GENI

Exploring Networks of the Future

CPqD International Workshop
New Architectures for Future Internet

Chip Elliott
September 23, 2009
www.geni.net

Sponsored by the National Science Foundation

Outline

- What is GENI?
- How we'll build it, how we'll use it (Two Comic Books)
- The GENI system concept
- GENI Spiral 1
- GENI Spiral 2, starting soon
- How can you participate?

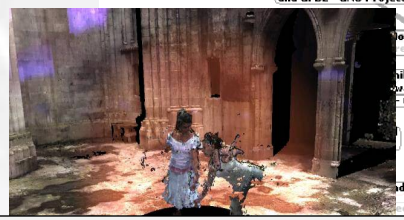
Global networks are creating extremely important new challenges

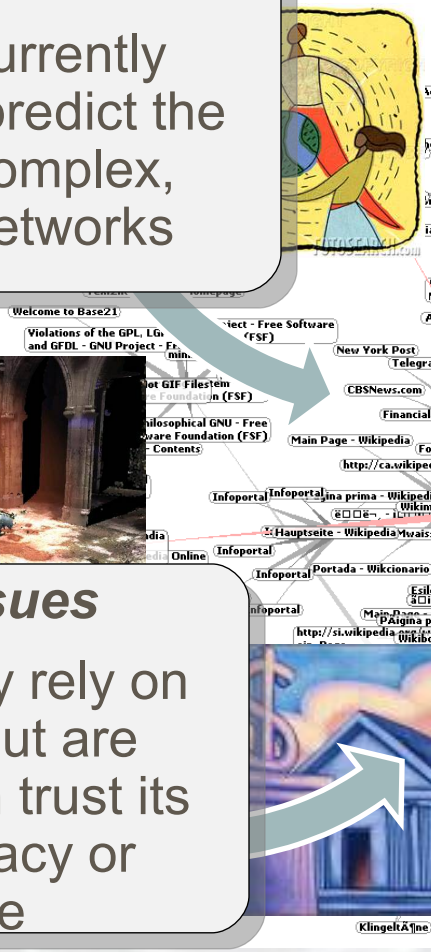
Science Issues

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 that can trust its security, privacy or resilience

Network Science & Engineering (NetSE)

Science → Understand the complexity of large-scale networks → Network science and engineering researchers

- Understand emergent behaviors, local-global interactions, system failures and/or degradations
- Develop models that accurately predict and control network behaviors

Technology → Develop new architectures, exploiting new substrates → Distributed systems and substrate researchers

- Develop architectures for self-evolving, robust, manageable future networks
- Develop design principles for seamless mobility support
- Leverage optical and wireless substrates for reliability and performance
- Understand the fundamental potential and limitations of technology

Society → Enable new applications and new economies, while ensuring security and privacy → Security, privacy, economics, AI, social science researchers

- Design secure, survivable, persistent systems, especially when under attack
- Understand technical, economic and legal design trade-offs, enable privacy protection
- Explore AI-inspired and game-theoretic paradigms for resource and performance optimization

GENI creates major opportunities for academia and industry to . . .

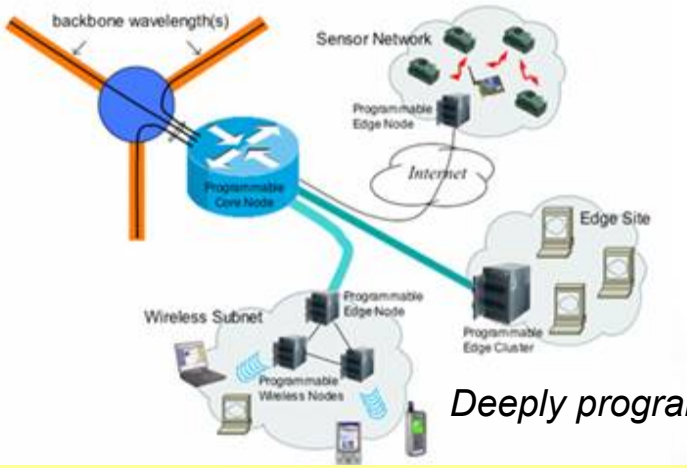
Understand global networks and their evolving interactions with society

Innovate at the frontiers of network science and engineering

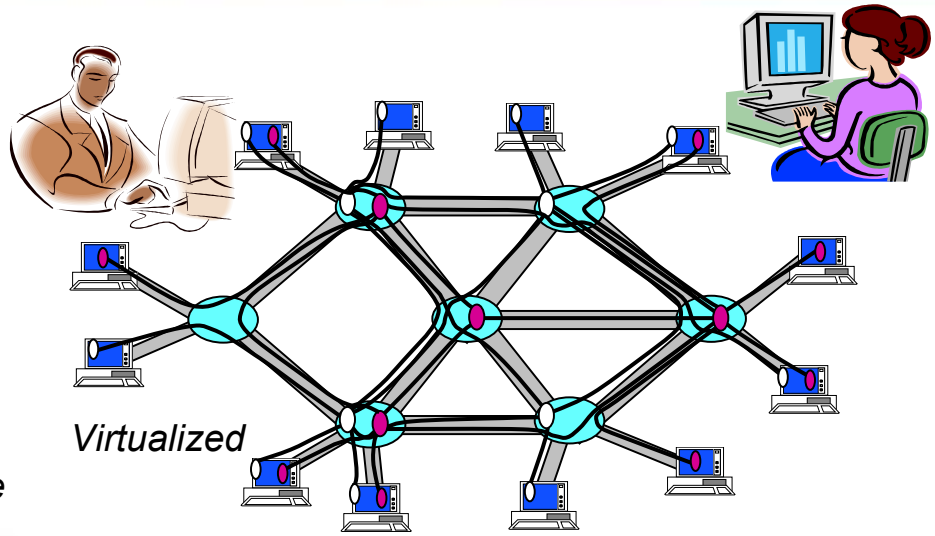
Transform **the science of network research and the larger world of communications**

GENI Conceptual Design

Infrastructure to support at-scale experimentation

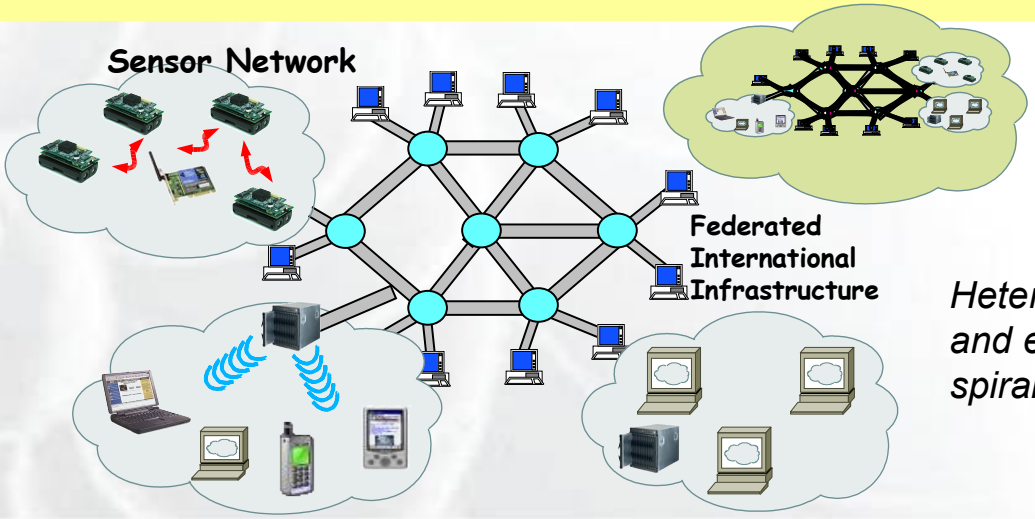


Deeply programmable



Virtualized

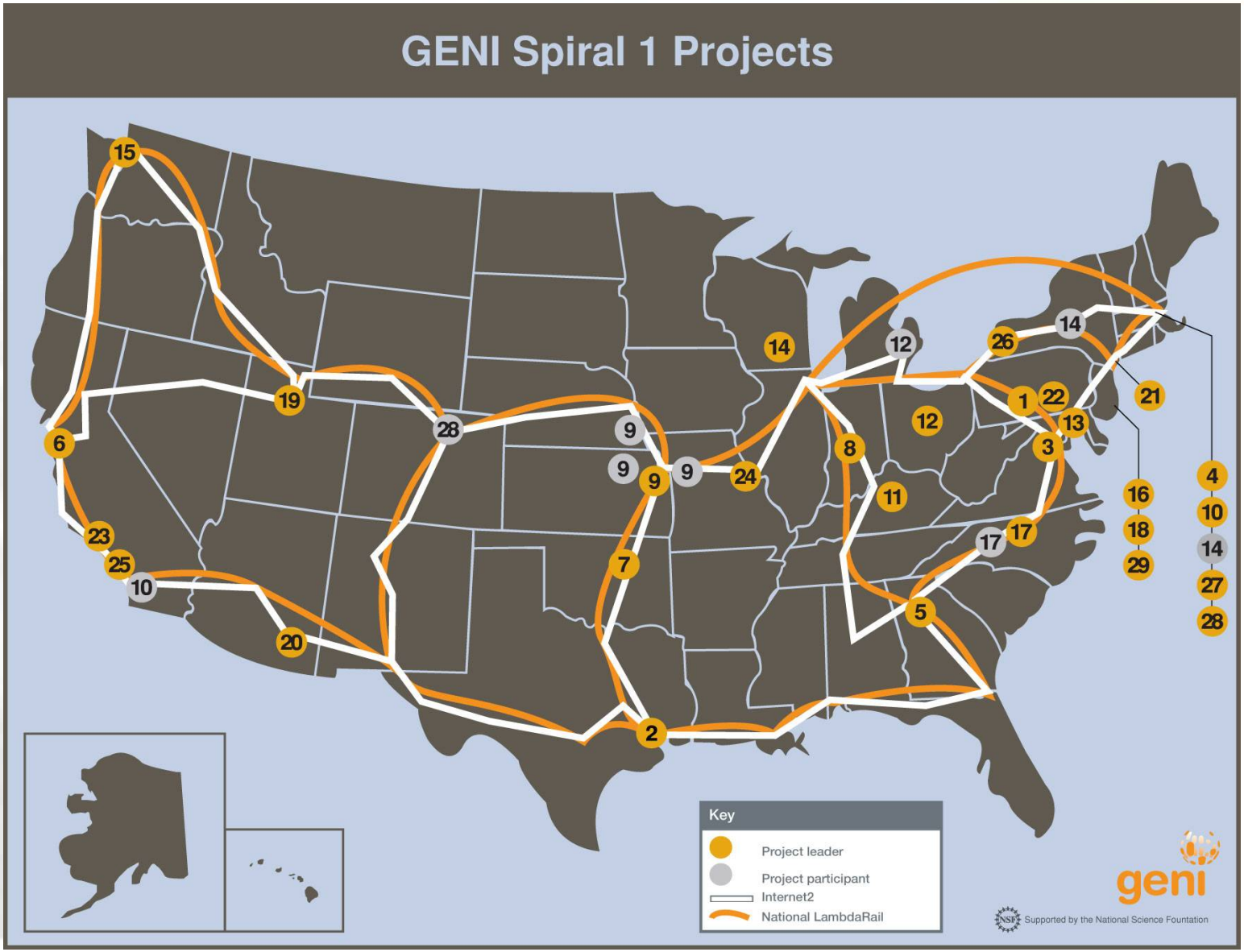
Programmable & federated, with end-to-end virtualized "slices"



Heterogeneous, and evolving over time via spiral development

Current status - GENI Spiral 1

Rapid prototyping, integration, and early experiments



Spiral 1 Academic-Industrial Teams

Project Name	Project Lead	Project Participants
1. CMUlab	Carnegie Mellon University	
2. D Meas	University of Houston	
3. Digital Object Registry	Corporation for National Research Initiatives (CNRI)	
4. DOME	University of Massachusetts Amherst	
5. DTunnels	The Georgia Institute of Technology	
6. EnterpriseGENI	Stanford University	
7. GENI4YR	Langston University	
8. GMOC	Indiana University	
9. GpENI	University of Kansas	Kansas State University, University of Nebraska-Lincoln, The University of Missouri-Kansas City (UMKC)
10. GushProto	Williams College	UC San Diego
11. INSTOOLS	University of Kentucky	
12. KANSEI	Ohio State University	Wayne State University
13. MAX	University of Maryland	
14. MeasurementSys	University of Wisconsin-Madison	Boston University, Colgate University
15. MillionNodeGENI	University of Washington (Seattle)	
16. ORBIT	Rutgers University	
17. ORCA/BEN	The Renaissance Computing Institute (RENCI)	Duke University
18. PlanetLab	Princeton University	
19. ProtoGENI	University of Utah	
20. PROVSERV	University of Arizona	
21. ERM	Columbia	
22. REGOPT	Pittsburgh Supercomputing Center (PSC)	
23. SECARCH	SPARTA, Inc.	
24. SPP	Washington University	
25. TIED	USC Information Sciences Institute	University of California, Berkeley
26. UB_OANets	SUNY Buffalo	
27. UMLPEN	University of Massachusetts Lowell	
28. ViSE	University of Massachusetts Amherst	
29. WiMAX	Rutgers University	

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How We'll Use GENI

Note that this is the "classics illustrated" version – a comic book!

Please read the Network Science and Engineering Research Agenda to learn all about the community's vision for the research it will enable. Your suggestions are very much appreciated!

A bright idea

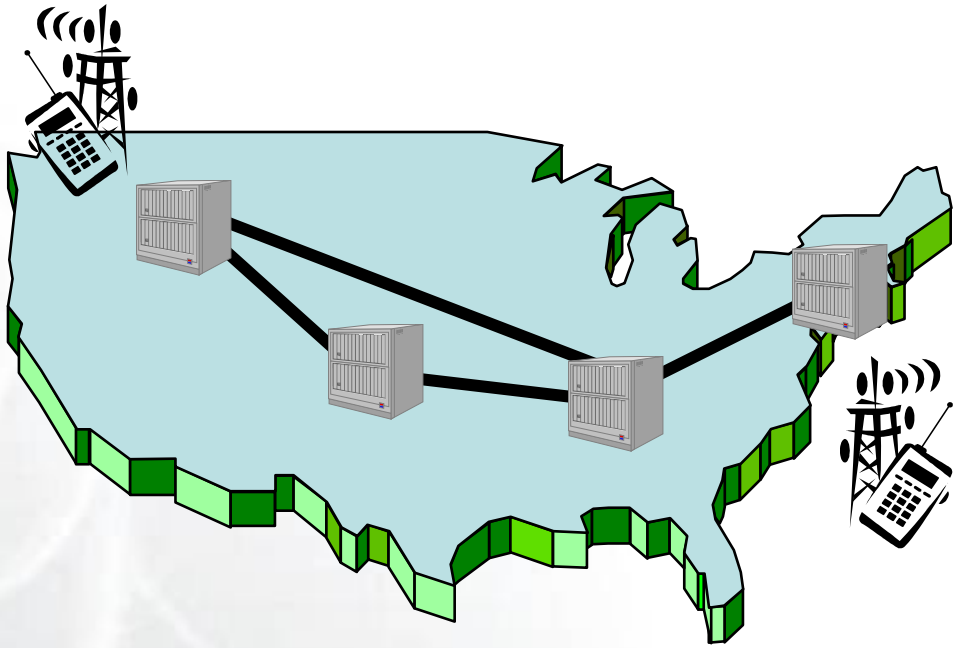
I have a great idea! The original Internet architecture was designed to connect one computer to another – but a better architecture would be fundamentally based on PEOPLE and CONTENT!

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 clusters of CPUs and disks, bulk data transfer devices ('routers'), and wireless access devices throughout the GENI suite, and started taking measurements . . .



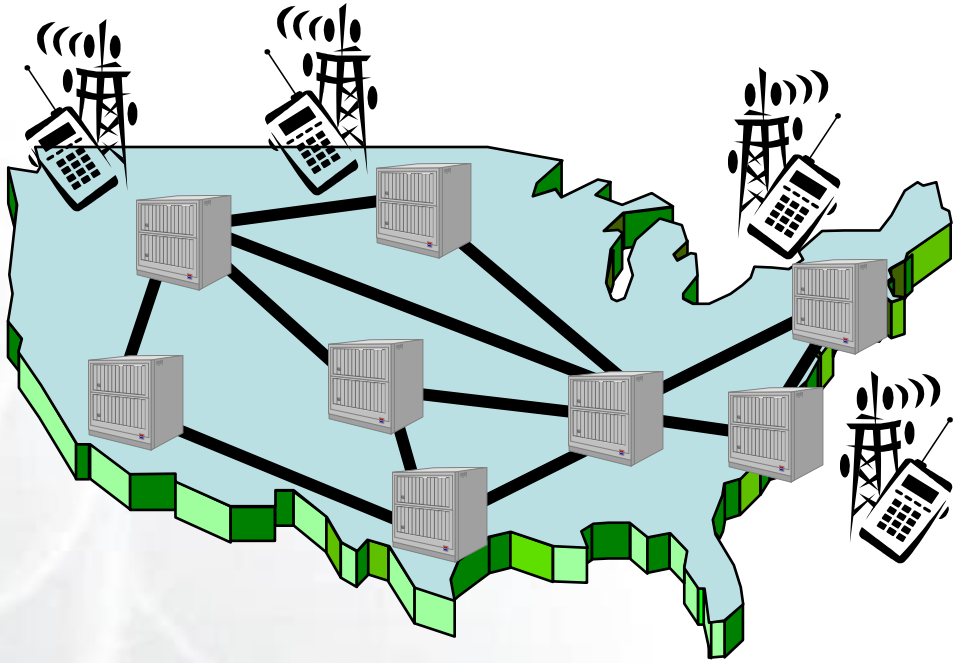
He uses a modest slice of GENI, sharing its infrastructure with many other concurrent experiments.

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.

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 reliable 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 Network Science and Engineering** program.

Moral of this story

- GENI is meant to enable . . .
  - Trials of new architectures, which may or may not be compatible with today's Internet
  - Long-running, realistic experiments with enough instrumentation to provide real insights and data
  - 'Opt in' for real users into long-running experiments
  - Large-scale growth for successful experiments, so good ideas can be shaken down at scale
- A reminder . . .
  - GENI itself is not an experiment !
  - GENI is a suite of infrastructure on which experiments run

GENI creates a huge opportunity for ambitious research!

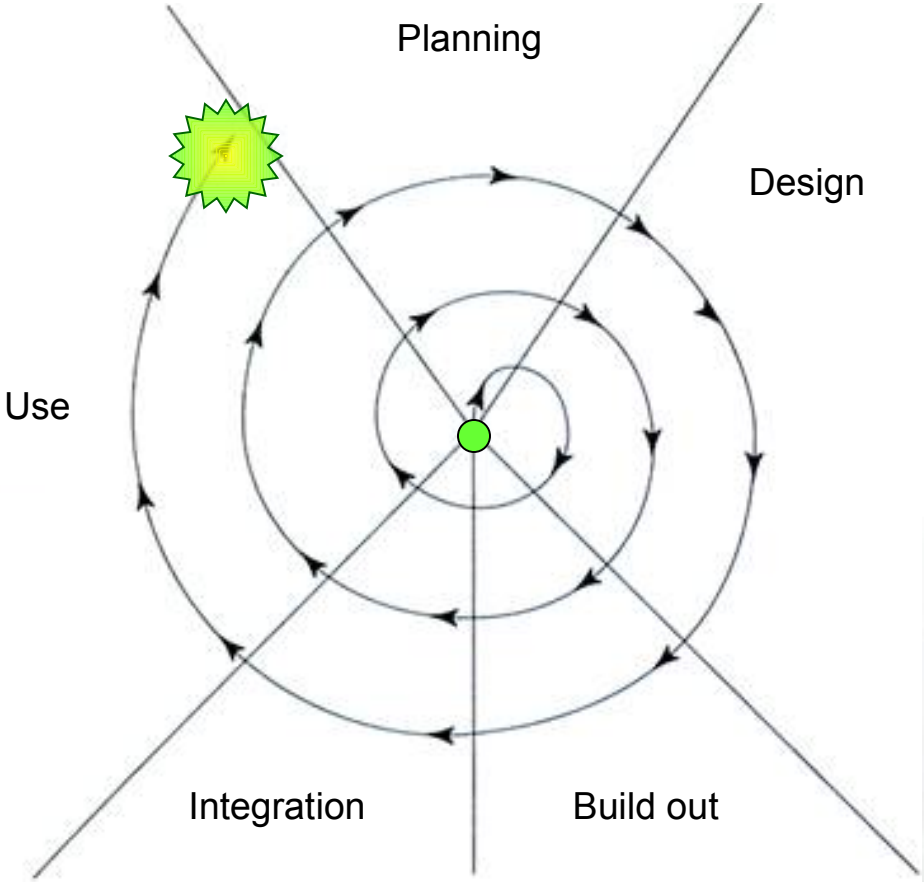
How We'll Build GENI

Note that this is the "classics illustrated" version – a comic book!

Please read the GENI System Overview and GENI Spiral 1 Overview for detailed planning information.

Spiral Development

GENI grows through a well-structured, adaptive process

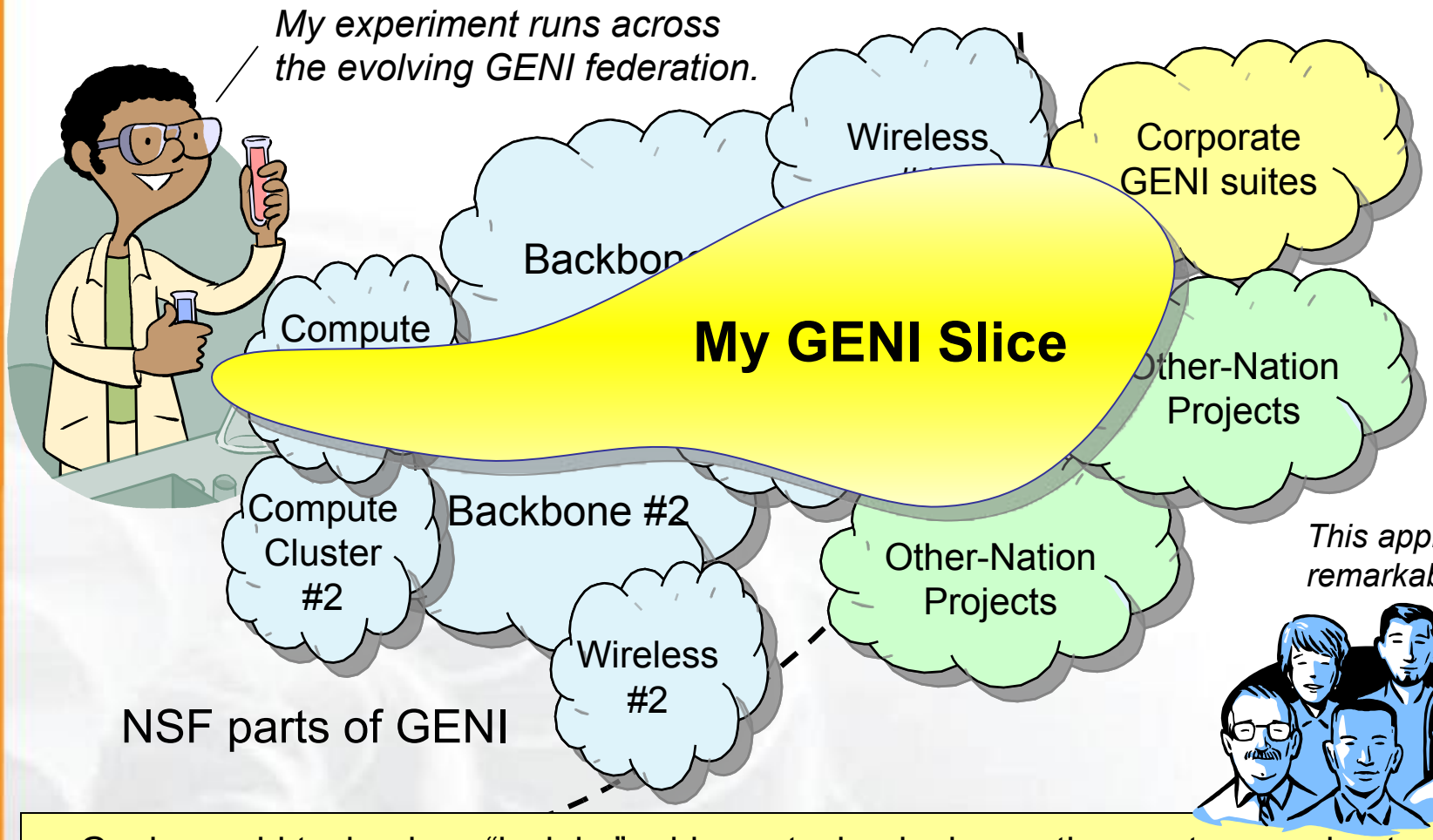


GENI Prototyping Plan

- An achievable **Spiral 1**
  Rev 1 control frameworks, federation of multiple substrates (clusters, wireless, regional / national optical net with early GENI 'routers', some existing testbeds), Rev 1 user interface and instrumentation.
- Envisioned **ultimate goal**
  Example: Planning Group's desired GENI suite, probably trimmed some ways and expanded others. Incorporates large-scale distributed computing resources, high-speed backbone nodes, nationwide optical networks, wireless & sensor nets, etc.
- Spiral Development Process
  Re-evaluate goals and technologies yearly by a systematic process, decide what to prototype and build next.

Federation

GENI grows by "gluing together" 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"

Infrastructure examples in Spiral 1

DRAGON core nodes
Mid-Atlantic Crossroads

WAIL, U. Wisconsin-Madison

DieselNet, U. Mass Amherst

ViSE, U. Mass Amherst

SPPs, Wash U.

ORBIT, Rutgers WINLAB

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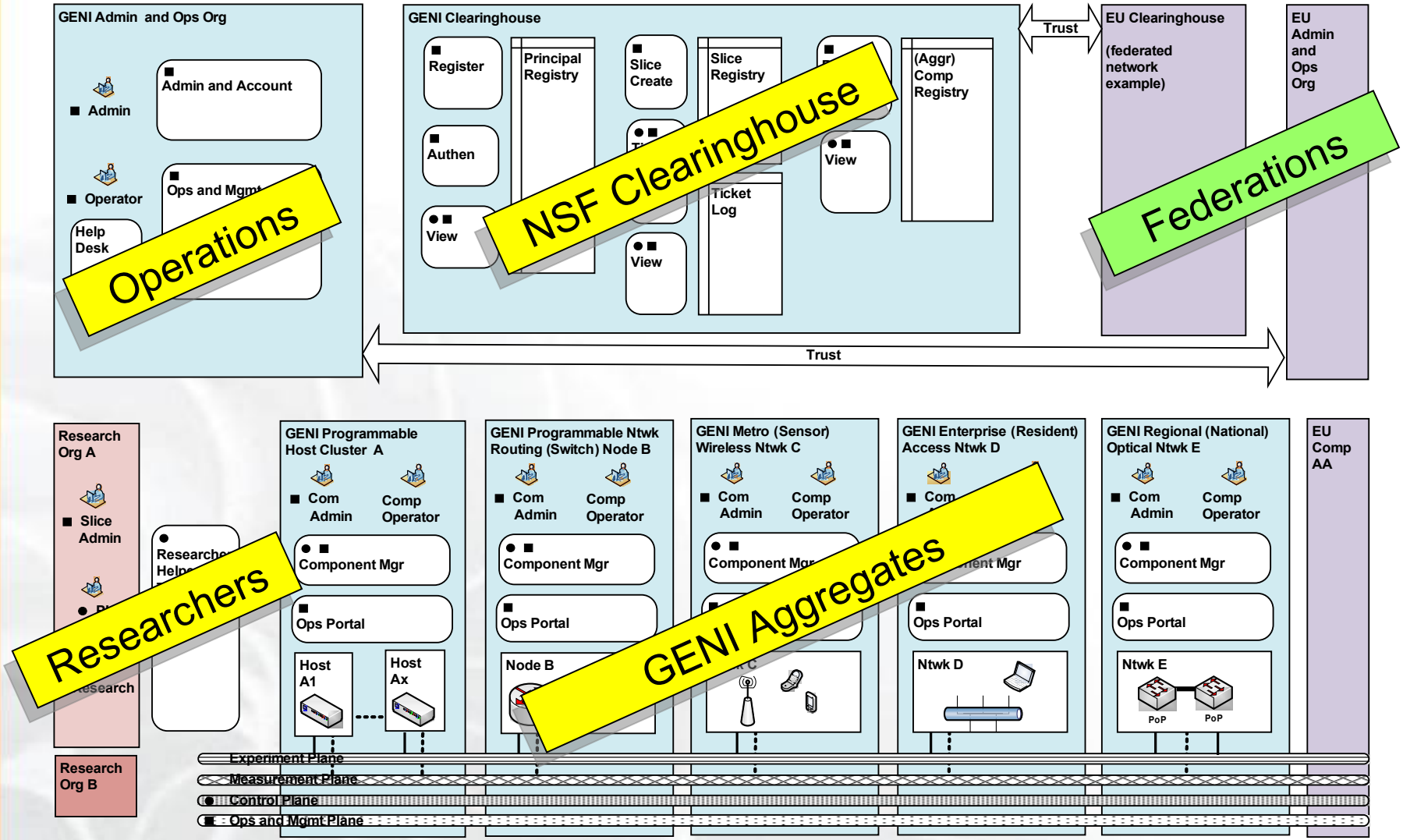
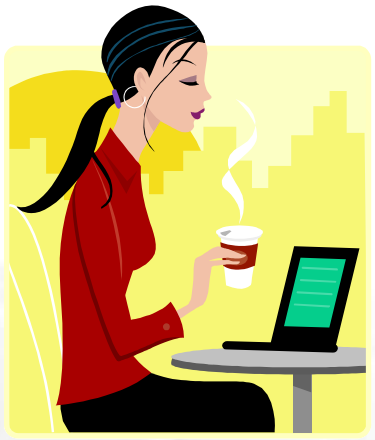
GENI System Decomposition (simplified)

Engineering analysis drives Spiral 1 integration



Resource discovery

Aggregates publish resources, schedules, etc., via clearinghouses



Researcher

What resources can I use?

GENI Clearinghouse

These

Components

Aggregate A
Computer Cluster

Components

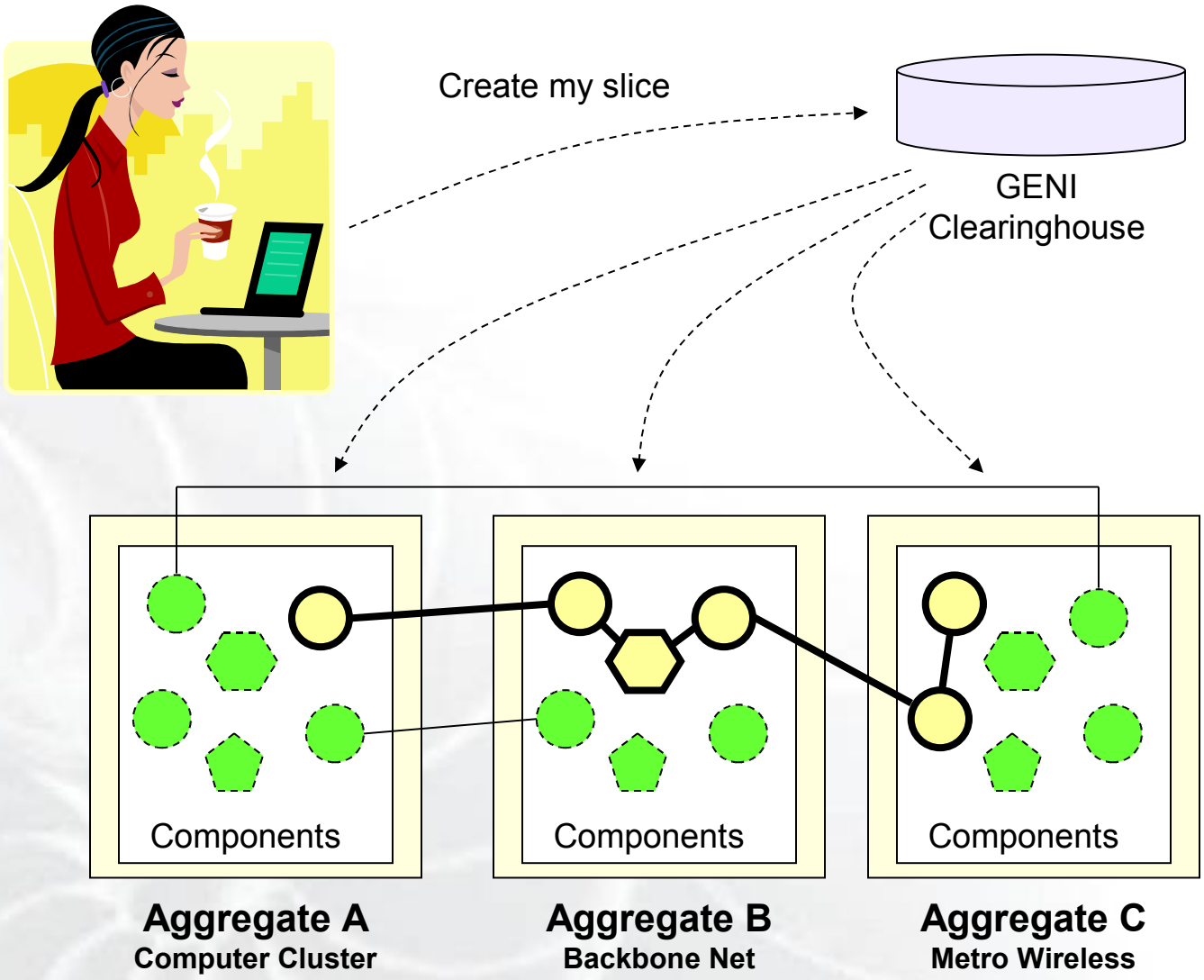
Aggregate B
Backbone Net

Components

Aggregate C
Metro Wireless

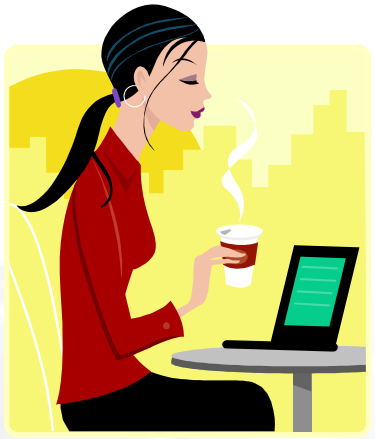
Slice creation

Clearinghouse checks credentials & enforces policy
Aggregates allocate resources & create topologies

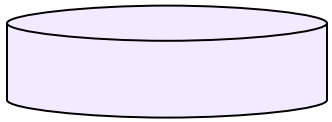


Experimentation

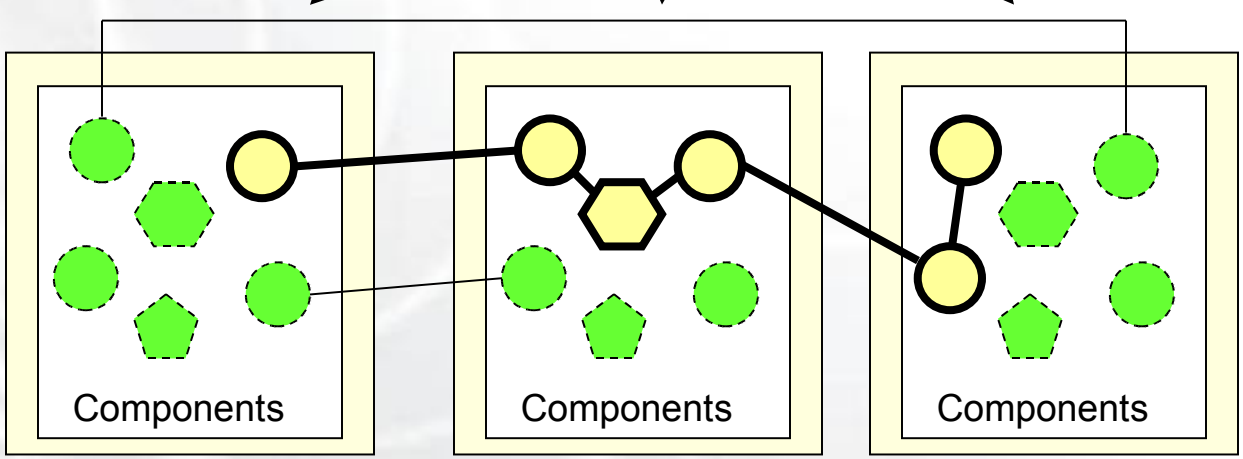
Researcher loads software, debugs, collects measurements



Experiment – Install my software, debug, collect data, retry, etc.

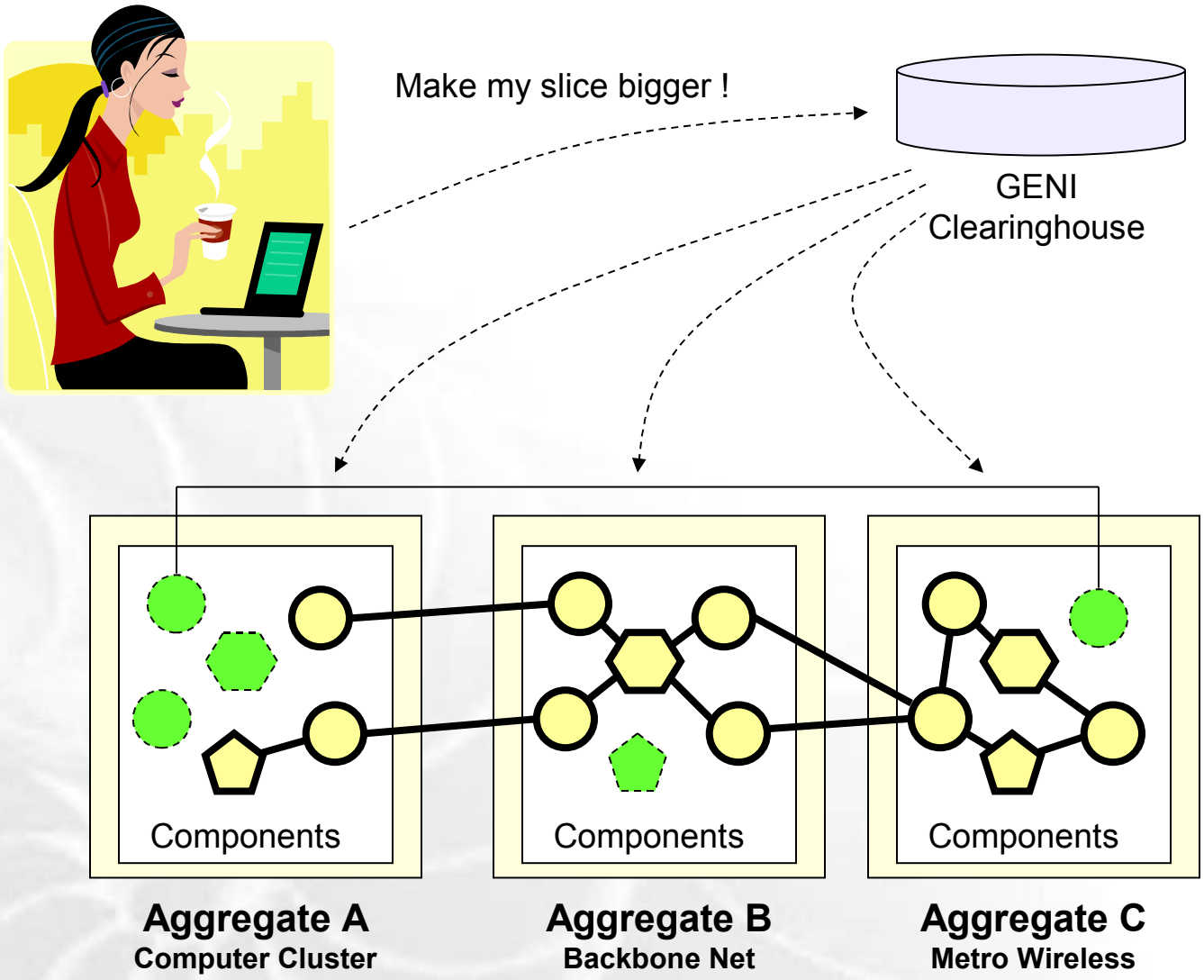


GENI Clearinghouse



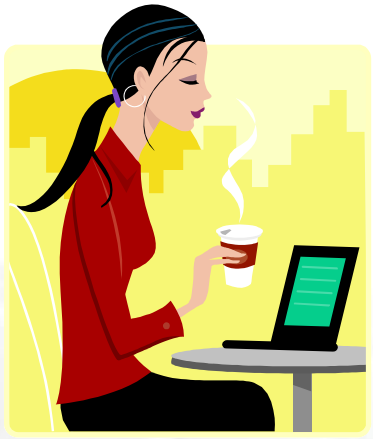
Slice growth & revision

Allows successful, long-running experiments to grow larger



Federation of Clearinghouses

Growth path to international, semi-private, and commercial GENIs



Make my slice even bigger !

GENI Clearinghouse

Federated Clearinghouse

Components

Components

Components

Components

Aggregate A
Computer Cluster

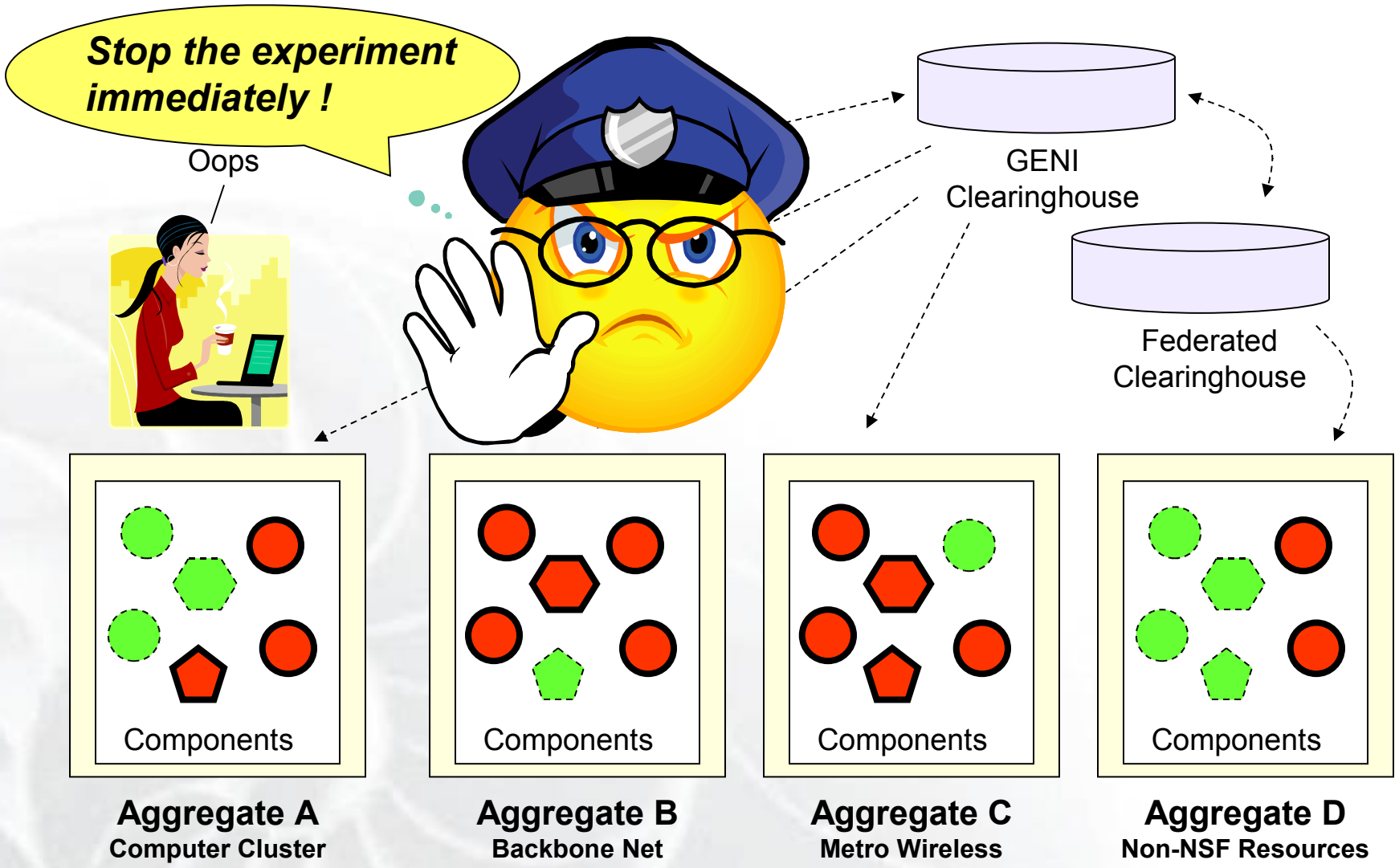
Aggregate B
Backbone Net

Aggregate C
Metro Wireless

Aggregate D
Non-NSF Resources

Operations & Management

Always present in background for usual reasons
Will need an 'emergency shutdown' mechanism



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GENI Spiral 1 is underway

GENI Project Office Announces $12M for Community-Based GENI Prototype Development

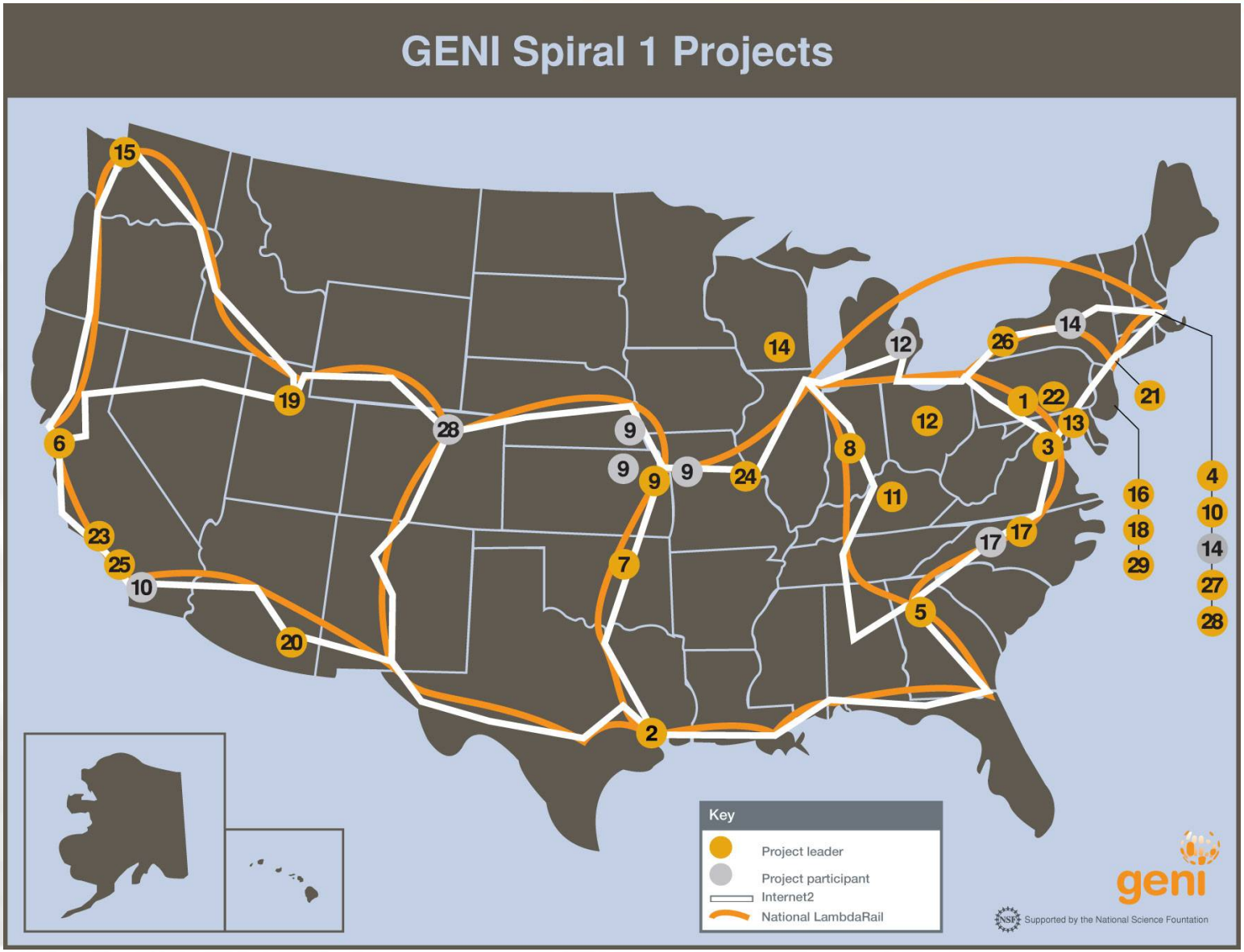
July 22, 2008

The GENI Project Office, operated by BBN Technologies, an advanced technologies solutions firm, announced today that it has been awarded a **three year grant worth approximately $4M a year** from the US National Science Foundation to perform GENI design and risk-reduction prototyping.

The funds will be used to contract with **29 university-industrial teams** selected through an open, peer-reviewed process. The first year funding will be used to **construct GENI Spiral 1, a set of early, functional prototypes** of key elements of the GENI system.

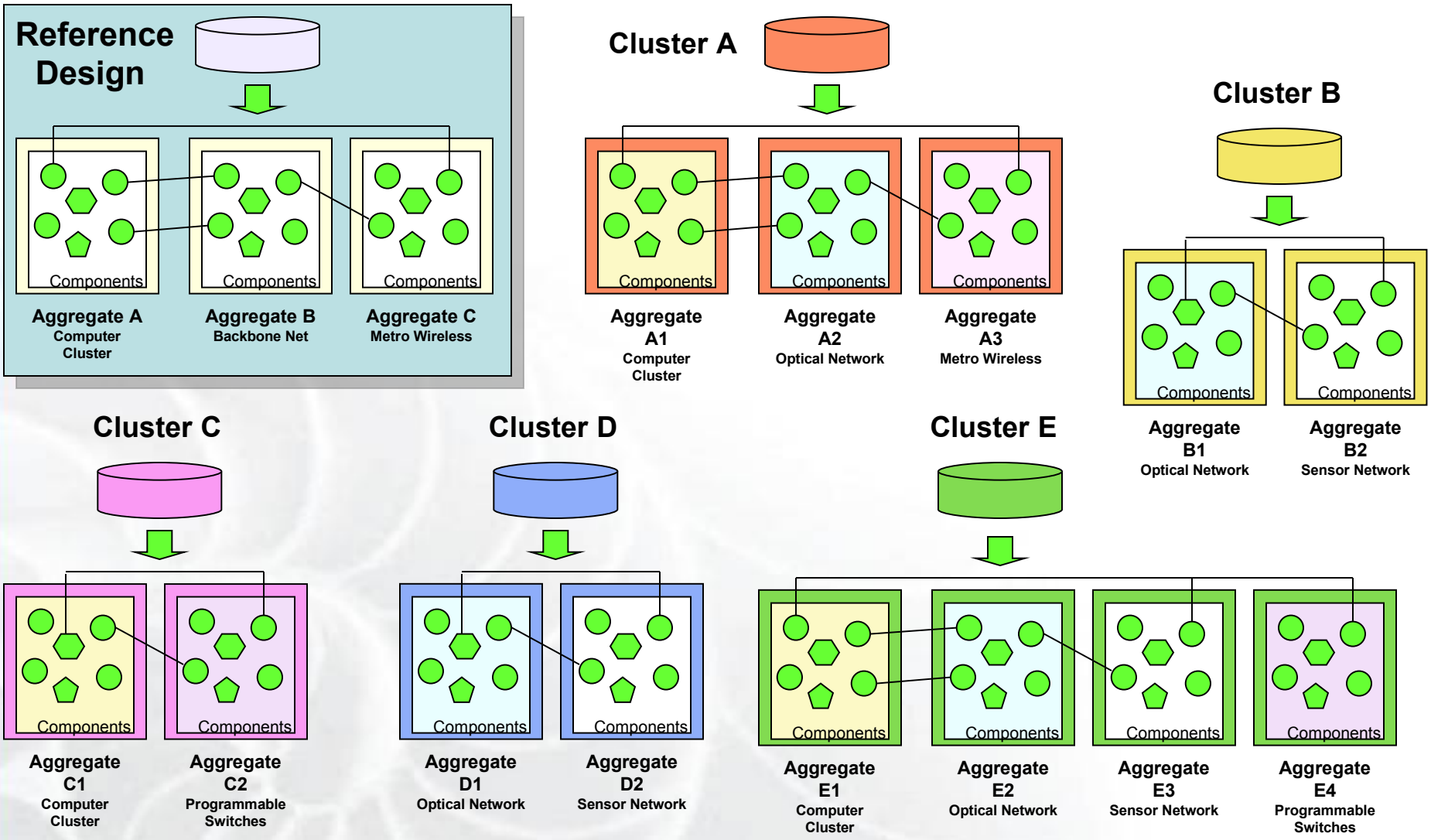
GENI Spiral 1

Rapid prototyping, integration, and early experiments



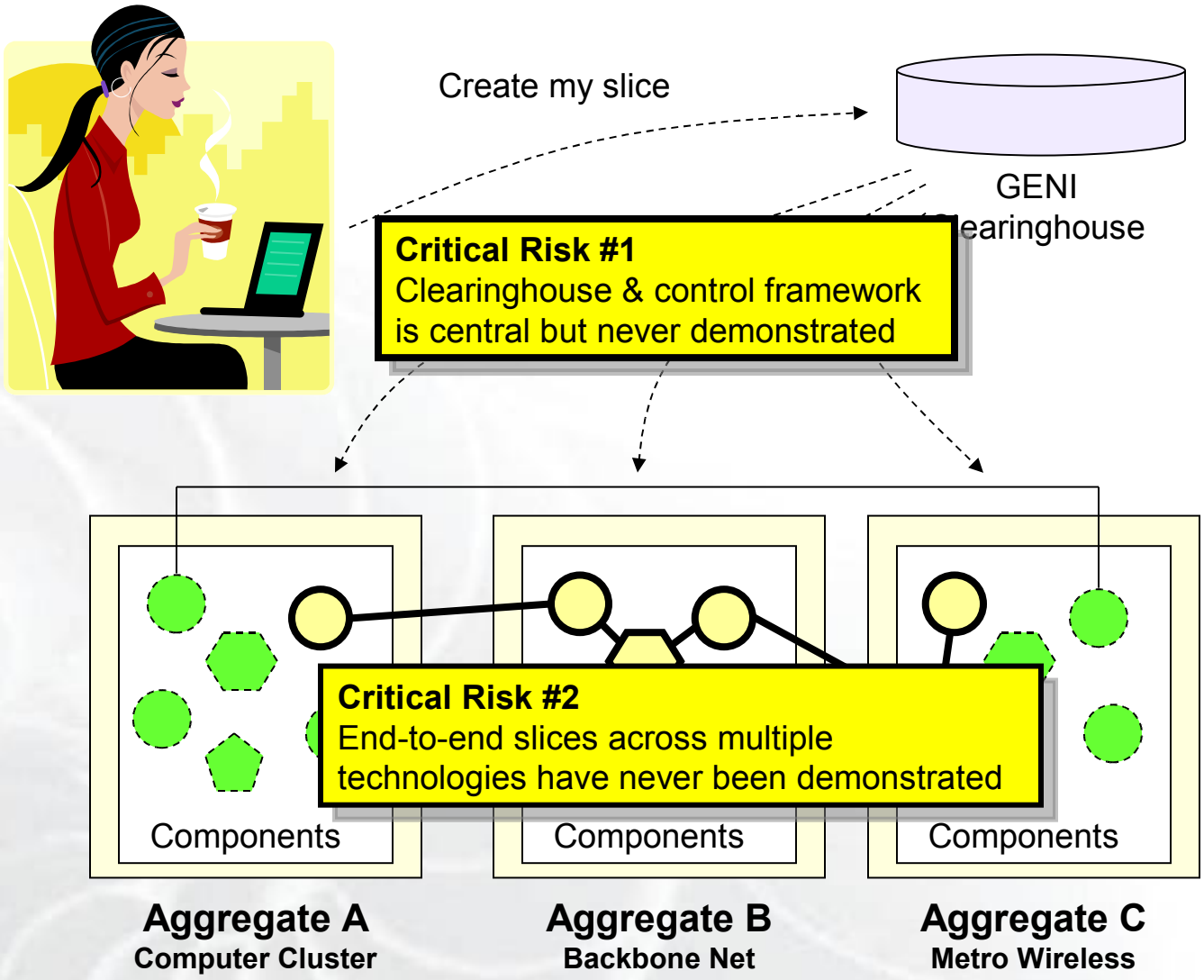
Spiral 1 integration and trial operations

Five competing control frameworks, wide variety of substrates



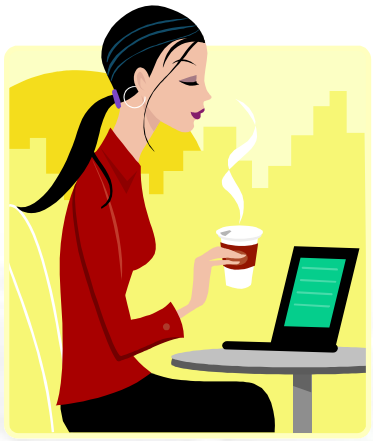
GENI's Critical Technical Risks

These risks drive the Prototyping Goals for GENI Spiral 1



Key Goals for GENI Spiral 1

Drive down critical technical risks in GENI's concept



Create my slice

GENI
nghouse

Goal #1
Fund multiple, competing teams to develop GENI Clearinghouse technology, encourage strong competition within the first few spirals

Goal #2
Demonstrate end-to-end slices across representative samples of the major substrates / technologies envisioned in GENI

Components

Components

Components

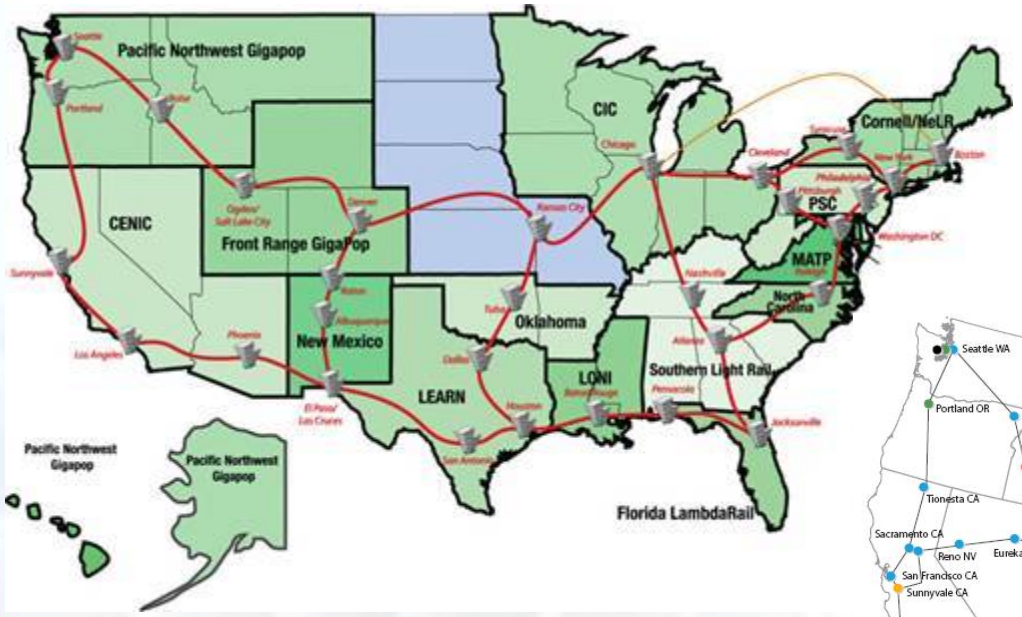
Aggregate A
Computer Cluster

Aggregate B
Backbone Net

Aggregate C
Metro Wireless

World-class expertise in GENI Partners

Internet2 and National Lambda Rail

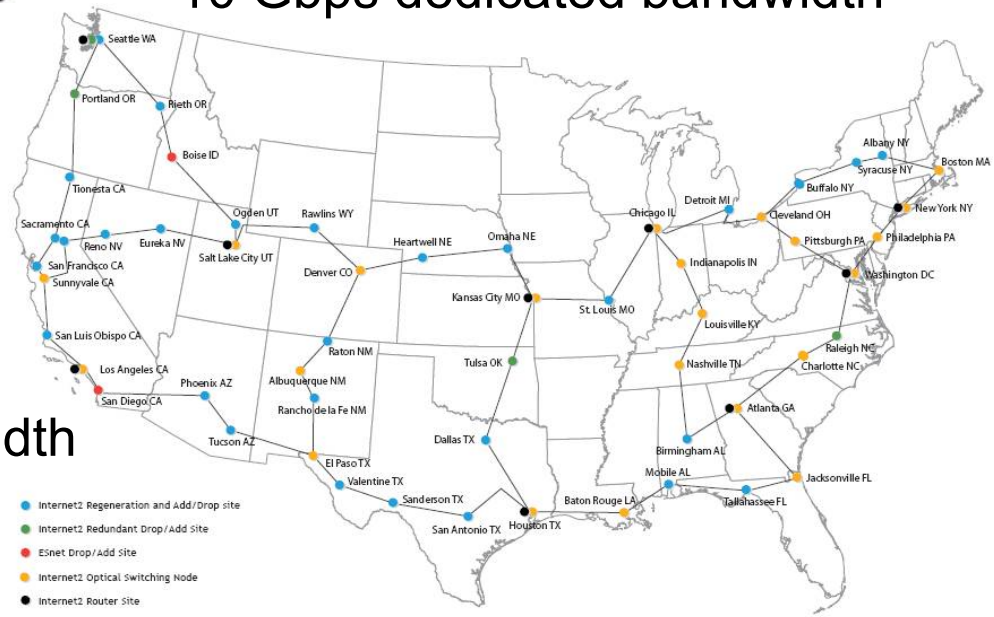


National Lambda Rail

Up to 30 Gbps nondedicated bandwidth

Internet2

10 Gbps dedicated bandwidth



40 Gbps capacity for GENI prototyping on two national footprints to provide Layer 2 Ethernet VLANs as slices (IP or non-IP)

GENI Spiral 1

- Provides the very first, national-scale prototype of an interoperable infrastructure suite for Network Science and Engineering experiments
- Creates an end-to-end GENI prototype in 6-12 months with broad academic and industrial participation, while encouraging strong competition in the design and implementation of GENI's control framework and clearinghouse
- Includes multiple national backbones and regional optical networks, campuses, compute and storage clusters, metropolitan wireless and sensor networks, instrumentation and measurement, and user opt-in
- Because the GENI control framework software presents very high technical and programmatic risk, the GPO has funded multiple, competing teams to integrate and demonstrate competing versions of the control software in Spiral 1

Nothing like GENI has ever existed; the integrated, end-to-end, virtualized, and sliceable infrastructure suite created in Spiral 1 will be entirely novel.

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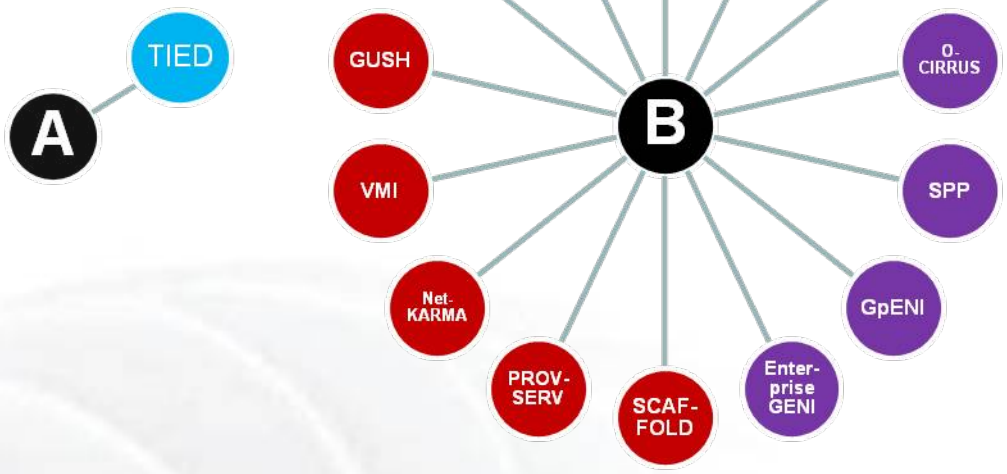
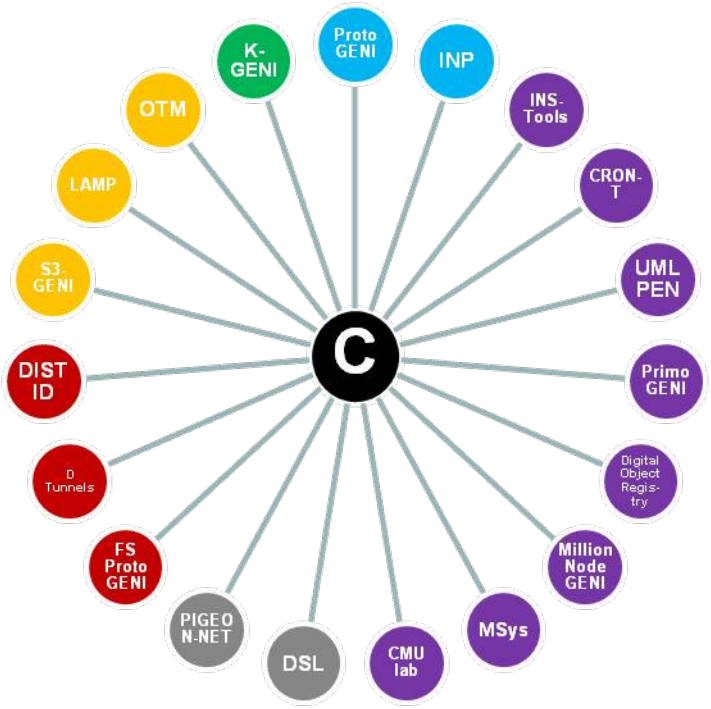
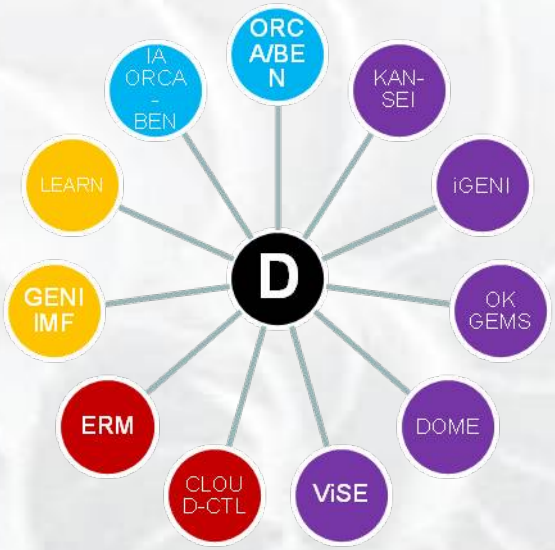
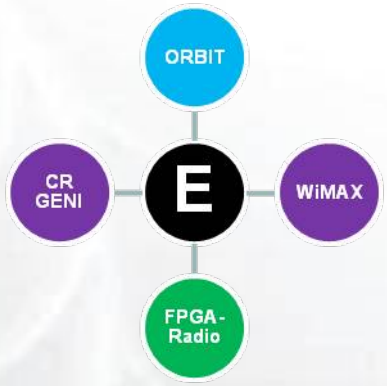








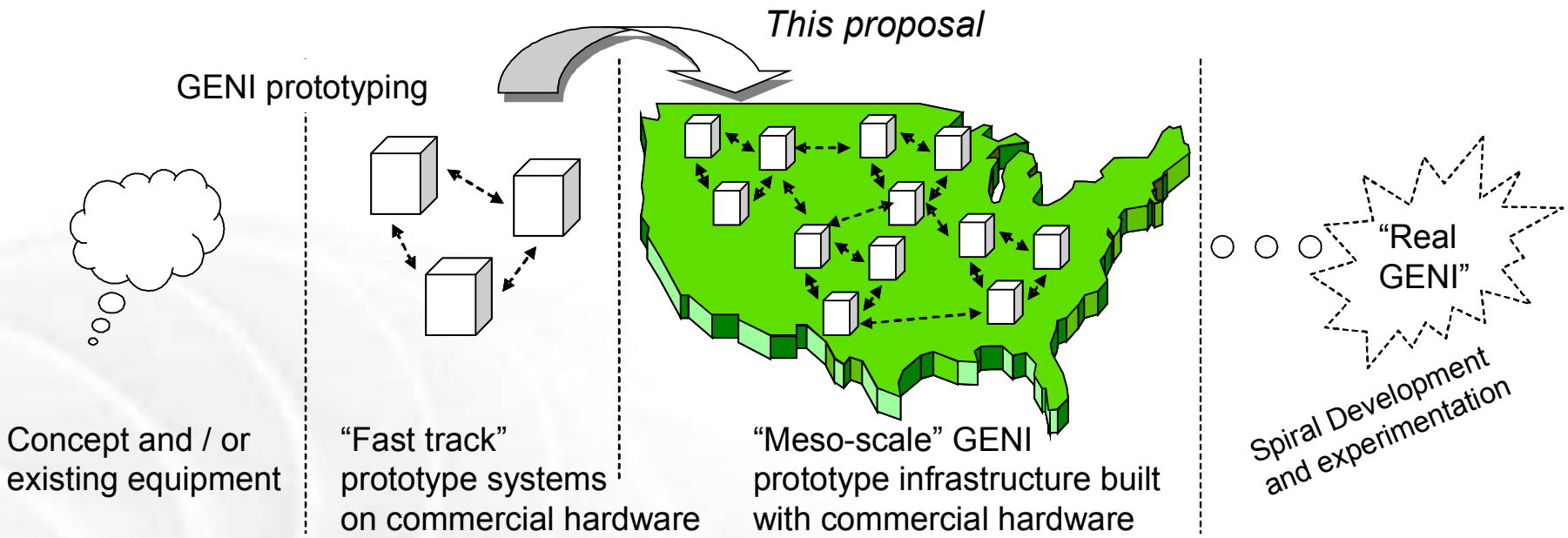
GENI Projects Not In Clusters:

DInfo-Subs
GMOC
REG OPT
CMUDP
SEC-POL
DSN-HIVE
GENI 4YR
SEC ARCH
DMeas
LEFA
Att-GENI
EXP-SEC

KEY

- Instrumentation & Measurement
- Control Framework
- Tools & Services
- Experiment
- Study
- Aggregate

Meso-scale prototyping



Rapid progress in GENI prototyping has created a remarkable opportunity to accelerate the creation of an end-to-end GENI infrastructure suite for "meso-scale" experiments, leveraging GENI-enabled commercial hardware, across more than a dozen campuses and two national research backbones

This slide describes a GPO proposal to NSF which is currently under review, and which may or may not be funded.

Benefits of meso-scale prototyping

- Create a compelling infrastructure for entirely new forms of **network science and engineering experimentation** at a much larger scale than has previously been available

- Stimulate **broad community participation and "opt in"** by early users across 13 major campuses, which can then grow by a further 21 campuses as the build-out progresses, with a strong partnership between researchers and campus infrastructure operators

- Forge a **strong academic / industrial base** by GENI-enabling commercial equipment from Arista, Cisco, HP, Juniper, and NEC, with software from AT&T Labs and Nicira.

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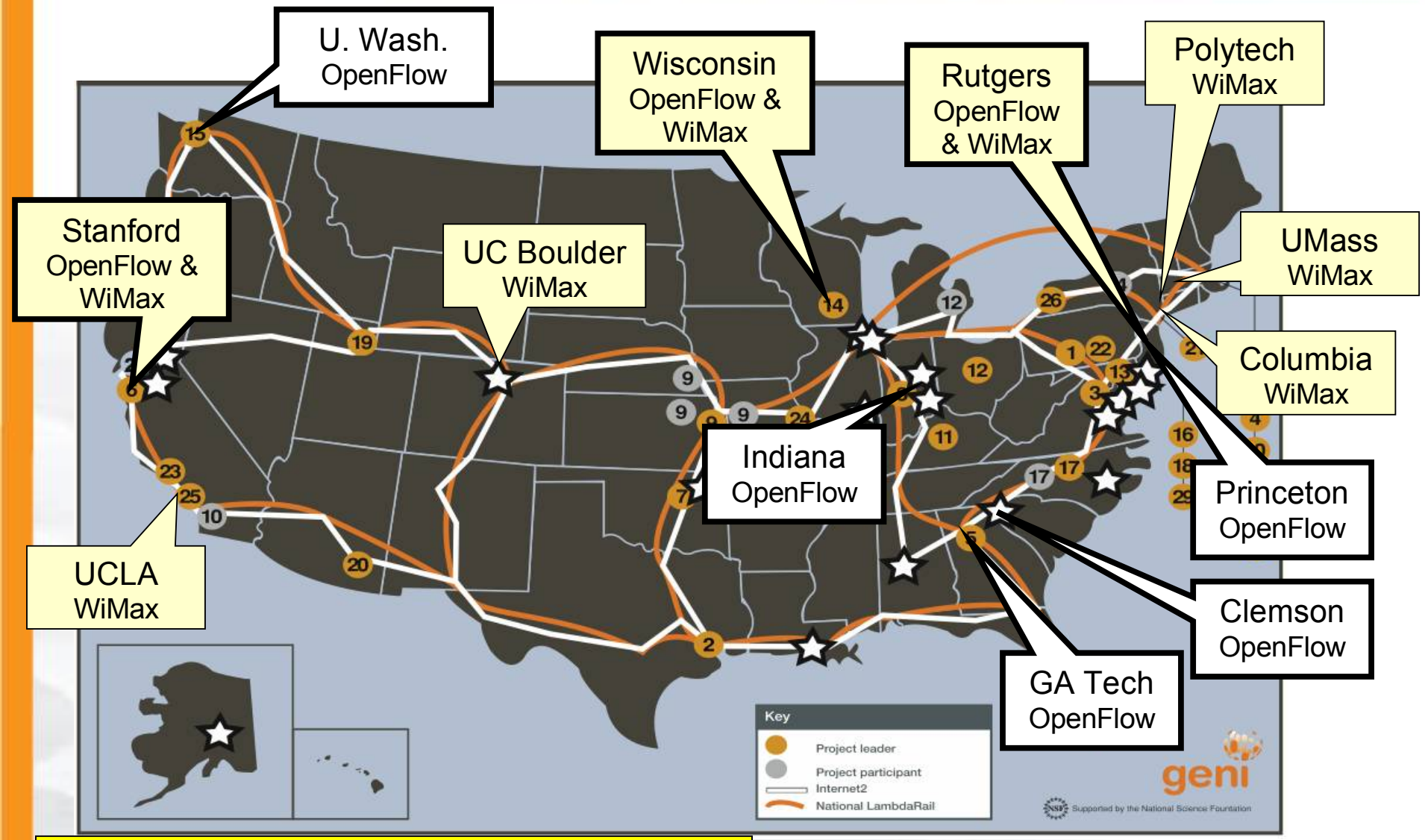
More than a dozen leading US universities

Meso-scale GENI campus prototypes



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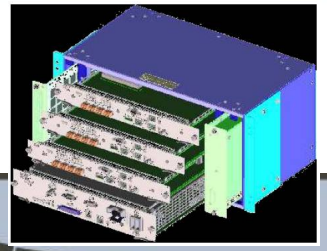
WINLAB lead
WiMax campus prototypes

NEC WiMax Base Stations



Wisconsin OpenFlow & WiMax

Rutgers OpenFlow & WiMax

Polytech WiMax

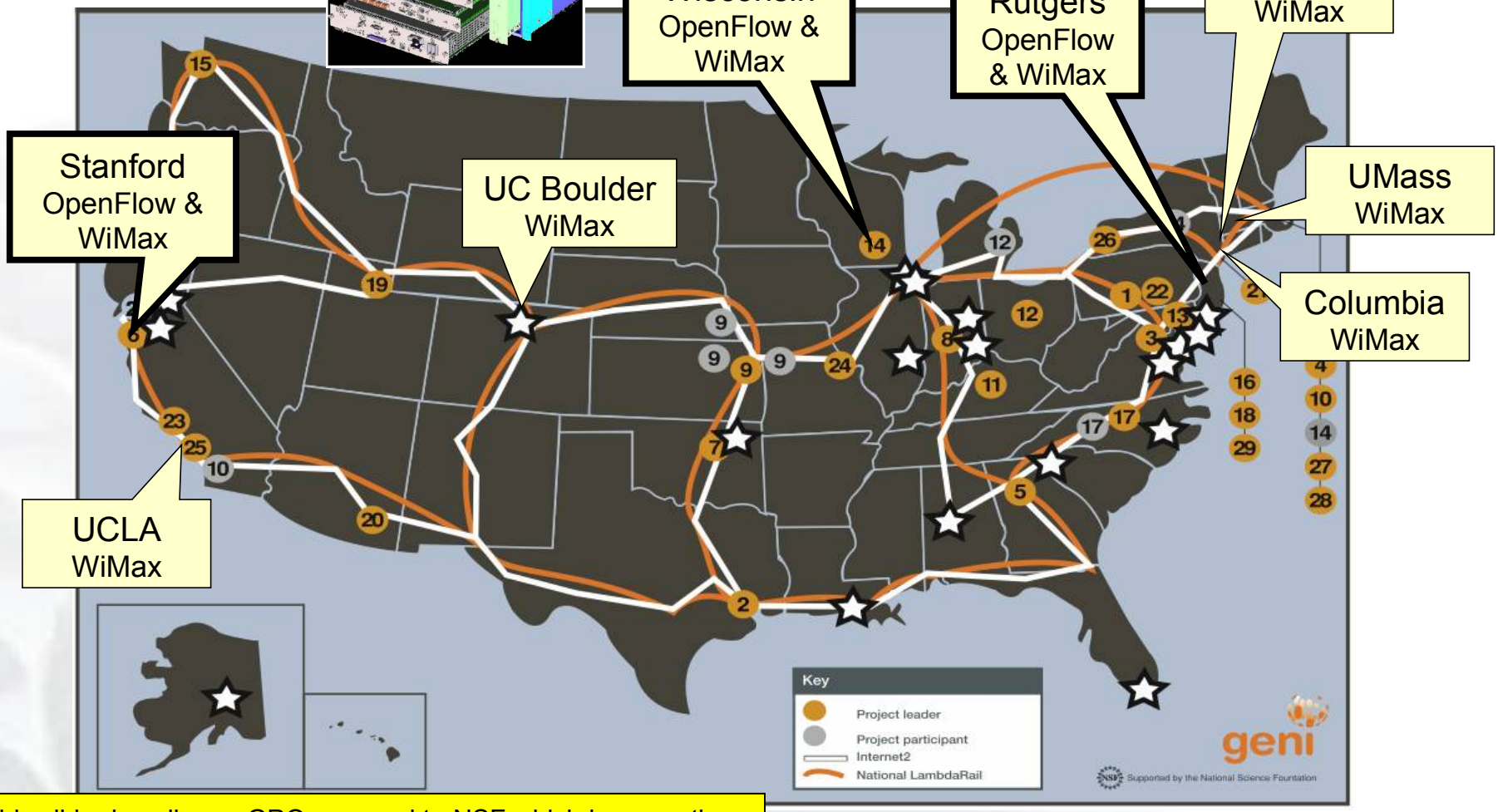
Stanford OpenFlow & WiMax

UC Boulder WiMax

UMass WiMax

Columbia WiMax

UCLA WiMax



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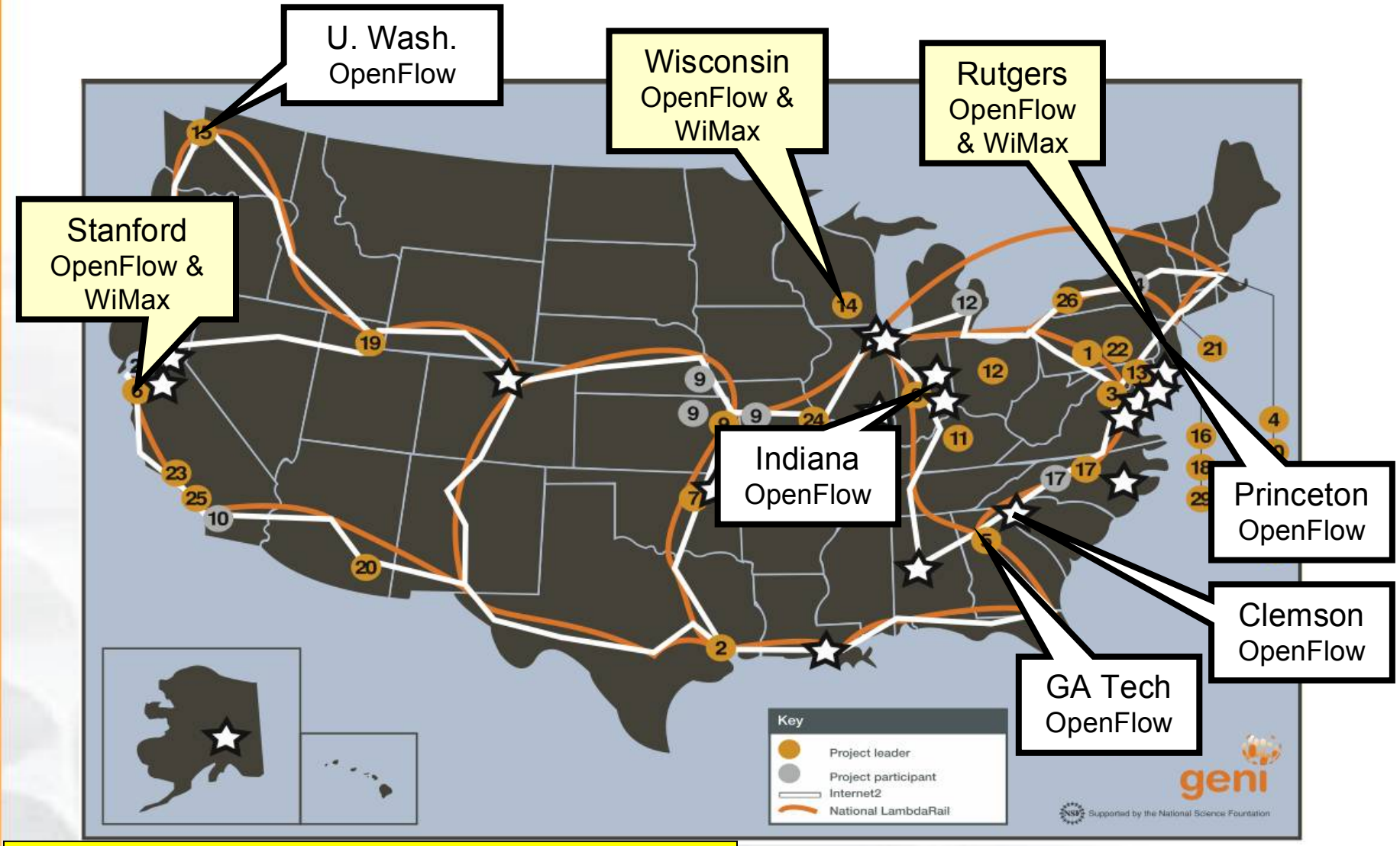
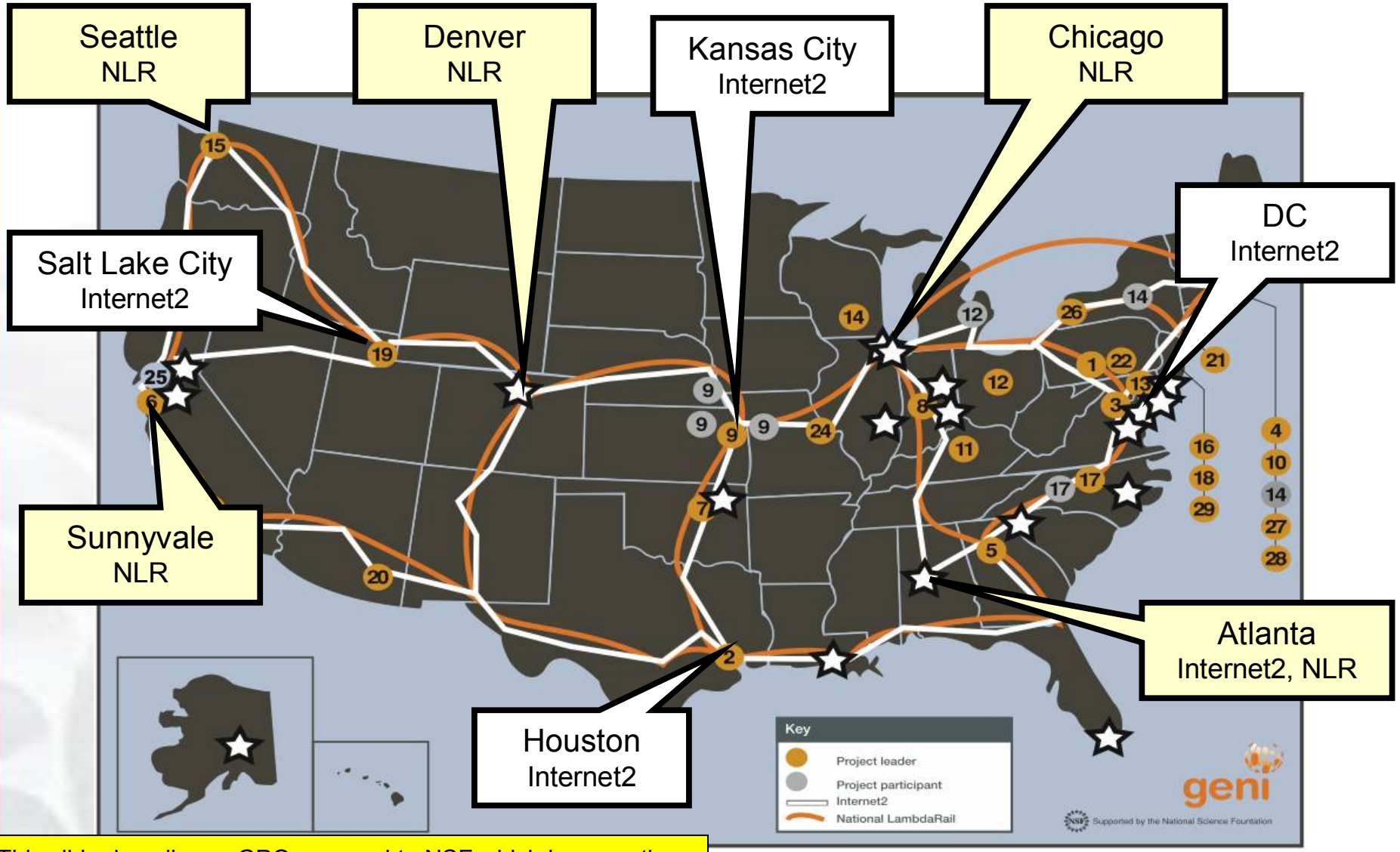
Stanford lead
OpenFlow campus prototypes



This slide describes a GPO proposal to NSF which is currently under review, and which may or may not be funded.

OpenFlow backbone prototypes through Internet2 and NLR (notional)



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OpenFlow prototypes (current plans,1 of 2)

 Arista 7124S Switch	• Rutgers • NLR	• Very appealing hardware platform (cheap, fast) • Strong links to Silicon Valley venture capital community
 Cisco 6509 Switch	• Clemson • Rutgers	• Mild endorsement and commitment from Cisco in proposal
 HP ProCurve 5400 Switch	• Stanford • Georgia Tech • Indiana University • Princeton (eval) • UW Madison (eval) • U. Washington • Internet2	• **Stanford has demonstrated OpenFlow on HP ProCurve switches** • Strong endorsement from vendor in proposal • ProtoGENI is deploying HP ProCurve switches in Internet2 backbone (3 sites this summer)

This slide describes a GPO proposal to NSF which is currently under review, and which may or may not be funded.

OpenFlow prototypes (current plans, 2 of 2)

 Juniper MX240 Ethernet Services Router	• Clemson	• Strong endorsement from vendor in proposal • Note vendor commonality with ShadowNet proposal (in Internet2 backbone)
 NEC IP8800 Ethernet Switch	• Georgia Tech • Princeton (eval) • Rutgers • UW Madison (eval)	• **Stanford has demonstrated OpenFlow on NEC switches** • Strong endorsement from vendor in proposal • NEC also supplying OpenFlow-enabled WiMax basestations for campus builds

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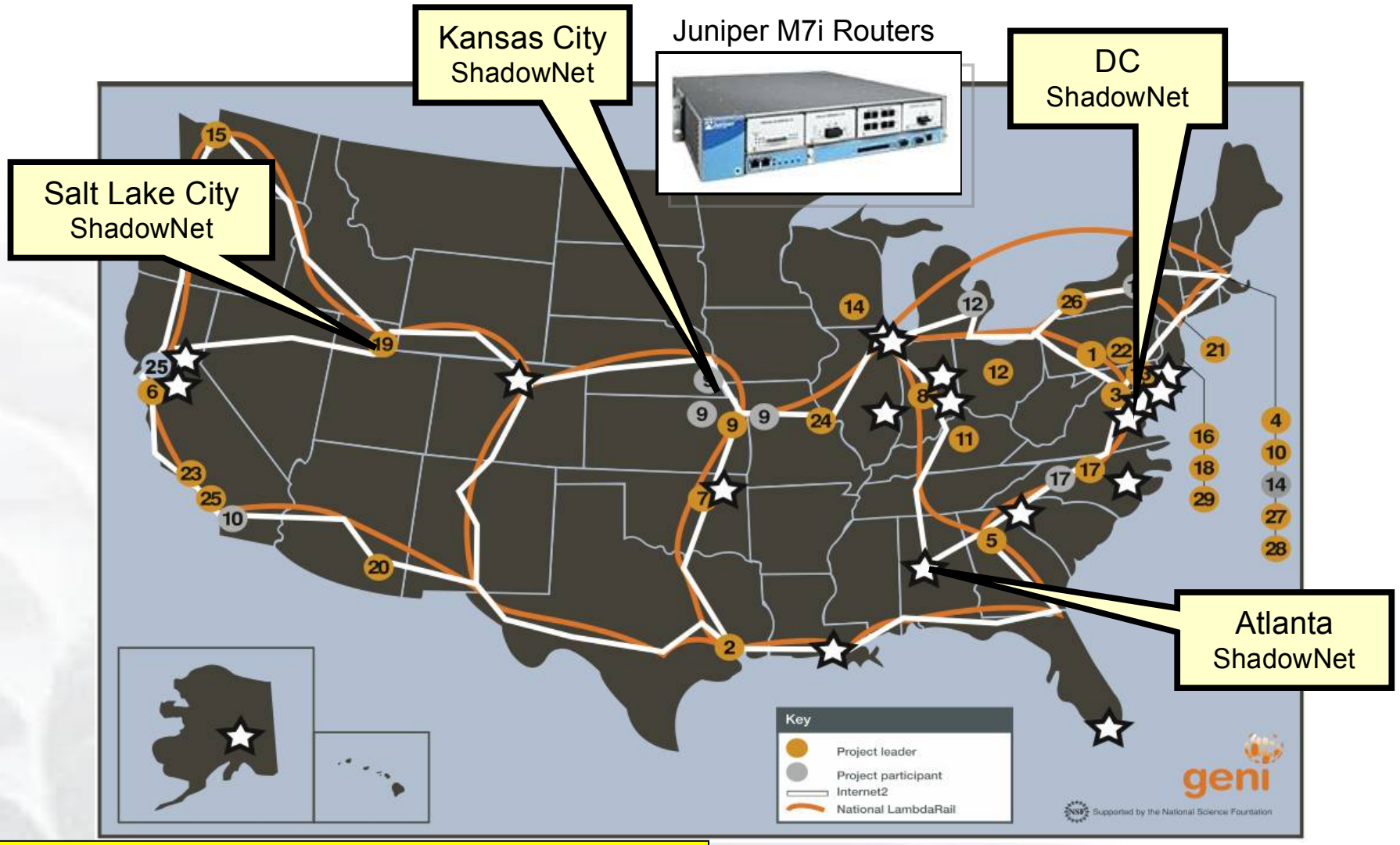
ShadowNet prototype
Internet2 backbone (ProtoGENI sites)



This slide describes a GPO proposal to NSF which is currently under review, and which may or may not be funded.

Outline

- What is GENI?
- How we'll build it, how we'll use it (Two Comic Books)
- The GENI system concept
- GENI Spiral 1
- GENI Spiral 2, starting soon
- How can you participate?

GENI is being Designed & Built by the Community
Via an Open, Transparent, & Fair GPO Process

- All design, prototyping, & construction will be performed by the research community (academia & industry)
- 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 will be fair and even-handed
  - BBN brings no technology to the table
  - BBN does not intend to write any GENI software, nor does it envision bidding on any prototyping or construction activities (but “never say never”)
  - If BBN does create any GENI technology, it will be made public at no cost

Working Groups drive GENI's Technical Design
Meet every 4 Months to Review Progress Together

- **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 in person
  - Each led by Chair(s), plus a professional System Engineer
- **GENI Engineering Conferences**, open to all who fit in the room
  - Held at regular 4-month periods
  - Held on / near university campuses (volunteers?)
  - All GPO-funded teams required to participate
  - Systematic, open review of each Working Group status (all documents and prototypes / trials / etc.)
  - Also time for Working Groups to meet face-to-face
  - Results in prioritized list for next round of prototype funding areas (priorities decided by NetSE and GPO)

GENI Engineering Conferences
Meet every 4 months to review progress together

- **6th meeting, open to all: November 16–18, 2009, Salt Lake City**
  - Team meetings, integrated demos, Working Group meetings
  - Also discuss GPO solicitation, how to submit a proposal, evaluation process & criteria, how much money, etc.
  - **Travel grants** to US academics for participant diversity
- Subsequent Meetings, open to all who fit in the room
  - Held at regular 4-month periods
  - Held on / near university campuses (volunteers?)
  - All GPO-funded teams required to participate
  - Systematic, open review of each Working Group status (all documents and prototypes / trials / etc.)
  - Also time for Working Groups to meet face-to-face
  - Discussion will provide input to subsequent spiral goals

GPO Solicitations
Academic-industrial teams favored but not required

- **Second solicitation closed on Feb. 20, 2009**

- What kinds of proposals do we solicit?
  - Analyses & idea papers
  - Prototypes of high-risk GENI technology
  - Integrations and trials of prototypes
- How are proposals judged?
  - Merit review
  - Joint academic / industrial teams are favored but not required
  - Open source will be favored but not required
    (IP licenses on www.geni.net)

GENI is a Huge Opportunity

- **GENI is an unbelievably exciting project for the community**
  - Our research community has changed the world profoundly. GENI opens up a space to do it again.
- **We believe the whole community will build GENI together**
  - Our vision is for a very lean, fast-moving GPO, with substantially all design and prototyping performed by academic and industry research teams.
- **GENI Spiral 1 is now underway !**
  - within a GENI project framework that is open, transparent, and broadly inclusive.

www.geni.net

Clearing house for all GENI news and documents