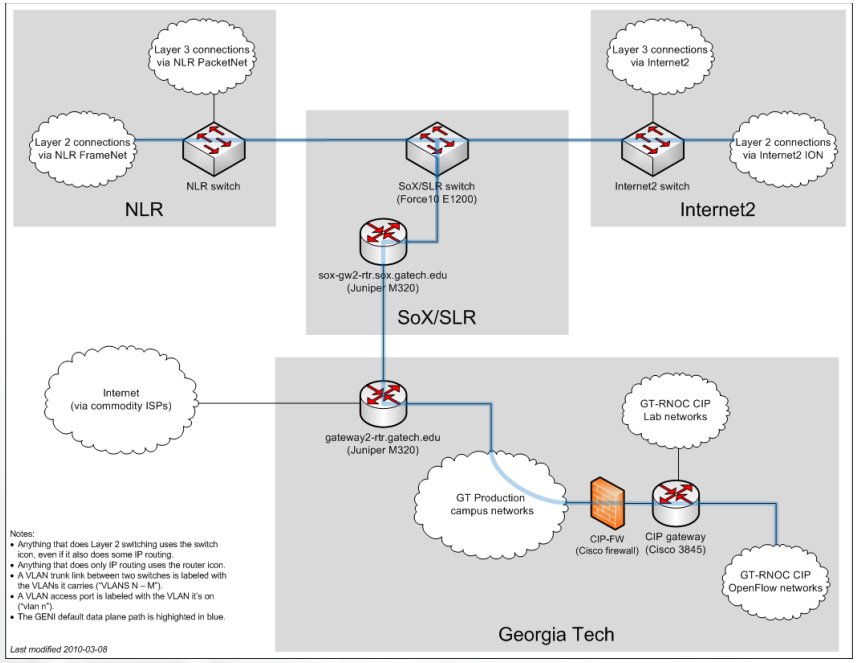
Georgia Tech: a great example
One of the first 14 GENI-enabled campuses

Nick Feamster
PI

Ellen Zegura

Russ Clark,
GT-RNOC

Ron
Hutchins,
OIT

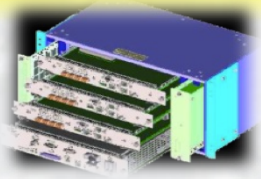


- OpenFlow in 2 GT-RNOC lab bldgs ***now***
- OpenFlow/BGPMux coursework ***now***
- Dormitory trial
- Students will "live in the future" – Internet in one slice, multiple future internets in additional slices

Trials of "GENI-enabled" commercial equipment

HP ProCurve 5400 Switch

Juniper MX240 Ethernet Services Router



NEC WiMAX Base Station

HTC Android smart phone

Toroki LightSwitch 4810

GENI racks

NEC IP8800 Ethernet Switch

Arista 7124S Switch

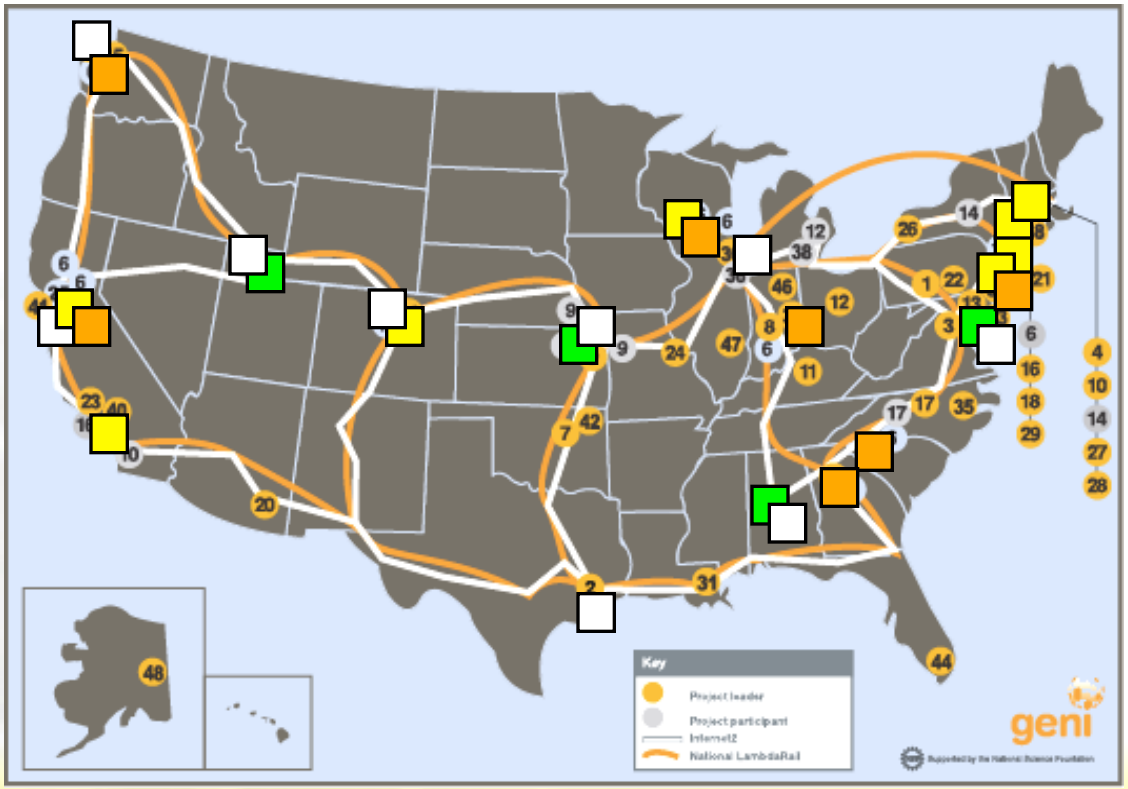
Spiral 2 infrastructure examples
Building the GENI Meso-scale Prototype

OpenFlow

Stanford
U Washington
Wisconsin
Indiana
Rutgers
Princeton
Clemson
Georgia Tech

ShadowNet

Salt Lake City
Kansas City
DC
Atlanta



WiMAX

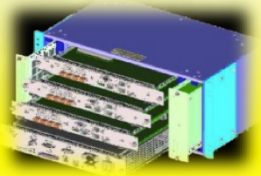
Stanford
UCLA
UC Boulder
Wisconsin
Rutgers
Polytech
UMass
Columbia

OpenFlow Backbones

Seattle
Salt Lake City
Sunnyvale
Denver
Kansas City
Houston
Chicago
DC
Atlanta


HP ProCurve 5400 Switch


Juniper MX240 Ethernet Services Router


NEC WiMAX Base Station


HTC Android smart phone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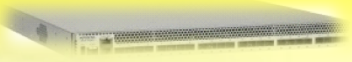
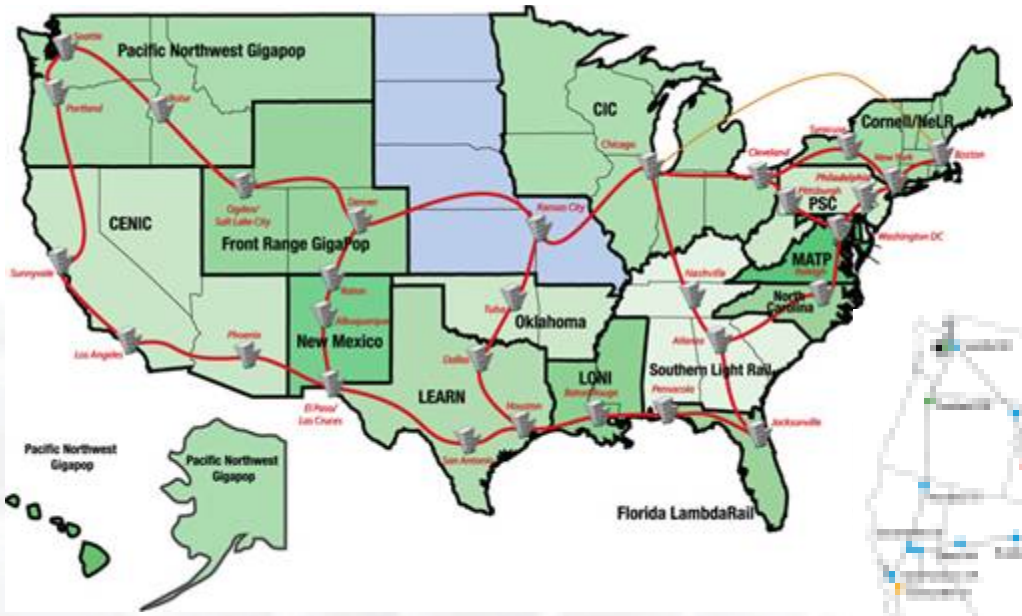
GENI racks


NEC IP8800 Ethernet Switch

OpenFlow


Arista 7124S Switch

National LambdaRail and Internet2



National LambdaRail

Up to 30 Gbps bandwidth

Internet2

ProtoGENI & SPP

Buildout for GENI prototyping within two national footprints to provide end-to-end GENI slices (IP or non-IP)


BEN
Breakable Experimental Network
of the Future
ORBIT
PLANETLAB
An open platform for developing, deploying, and accessing planetary-scale services
ProtoGENI
UIC
Many, many groups are already engaged in building GENI
THE QUILT
at&t
ARISTA
Battelle
ca
ciena
cisco
Corporation for National Research Initiatives
FUJITSU
hp invent
IBM
infinera
INTERNET2
JEFFREY HUNKER ASSOCIATES LLC
JUNIPER NETWORKS
Microsoft
NETRONOME
nicira
NLR light the future
NEC
Qwest
Radio Technology Systems
SPARTA
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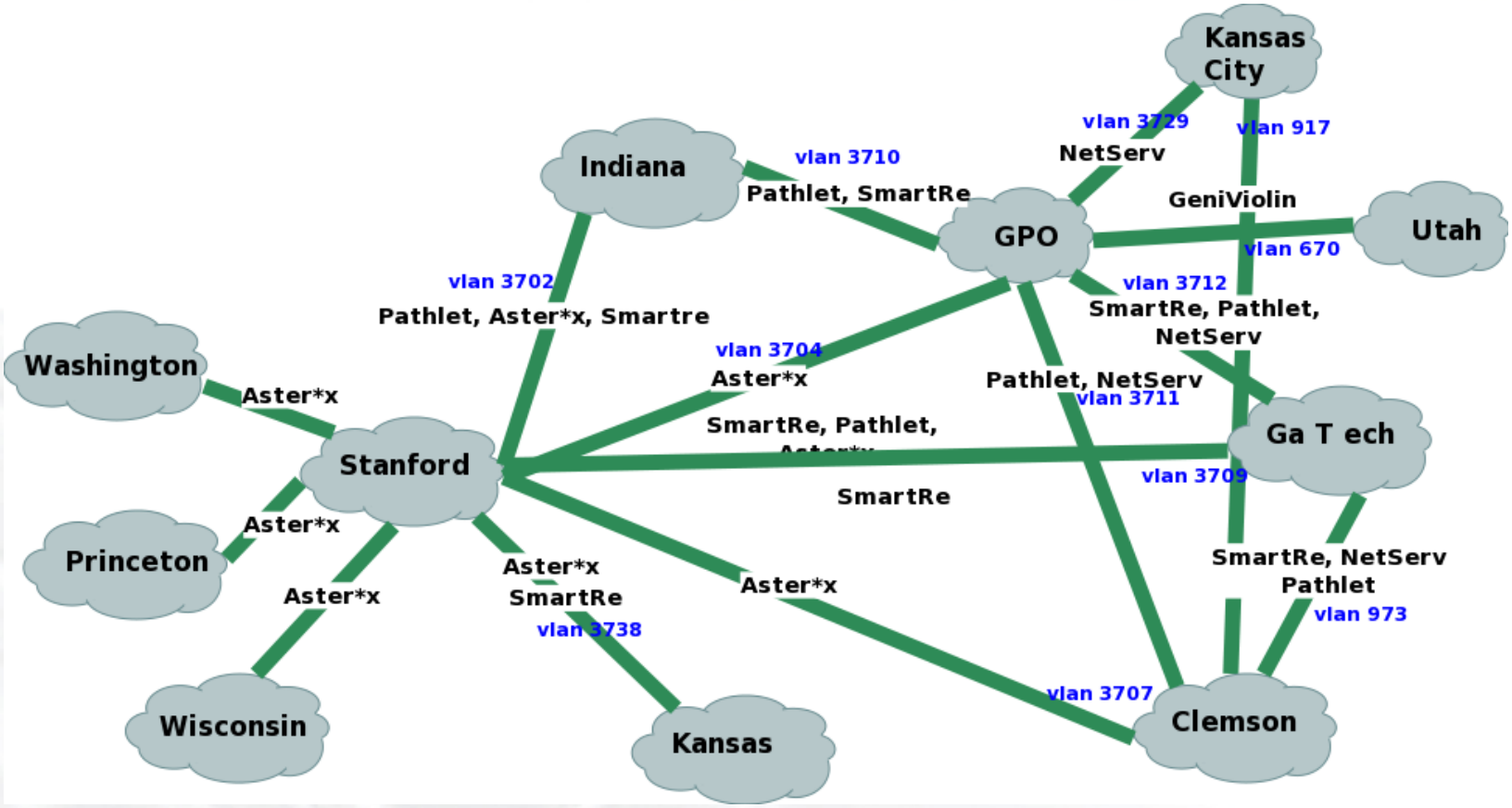
Recent GENI news
Major research demos, Nov 2010

9 major experiments demo'd at GEC 9 (Nov 2010)

- **Some of the nation's best young researchers . . .**
  - Academic and industrial
  - Networking and distributed systems
  - Some helped build GENI, most have not
- **Demonstrating their earliest research experiments**
  - Many different ideas for "future internets"
  - Now being **tried out experimentally** for the first time
- On the nationwide, "meso-scale" GENI prototype

GENI supported 9 different future internet experiments, simultaneously, each in its own slice

GENI meso-scale infrastructure for GEC 9 demos



- Nationwide GENI slices, a different experiment in each slice
- Spanning 15 campuses, 2 national backbones, 11 regional networks
- All using “GENI-enabled” commercial equipment

Pathlet Architecture

GEC 9 experiment demonstration

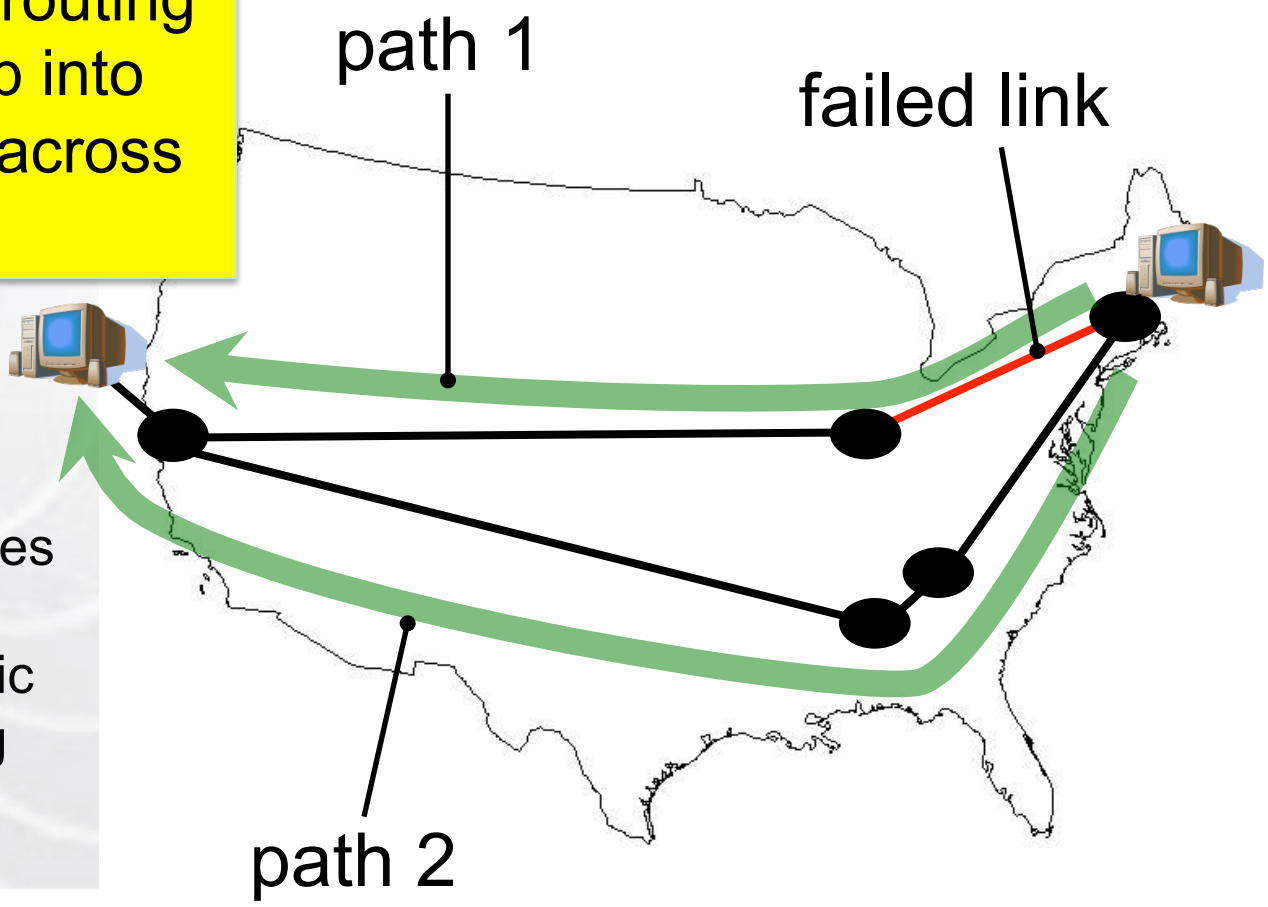
ILLINOIS
UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

Resilient Routing in the Pathlet Architecture

Ashish Vulimiri and Brighten Godfrey
University of Illinois at Urbana-Champaign

Deploy innovative routing architecture deep into network switches across the US

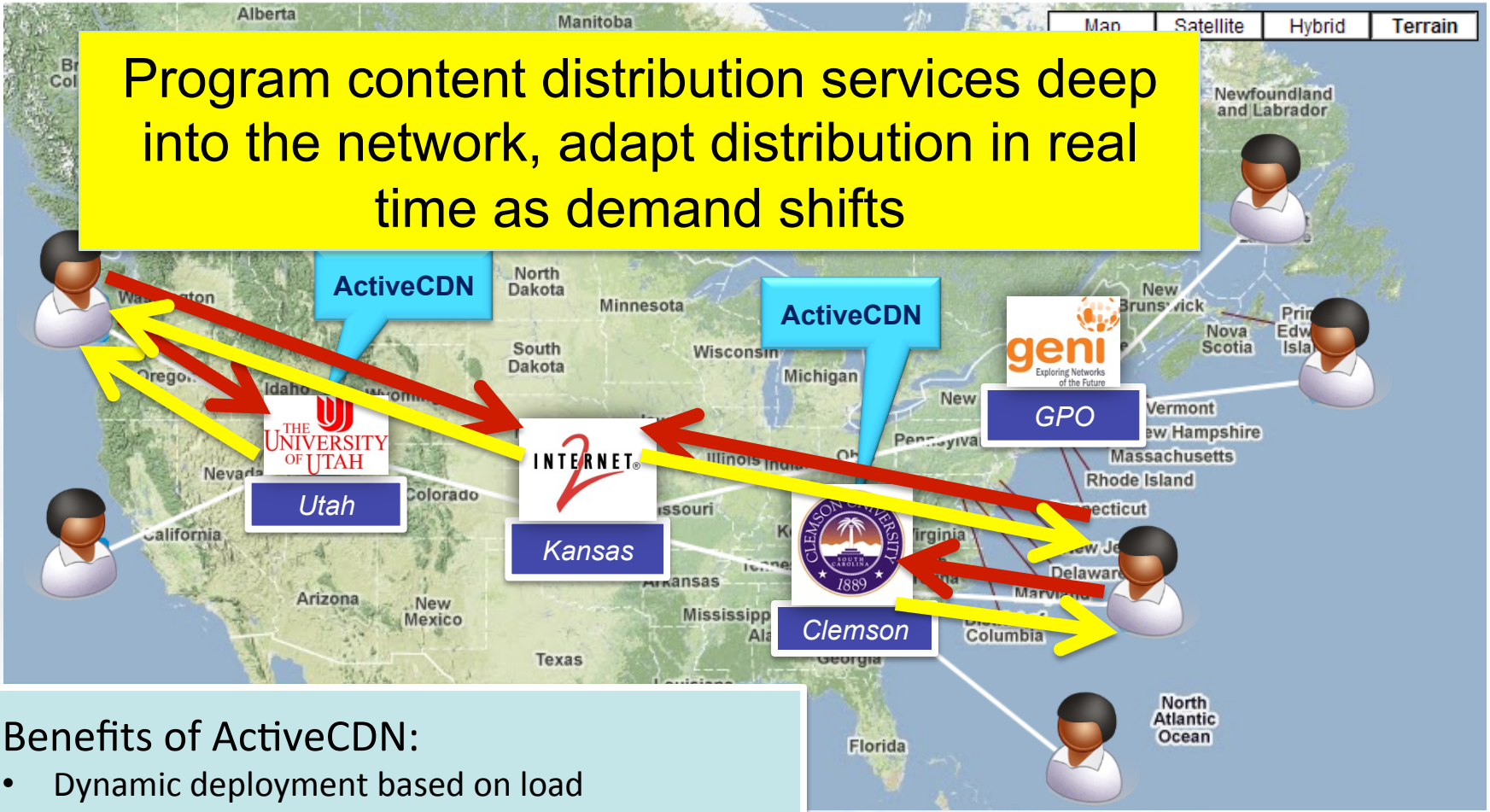
- Lets *users* monitor and select their own network paths to optimize their services
- Protects critical traffic even without waiting for adaptation time



Sponsored by the National Science Foundation

ActiveCDN

GEC 9 experiment demonstration



Benefits of ActiveCDN:

- Dynamic deployment based on load
- Localized services such as weather, ads and news

Jae Woo Lee, Jan Janak, Roberto Francescangeli, SumanSrinivasan, Eric Liu, Michael Kester, SalmanBaset, Wonsang Song, and Henning Schulzrinne
Internet Real-Time Lab, Columbia University

Weather NowCasting

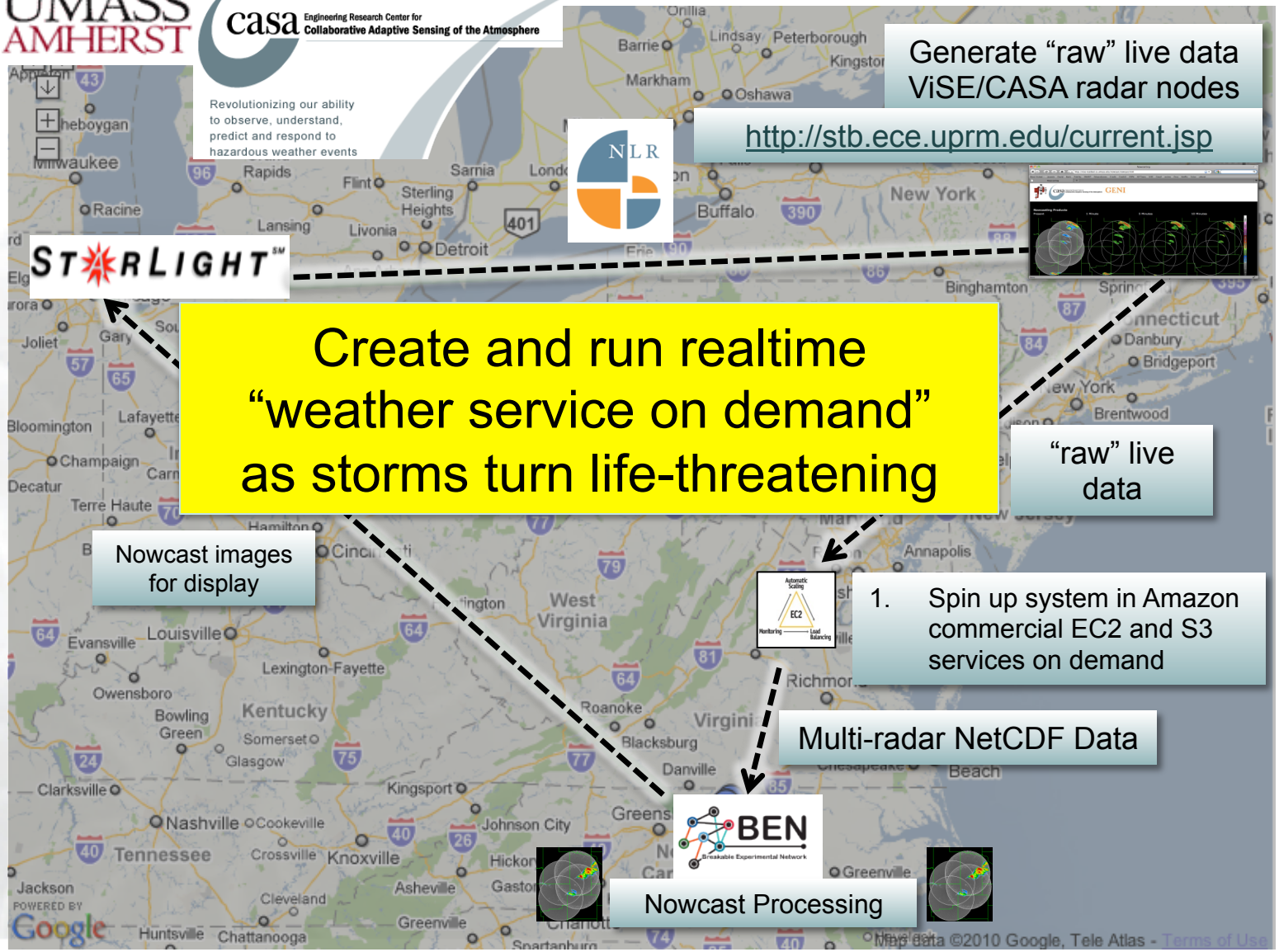
GEC 9 experiment demonstration

ViSE views steerable radars as shared, virtualized resources
http://geni.cs.umass.edu/vise

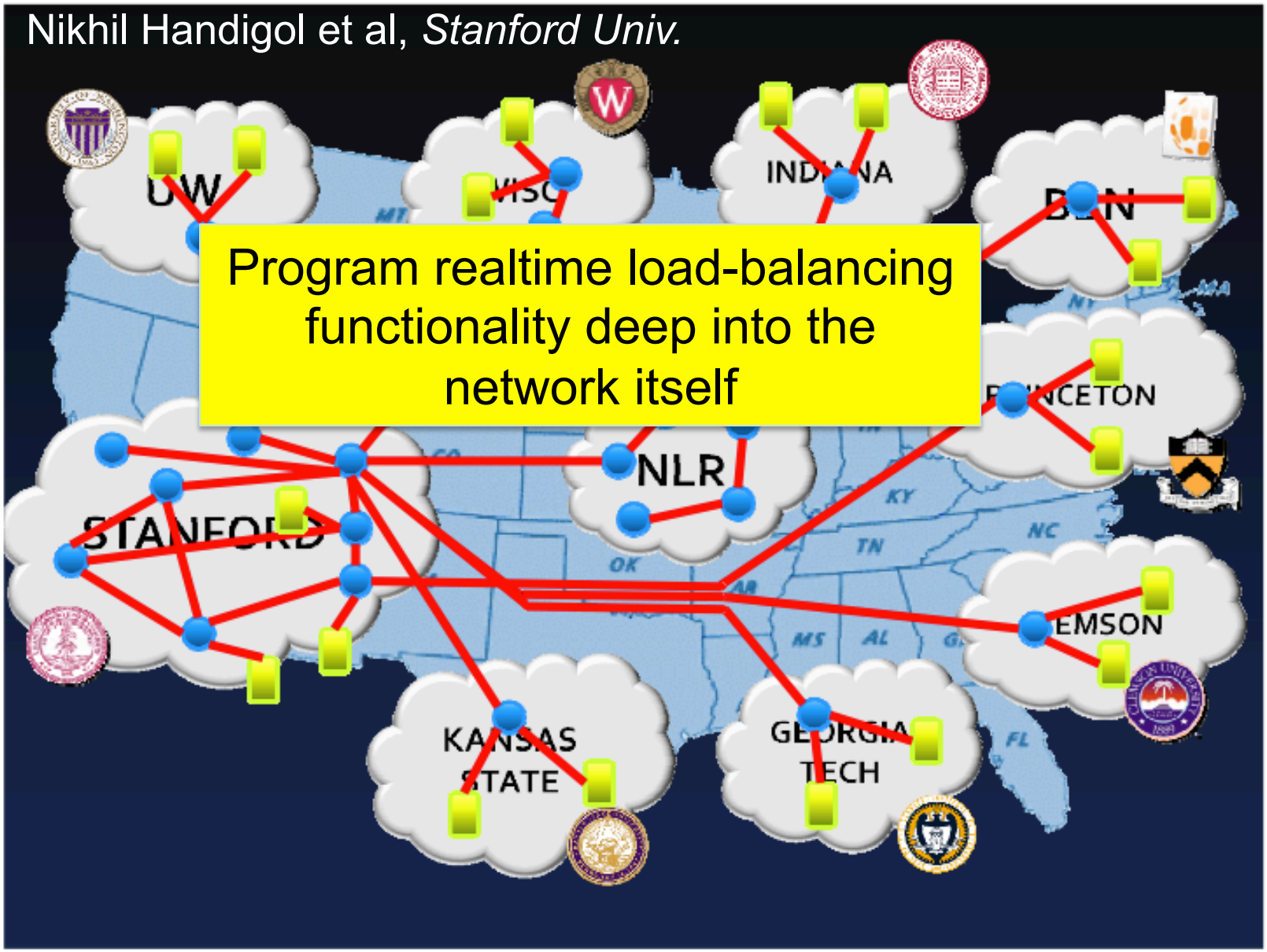
David Irwin et al

UMASS AMHERST

casa Engineering Research Center for Collaborative Adaptive Sensing of the Atmosphere
Revolutionizing our ability to observe, understand, predict and respond to hazardous weather events



Aster*x Load Balancing (via OpenFlow)



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GENI's next steps

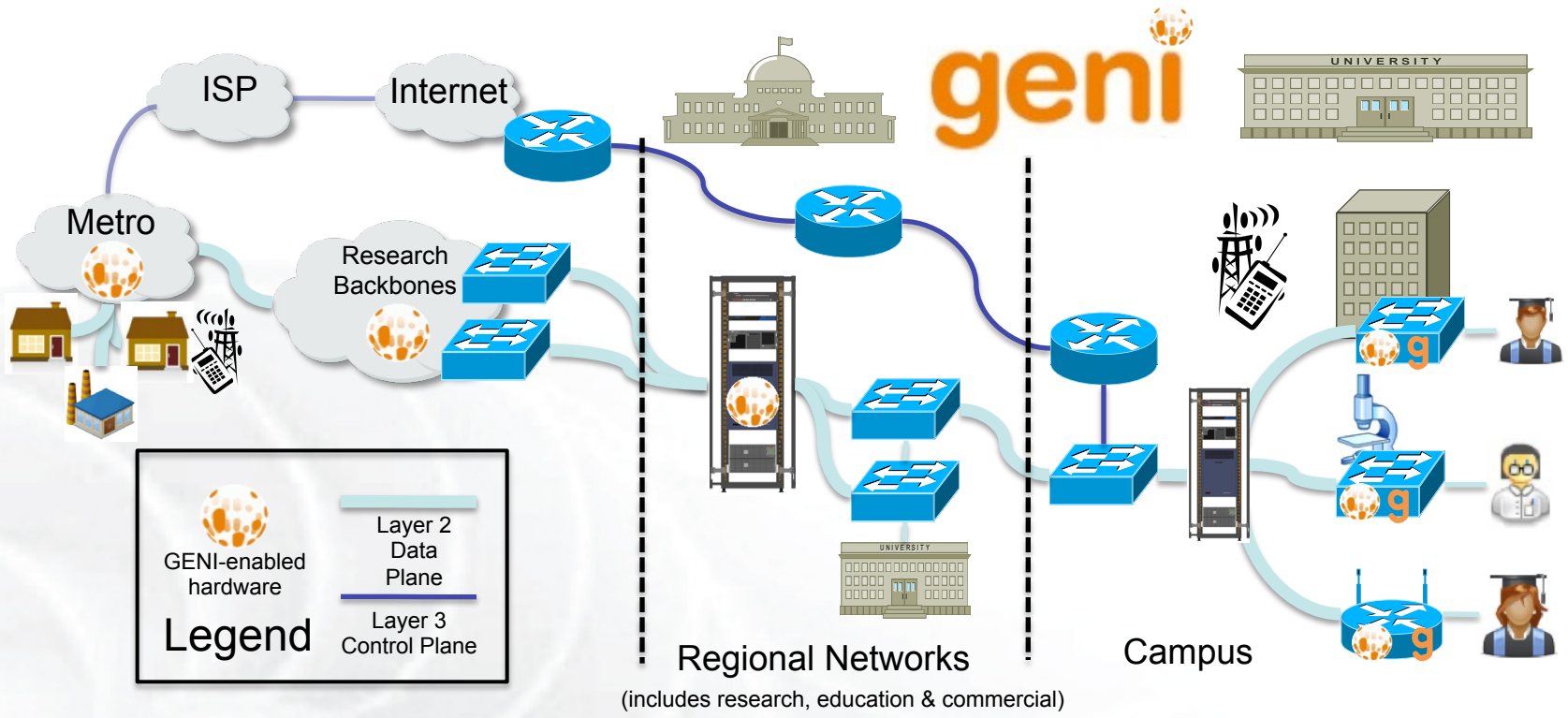
- **Substantially ramp up research experimentation**
  - Support experimenters via training, course materials, summer camps, and help desk
  - Transition to reliable operations
- **Grow GENI's footprint nationwide**
  - Increase number of GENI-enabled campuses
  - Enhance build-outs in campuses and backbones
  - GENI-enable 5-6 regional networks
  - Deploy 50-80 GENI-racks throughout US
- **Begin to grow from meso-scale to "at scale" GENI**

Growing to "at scale" GENI

- GENI Solicitation 3
  - More **WiMAX base stations** with Android handsets
  - GENI-enable 5-6 **regional networks**
  - Inject more **OpenFlow switches** into Internet2 and NLR
  - Add **GENI Racks** to 50-80 locations within campuses, regionals, and backbone networks
- Grow to 50, then 100-200 campuses
  - 2nd CIO workshop, July 2011
  - "Buddy system" for each meso-scale campus to guide 2-3 new campuses
  - Increase GENI-enabled campuses from 14 to 40-50 in a staged manner, over several years
  - Repeat once, to grow to 100-200 campuses
- Transition to community governance

GENI Racks serve as programmable routers, distributed clouds, content distribution nodes, caching or transcoding nodes, etc

Envisioned architecture



- Flexible network / cloud research infrastructure
- Also suitable for physics, genomics, other domain science
- Support “hybrid circuit” model plus much more (OpenFlow)
- Distributed cloud (racks) for content caching, acceleration, etc.

Growing GENI: near-term plans

- **Solicitation 3** expands “meso-scale” build
  - Inject more OpenFlow into backbones
  - Field OpenFlow in 5-6 regionals
  - Field 50-80 GENI racks in campuses, regionals
  - Boost WiMAX deployments
- **US Ignite** adds 6 cities initially
  - GENI rack / OpenFlow in cities
  - Layer 2 transport enables both IP and non-IP
  - (More discussion later in these slides)

Growing GENI to 30-50 campuses

- "Buddy system" for high-performing meso-scale campuses to guide 3-5 new campuses
  - Increase GENI-enabled campuses from 40-50 in a staged manner, over several years
- Won't be a "cold call" to these new campuses
  - We already have close ties to GENI researchers at likely candidate campuses
  - However, campus CIOs will be critically important
- Engaging with campus CIOs, July 2011
  - Need to get their input, guidance, support
  - O'Hare CIO meeting was a great success
  - Repeat meeting in July 2011 with more campus CIOs

Growing to the "at scale" GENI

- Suggest 100-200 US campuses as target for "at scale"
  - Both academia and national labs
  - GENI-enable the campuses
  - Their students, faculty, staff can then "live in the future" using both today's Internet and many experiments
  - Build out backbones, regionals, and shared clouds to support the campuses
- Grow via ongoing spiral development
  - Identify, understand, and drive down risks
  - Learn what is useful and what is not
  - Early GENI campuses can help later ones
- Transition to community governance

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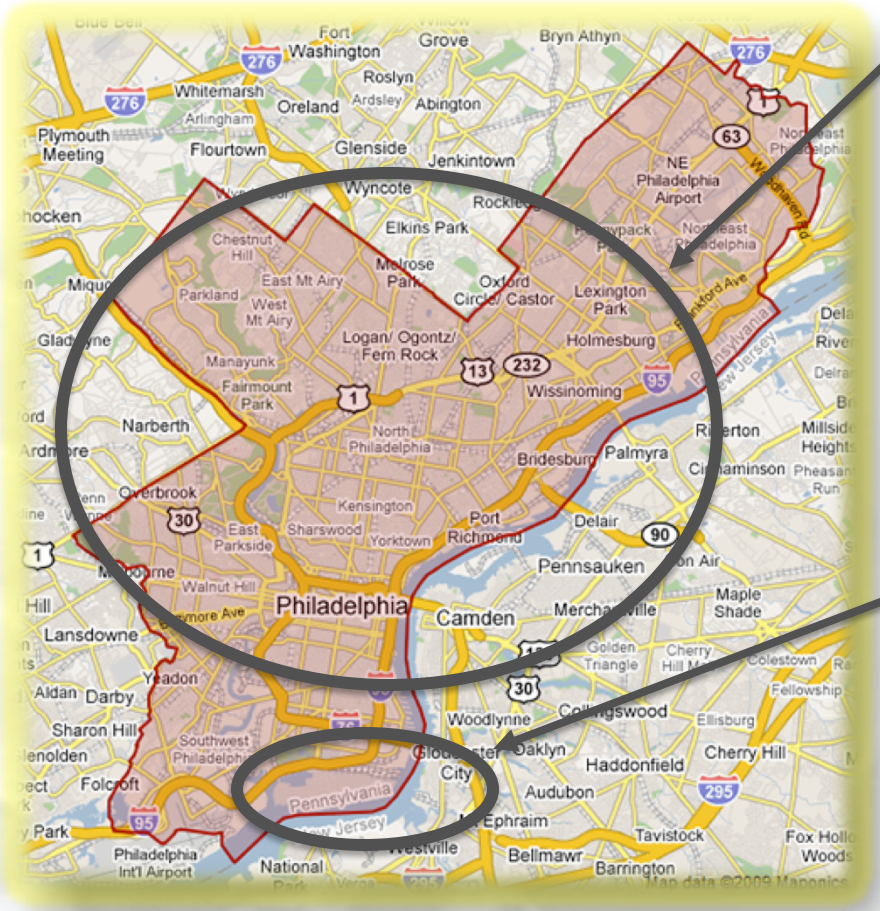
GENI-enabled cities

An unexpected and exciting idea from Philadelphia



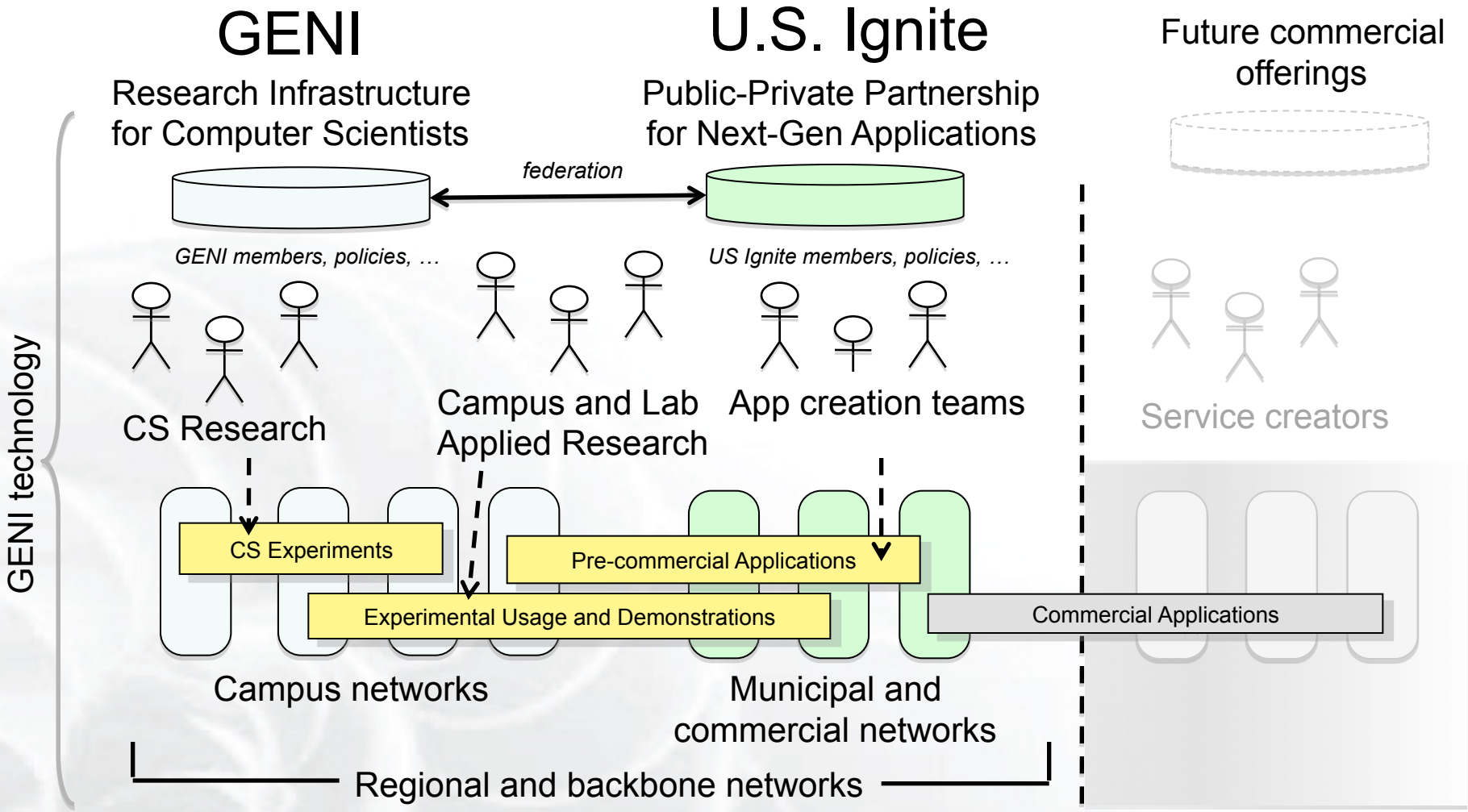
- **Municipal wireless**
  - "GENI lite" with legacy equipment
  - Create 1 SSID per slice in WiFi
  - Configure 1 VLAN per slice, backhaul
  - At city gateway, tie into national footprint via 1 GRE tunnel / slice
  - Add Linux box to manage slices
  - Citizens "tune in" to future internets via selecting SSID
  - (Already demo'd at Stanford)
- **Naval Shipyard build-out**
  - Greenfield, might do "full up" GENI
  - Select commercial vendor(s) that can support GENI (OpenFlow)
  - Perform build-out much like GENI campuses
  - Can leverage experience to date
  - (Low risk - Fallback: use equipment in its normal commercial way)

GENI-enabled cities
First concrete step in US Ignite activity

- Very strong interest from 6 US cities to date
  - Chattanooga, Cleveland, Lafayette LA, Philadelphia, Salt Lake City region, Washington DC
  - Their citizens will be able to “live in the future”
- Cities can be GENI-enabled very rapidly
  - We have visited all 6 cities for surveys, discussions
  - GENI rack, OpenFlow, and Layer 2 connectivity appear quite feasible
  - Can be federated into GENI very quickly
- Can support experimental, gigabit applications in GENI slices through cities
  - Creates **tremendous** new research opportunities

U.S. Ignite is now taking shape

Bridging CS Experiments to Next-Gen Applications in Cities



U.S. Ignite is a new organization that will promote advanced applications and infrastructure leveraging GENI research and technologies.

Draft of Ignite City Technical Architecture

Early DRAFT CONCEPT – for discussion only!

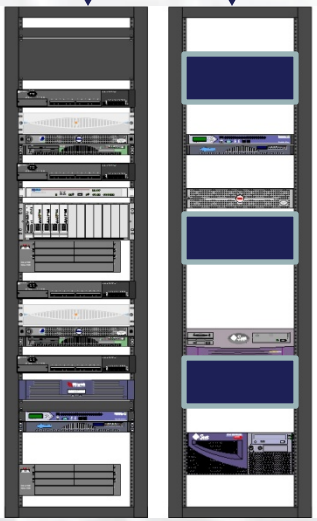
Existing head-end

Most equipment not shown

Existing ISP connects

Layer 3 GENI control plane

Layer 2 connect to subscribers

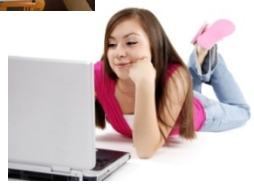


OpenFlow switch(es)
Flowvisor
Remote management
Instrumentation
Aggregate manager
Measurement
Programmable PCs
Storage
Video switch (opt)

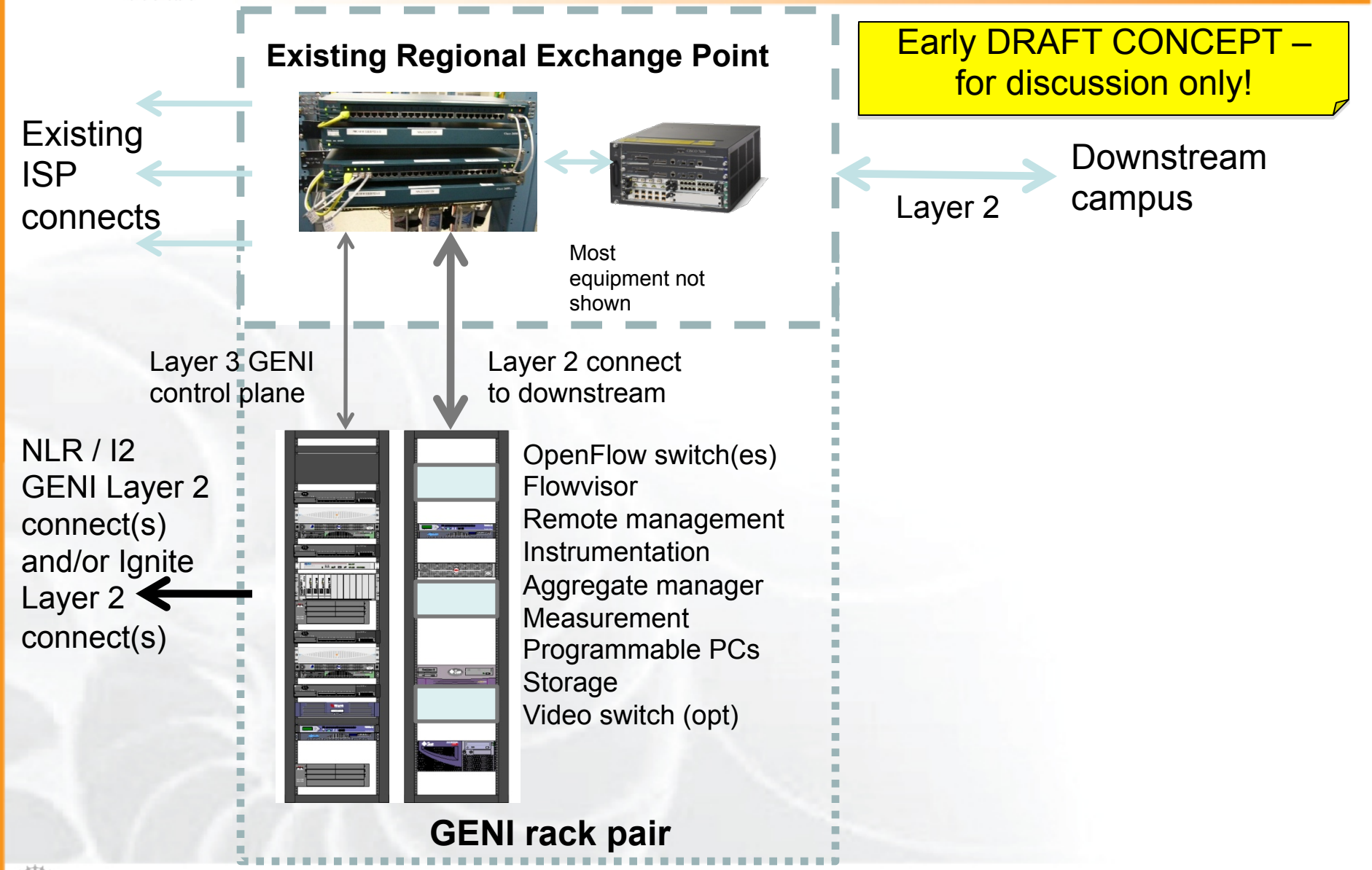
Layer 2 Ignite Connect (1 GE or 10GE)

New GENI / Ignite rack pair

Home

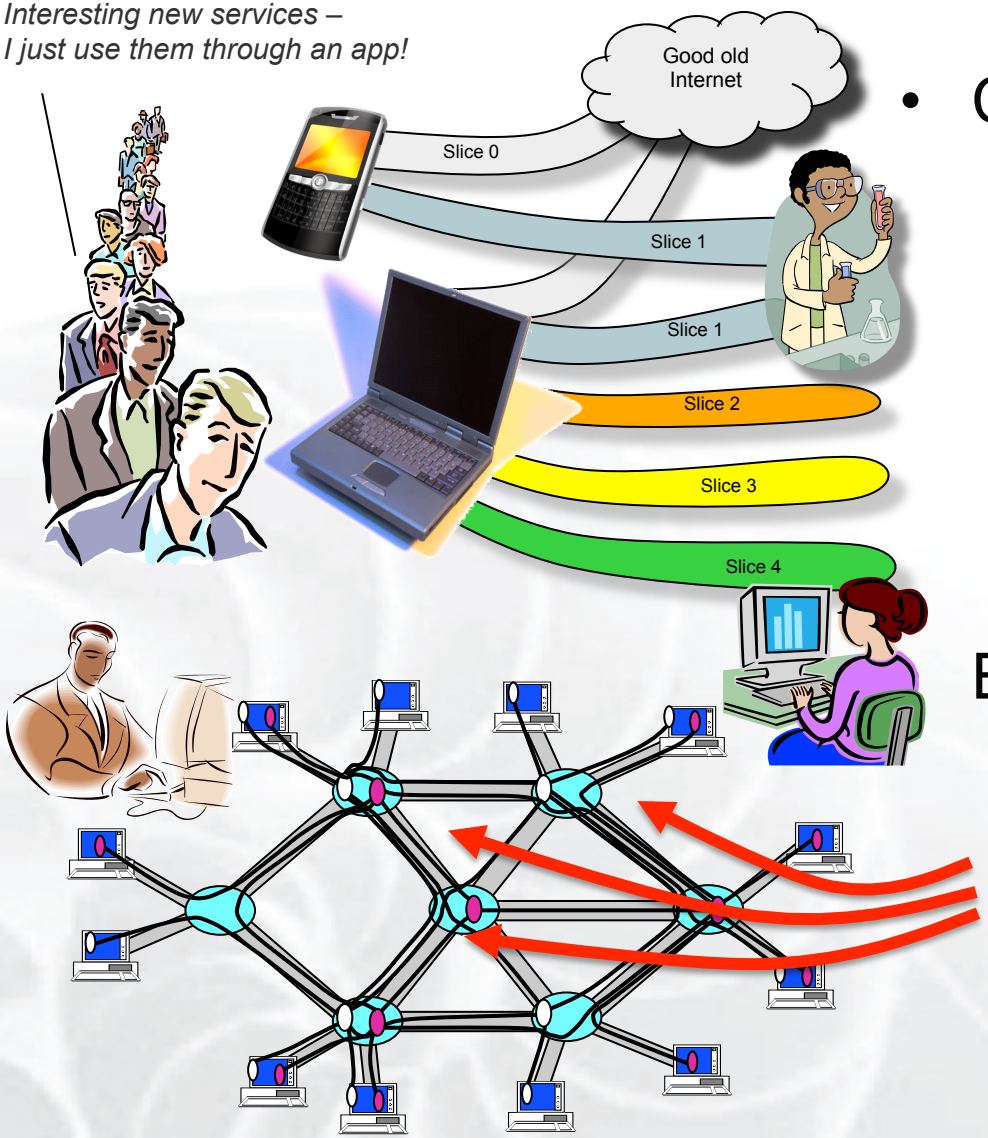


Draft of Regional Network Technical Architecture



What would it look like?
"Cities living in the future"

Interesting new services –
I just use them through an app!



- Citizens' view
  - Great new applications
  - New content services . . .
  - New weather services . . .
  - New health services . . .
  - New energy services . . .
  - New government services . . .

Entrepreneurs' view

- Next-generation applications can be cheaply & rapidly rolled out
- "My software goes HERE"
- Create and try out new apps that exploit deep programmability
- Experiment with cities "living in the future" to gain market edge

U.S. Ignite workshops

- Two workshops to date
  - May 16 at NSF (http://www.nsf.gov/cise/usignite/usignite_workshop.jsp)
  - June 9 at Case Western
- Basic goal: matchmaking between cities / researchers
  - Run research applications across one or more cities
  - Focus areas: health, energy, public safety, education
- NSF expects to solicit & fund proposals (fall?)
- 3rd workshop probable

- Very informative CCC blogs re workshops:
- http://www.cccblog.org/2011/05/24/recapping-the-us-ignite-gigabit-applications-workshop/
- http://www.cccblog.org/2011/06/11/us-ignite-gigu-workshops-living-the-future-today/

U.S. Ignite in broadband cities
A huge opportunity for innovation & leap-ahead

- **Slicing** and **deep programmability** greatly expand the revolutionary potential of broadband
  - Citizens of the fortunate cities can “live in the future”
  - Today’s Internet on Channel 1
  - Many new next-generation applications on Channels 2, 3, . . .
  - Opens up leading-edge, high impact research fields
  - Creates huge opportunities for innovation and leap-ahead
- Appears fairly simple / low-cost technically
  - Depends on network equipment selected, etc.
- Social aspects are very important (city ≠ campus!)

Outline

- GENI – Exploring future internets at scale
- Introducing GENI: an example
- GENI's growing suite of infrastructure
- Experiments going live across the US!
- What's next for GENI?
- GENI and U.S. Ignite
- How can you participate?
- Suggested GEC11 sessions for newcomers

Want to run an experiment?

- **Shakedown experiments in progress**
  - "The brave pioneers"
- **GENI Experimenters Workshop -** Princeton, June 29-30, 2010
  - Co-chaired by Jennifer Rexford and Guru Parulkar
  - 54 researchers participated (pairs of prof + student)
  - Dozens of quick-turn proposals submitted to NSF
  - Excellent experimental research starts ramping up in early fall
- **CISE "Future Internet Architectures" program**
  - "stimulate innovative and creative research to explore, design, and evaluate trustworthy future Internet architectures"
  - "design and experiment with new network architectures and networking concepts"
  - "proposals must describe plans to prototype and evaluate the proposed architectures; this may require the construction of new artifacts or the use of research infrastructure like GENI or the NCR (National Cyber Range)"

Talk to NSF CISE or Mark Berman, GPO (mberman@bbn.com)

Want to affiliate your infrastructure?

- If so, you will become a new GENI “aggregate”
  - You own / operate your aggregate, and “affiliate” into GENI
  - You make (some of) your resources available for experiments
  - Examples: testbeds, campuses, regionals and backbone networks, commercial providers, . . .
- Three actions needed on your part
  - Download GENI API software, modify to reflect your infrastructure resources and local policies
  - Connect to GENI, ideally at Layer 2 but otherwise via GRE tunnel
  - Agree to GENI policies, sign MOUs, join GENI operations
- Reminder: GENI is still an early prototype!

If interested, contact Heidi Dempsey (hdempsey@bbn.com)

Want to help create GENI?

- All design, prototyping, & development is performed by the research community (academia & industry)
  - Working Groups, open to all
    - The locus for all GENI technical design
    - Patterned on the early IETF
    - Discuss by email, create documents, meet 3x per year
    - Each led by Chair(s), plus a professional System Engineer
- Openness is emphasized
  - Design process is open, transparent, and broadly inclusive
  - Open-source solutions are strongly preferred
  - Intellectual property is OK, under no-fee license for GENI use
- GPO is fair and even-handed

GENI Engineering Conferences
Meet every 4 months to review progress together

- **12th meeting, open to all:**
  2–4 November 2011, U. of Missouri, Kansas City
  - 3 tracks: software, campuses, experimenters
  - Tutorials and workshops
  - **Travel grants** to US academics for participant diversity

Suggested GEC11 Sessions for Newcomers

start time	Experimenter Track	Campus Track	Software Track
Day 1: Tuesday, July 26			
8:00 AM			
8:30 AM			
9:00 AM	★ Intro to GENI Talk		Control Framework Highlights
9:30 AM			Selected
10:00 AM	Break		
10:30 AM	★ Survey of Resources	OpenFlow Campus Deployment	Project Highlights
11:00 AM			
11:30 AM	Lunch		
12:00 PM			
12:30 PM	★ Tutorial: Introduction to GENI using Flack and the Instrumentation Portal	Operations Update	Authorization
1:00 PM			
1:30 PM		Plastic Slices Report-out	Identity
2:00 PM			
2:30 PM	Break		
3:00 PM	★ Advanced Topics in Networking Experiments using GENI	NetServ Tutorial	Federation (Joint Campus & Software)
3:30 PM			
4:00 PM			
4:30 PM			
5:00 PM			
5:30 PM	Poster & Networking Event		
6:00 PM			
6:30 PM			
7:00 PM			
7:30 PM			

GPO Office Hours

start time	Experimenter Track	Campus Track	Software Track
Day 2: Wednesday, July 27			
8:00 AM	Breakfast		
8:30 AM	Welcome		
9:00 AM	Plenary Session		
9:30 AM			
10:00 AM			
10:30 AM	Break		
11:00 AM	Plenary Session		
11:30 AM			
12:00 PM	Lunch		
12:30 PM			
1:00 PM	★ Experiment workflow using Sface: A Tutorial	Monitoring Mini-Workshop	RSpec
1:30 PM			
2:00 PM		New Topics (Joint Campus & Software)	
2:30 PM	Break		
3:00 PM	Tutorial: Experiment Control using Gush	WiMAX Campus Deployment	Stitching
3:30 PM			
4:00 PM			
4:30 PM			
5:00 PM			
5:30 PM			
6:00 PM			
6:30 PM	Self-Organized BoF Dinners *(start times vary)*		
7:00 PM			
7:30 PM			

start time	Experimenter Track	Software Track	
Day 3: Thursday, July 28			
8:00 AM	Breakfast		
8:30 AM			
9:00 AM	★ Experimenter Roundtable (Joint Experimenter & Software)	ORCA Cluster	Workshop on Attribution in GENI
9:30 AM			
10:00 AM			
10:30 AM	Break		
11:00 AM	Outbriefs / Feedback / Wrap-up		
11:30 AM			
12:00 PM	Lunch		
12:30 PM			
1:00 PM	GpENI Tutorial	Instrumentation and Measurement Working Session	ProtoGENI Cluster
1:30 PM			
2:00 PM			
2:30 PM			
3:00 PM			
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6:00 PM			
6:30 PM			
7:00 PM			
7:30 PM			

★ Recommended for newcomers

REVISION: 11Jul11

Most hands-on tutorials require VirtualBox VM with GENI tools.

If you need help…

- GPO help table at the lunches, breaks and networking events on Tue and Wed
  - VirtualBox VM image with GEC tutorial software
  - Questions about GENI resources
  - Questions about GENI accounts
- After the GEC
  - Email: help@geni.net

GENI is a huge opportunity - Get involved!

ViSE Team

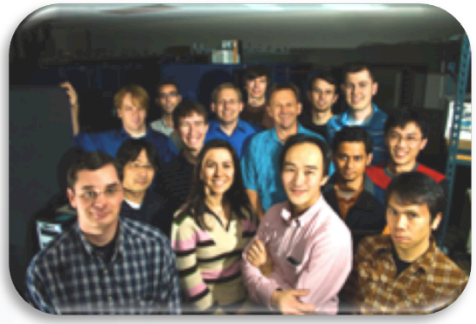
PlanetLab Team

ERM Team

ORCA/BEN Team

GUSH Team

Enterprise GENI Team



GPO points of contact

- Experiments . . . Mark Berman: mberman@bbn.com
- Prototyping . . . Aaron Falk: afalk@bbn.com
- Campus CIOs . . . Heidi Dempsey: hdempsey@bbn.com
- Industry . . . Chip Elliott: celliott@bbn.com

www.geni.net