Network Science and Engineering

Future Generation Networks

CISE/NSF

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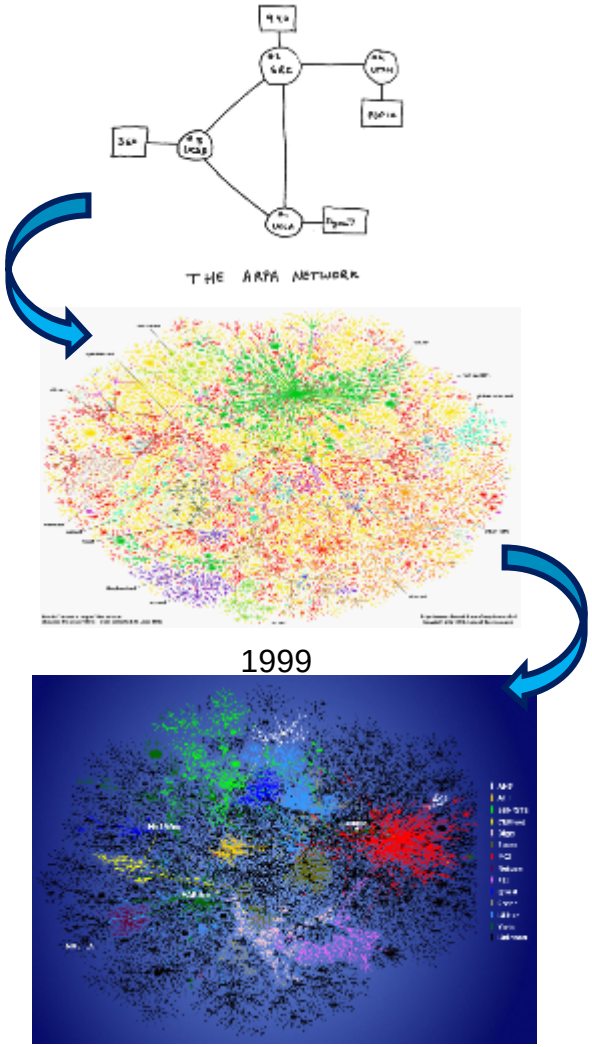
Acknowledgement: NetSE NSF Team

Outline

- Network Science and Engineering
  - Future Internet Design
  - NeTS Research Infrastructure
    - The GENI Concept
- Global Collaboration
- Concluding Remarks

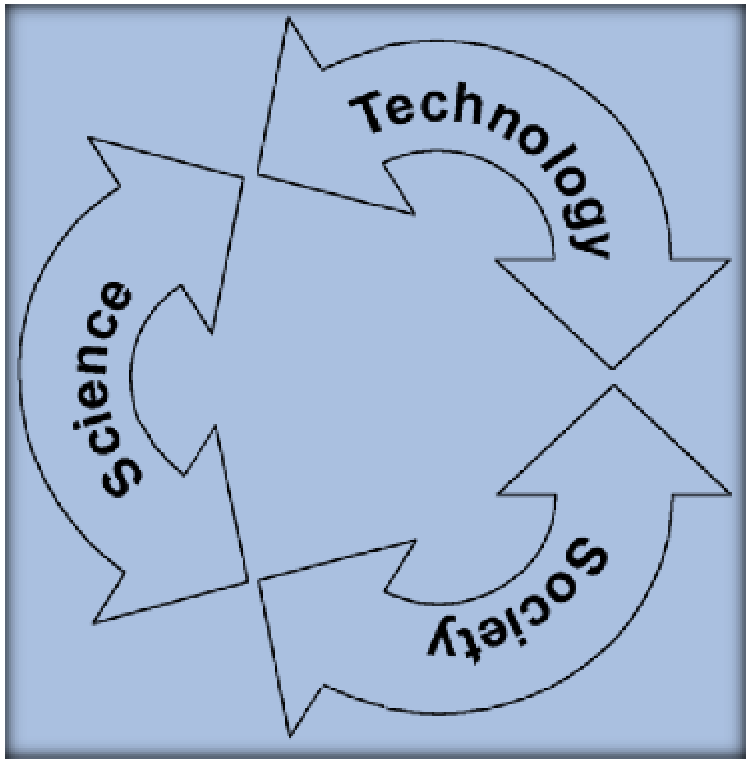
Internet – Where are we Now?

- ***The Internet is a critical infrastructure that enabled global communication and transformed society***
- *"… in the thirty-odd years since its invention, new uses and abuses, …, are pushing the Internet into realms that its original design neither anticipated nor easily accommodates."* Overcoming Barriers to Disruptive Innovation in Networking, NSF Workshop Report, 2005.
- ***The Internet will continue to evolve and become more complex***
  - At the same time, the Internet faces many challenges, not only related to its technical limitations but also to economic and social issues



Network Science & Engineering

- Is there a science for understanding the complexity of our networks so that we can engineer them to have predictable behavior?
  - In light of the Internet's growing role as a driver for innovation leading to economic growth and social well-being, there is a unique opportunity to consider this fundamental question in an economic, social and regulatory context



NSF Network SE Strategy

- NSF invests in NetSE research, education and research infrastructure through a number of “loosely coupled” programs
- CISE
  - Major Research Instrumentation, Computing Research Infrastructure, Computer Systems Research, Cyber Trust,
  - Network Technology and Systems, Next Generation Networked Information, Scientific Foundations for Internet’s Next Generation
- Engineering
  - Integrative, Hybrid and Complex Systems, Resilient and Sustainable Infrastructures, …
- Social, Behavioral and Economics Sciences
  - Human and Social Dynamics, Innovation and Organizational Change, Economics and Sciences and Society

CISE/NSF Strategy for NetSE

- NetSE Team
  - Deborah Crawford, Suzi Iacono, Larry Landweber*, Gracie Narcho, Paul Morton and Ty Znati
- Selected NetSE Activities
  - Future INternet Design (FIND)
  - NetSE Research Infrastructure
    - Global Environment for Network Innovation (GENI)

FIND — Future Internet Design

- **FIND is a major new long-term initiative of the Networking Technology and Systems (NeTS) Program**

Challenged the research community to create a network they want to have in 10 to 15 years!

- FIND Program Committee
  - Darleen Fisher (dlfisher@nsf.gov)
  - Allison Mankin (amankin@nsf.gov)

FIND – Clean Slate Design

- The intellectual scope of the FIND program is wide:
  - How can we design a network that is fundamentally more secure and available than today's Internet?
    - How would we conceive the security problem if we could start from a clean-slate?
  - How might such functions as information dissemination, location management or identity management best fit into new network architecture?
  - What will be the long-term impact of new technologies such as advanced wireless and optics?
  - How will economics and technology interact to shape the overall design of a future network?
  - How do we design a network that preserves a free and open society?

FIND 3-Phased Iterative Process

- **Research on architectural elements**
  - Naming, identities, forwarding, inter-domain protocols, etc.
  - Cross-cutting requirements of built-in security, robustness, and manageability etc.
- **Build community and formulate architectures**
  - Multiple Program meetings, focused on aspects of architectures
  - Inclusive of “architectural” researchers e.g. funded by NeTS, CyberTrust, DARPA, industry, internationally funded researchers, etc.
- ***Coordinated effort to assemble overarching coherent architectures***
  - ***Develop small number of architectures***
  - ***Simulate, emulate, test on research infrastructure***

F I N D

- **FY07 activities**
  - 83 proposals (54 projects)
    - Funded: 15 projects (~$11.5M)
  - FIND informational meetings
  - FIND Program meetings
- **Previous FYs**
  - 49 FIND active continuing projects
    - 41 active FIND-Funded projects
    - 8 projects funded through CAREER, etc…
- 18 Million per Year

Coordination and Opportunities

- Organized Future Internet Research panels at INFOCOMM, Technology Policy Research Conference, ICNP
- Opportunities for collaboration in NSF
  - SBE, ENG, BIO/GEO (CI)
- Collaboration outside of NSF
  - AFOSR, DARPA, EC Information Society FIRE, Japan's NICT

Selected FIND Projects

- **Postmodern Internet Architecture**
  - Calvert (GATech), Sterbenz (KU), Spring (UMd)
- **Clean Slate Approach to Network Security: SANE, inSANE, and Ethane**
  - McKeown (Stanford) and Akella (WISC)
- **Network Fabric for Personal, Social and Urban Sensor Applications**
  - Srivastava (UCLA), Paxson (ICSI)
- **Market Enabling Architecture**
  - Walrand (UCB), Musacchio (UCSC) Parekh (Bell Labs)

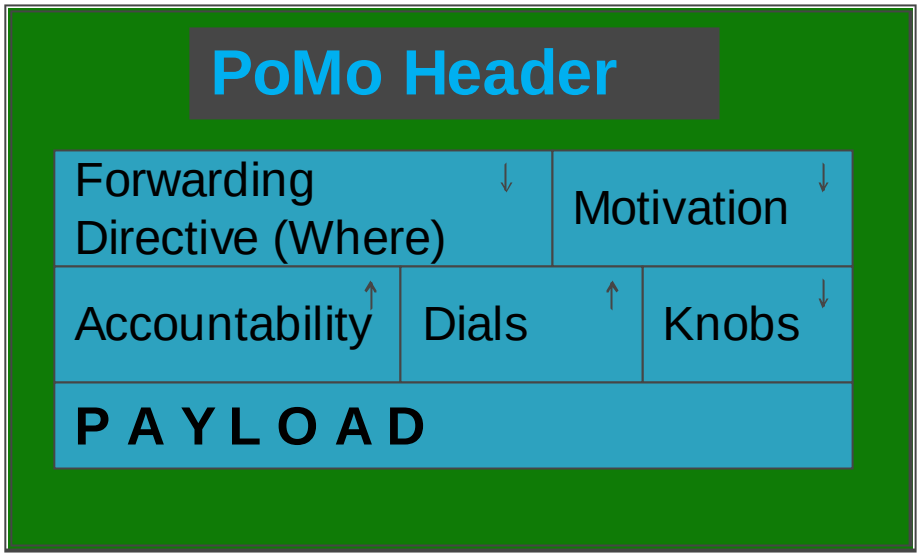
Postmodern Internet Architecture

Current Internetwork Layer Problems

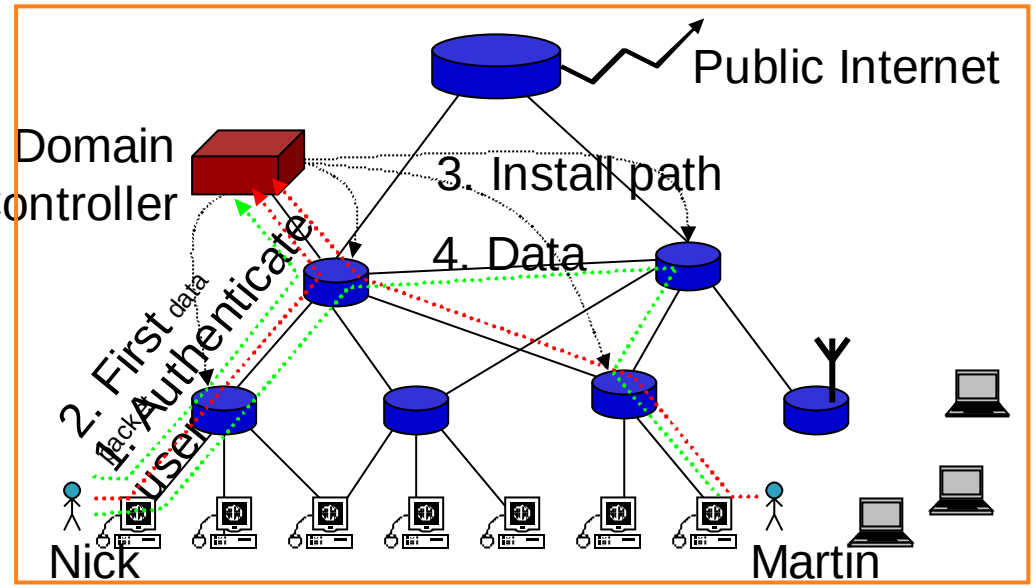
- ❖Too many policies and too little mechanisms
- ❖Infrastructure assumed mostly fixed and stable

New architecture concept

- ❖ **Thin network layer—no addressing**
- ❖ **Forward by identifying links, not endpoints**
- ❖ **Add economic incentives**
- ❖ **Include accountability—origin, path**
- ❖ **Dials and knobs—to advise transport/application** *from below* **and to network layer** *from above*



Secure Architecture for Networked Enterprise (SANE)



Schedule Goals

Q4 06	Q1 07	Q2 07	Q3 07	Q4 07
Ethane: v1.0				
			Ethane: v2.0	
Ethane: Local Deployment				
		Ethane: Remote Deployment		
inSANE: Invention				
			inSANE: v1.0	

- **Ask the question:** With a clean-slate, how can we design Public and Private networks to be inherently secure from the ground up?
- **Approach:** Force the origin and intent of traffic to be explicit
- **Private Networks:**
  - SANE: All network connectivity governed by global policy; Implement secure namespace
  - Ethane: Ethernet-compatible prototype; Domain Controller and custom Ethernet switch
- **Public Networks:** *Work yet to start*
- **Technology Transition**
  - Expect to work with commercial partners to transfer technology

Ethane Network Architecture:
Taking Control of Enterprise Networks

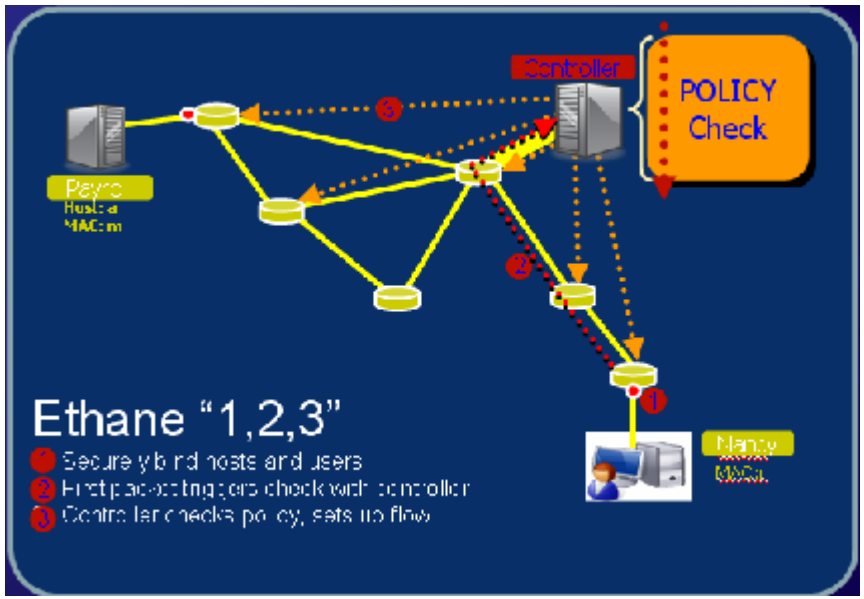
- Ethane is a new architecture to manage and control private networks (enterprises, government agencies, universities, residences)
- A central network policy is directly enforced in the network
- Ethane is backwardly compatible with existing end-host computers

Principle 1: Manage network using policy over real names
"Nancy can access Payroll"
"Laptops can't accept incoming connections"
"VoIP phones mustn't move"

Principle 2: Policy should dictate the path packets follow
"CEO traffic should not pass through engineering"
"Guest flows must pass through http proxy"
"Laptop flows must pass through IDS"

Principle 3: The origin of packets should be known
All users and end-hosts authenticated and securely bound

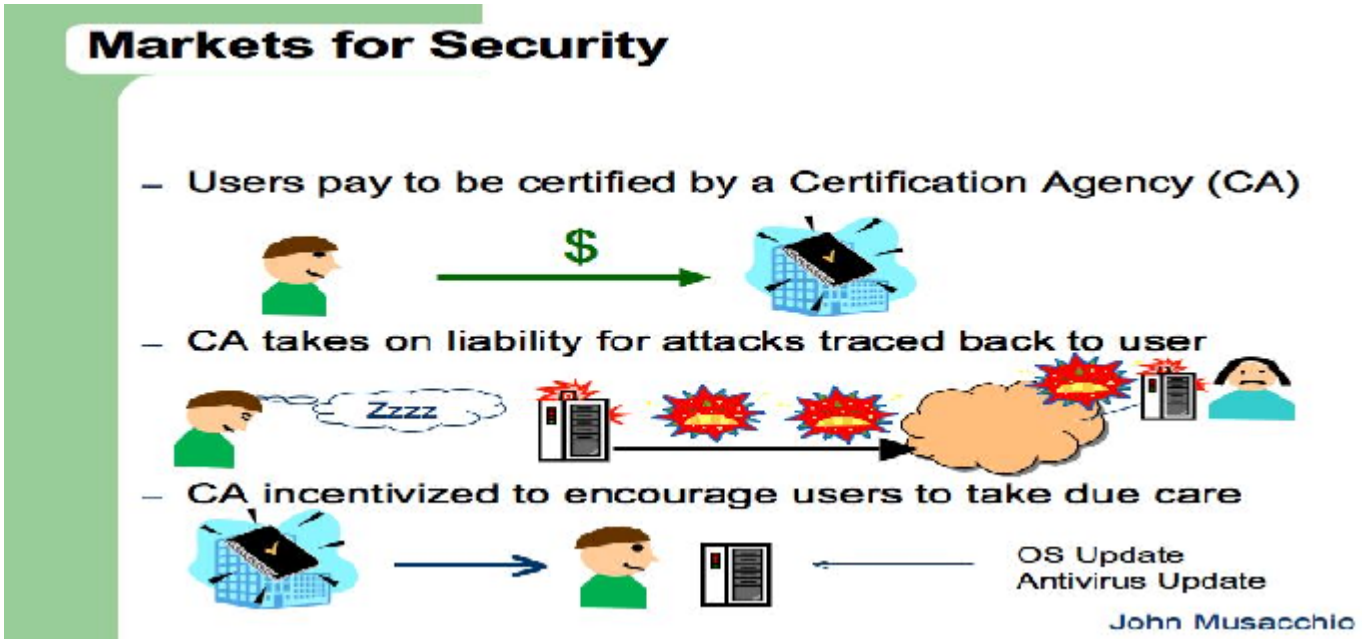
Principle 4: Network should log all connectivity
For diagnostics, compliance and auditing
"Who did Martin talk to last week?"



Stanford Testbed

- ✓ 17 Wireless and Gigabit Ethernet switches
- ✓ 300 hosts: VOIP phones, servers, workstations, printers
- ✓ Running 4 months
- ✓ 132 line policy file to re-create Stanford network policy

Market Enabling Architecture



- Incentives to go to CA if certified traffic receives protections under stress, while uncertified traffic does not
- Architectural requirements include improved traceability and mechanism for dropping uncertified traffic
- Internet is both an engineered system and an economic system
  - We must understand and architect both

Network Fabric for Personal, Social and Urban Sensor Applications

CENS
CENTER FOR EMBEDDED NETWORKED SENSING

Participatory Sensing

Automatically geocoded and uploaded participatory sensing data promises to make visible human concerns that were previously unobservable…or unacceptable

Urban sensing applications will leverage the millions of cell phone acoustic, image and bluetooth-connected sensors

Internet search, blog, and personal feeds, along with automated location tags, to achieve context, and in network processing for privacy and personal control

NOKIA Lifeblog

Home | What Is It? | Try | Buy | Blog
Overview | Product Info

Enabling Elements

- Over 2 x 10^9 users worldwide of cell phones.
- Automated geo-coding and pervasive connectivity
- Image and acoustic as data and metadata
- Local processing for data quality and triggering
- Spatial interface to data and authoring
- HCI for configurability of privacy/security policies is critical (Bellovin)

Going Forward

- Continuing phase 1
  - Stimulating curiosity and fostering creativity
- Preparing for phase 2
  - Building effective cross-area teams
  - Transitioning individual projects into architectures
- Anticipating phase 3
  - Pacing the research toward architectures in phased development and towards experimental research prototypes

nature International weekly journal of science

2020 – Future of Computing

Present and Future Results

- **Train new generation of systems researchers to build and understand large-scale systems**
- **Foster creative, innovative and transformational research**
- **Impact the Internet through clean-slate thinking & approaches**
  - New FIND idea results in deployment because of strong pull from market and from research communities
  - New creative insights for the Internet (e.g. accepted by Internet Engineering Task Force (IETF))
- **Create and deploy new services and applications**
- **Design and test alternate Internet architecture such that**
  - Alternate architecture(s) coexist with the current Internet
  - Virtualization becomes the norm with plurality of architectures
  - Unlikely that single architecture emerges and dominates

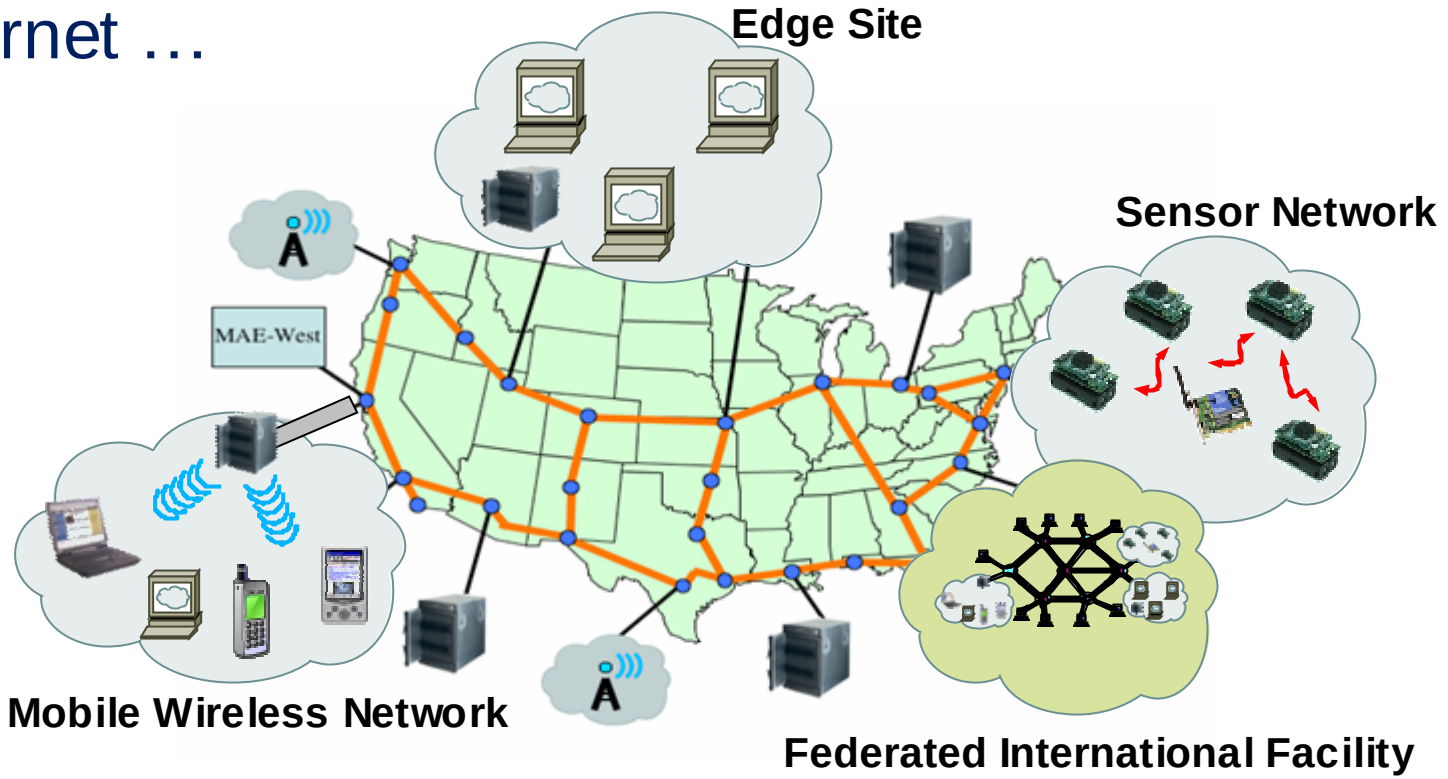
Not only theoretical studies but also the experimental testing of new ideas in settings sufficiently realistic, …

Experimental Infrastructure for Network Science

- While we can create theories about complex networks and simulate our models, only through experimentation can we validate our theories
  - As for any science, there is a need test out theories at scale.
    - A fully instrumented infrastructure in which to run our experiments, at scale.
      - Numbers and types of users, types of networks, numbers of nodes, geographical scope,

Experimental Infrastructure for NetSE

… a continental-scale internetworking "exploratorium" to support transformative research and experiments in a way that cannot be done in today's circumscribed Internet …



A Brief Background

- Informed by a 2005 community workshop recommendation, CISE has been investigation in community planning for a NetSE research infrastructure concept,
  - GENI: a Global Environment for Network Innovation
    - Grass-root effort for a small CISE community
    - Identified the need for a major facility
    - Development of a scientific motivation for such a facility
- GENI Science Council established in March 2007
- GENI Project Office was awarded to BBN Solutions LLC in May 2007

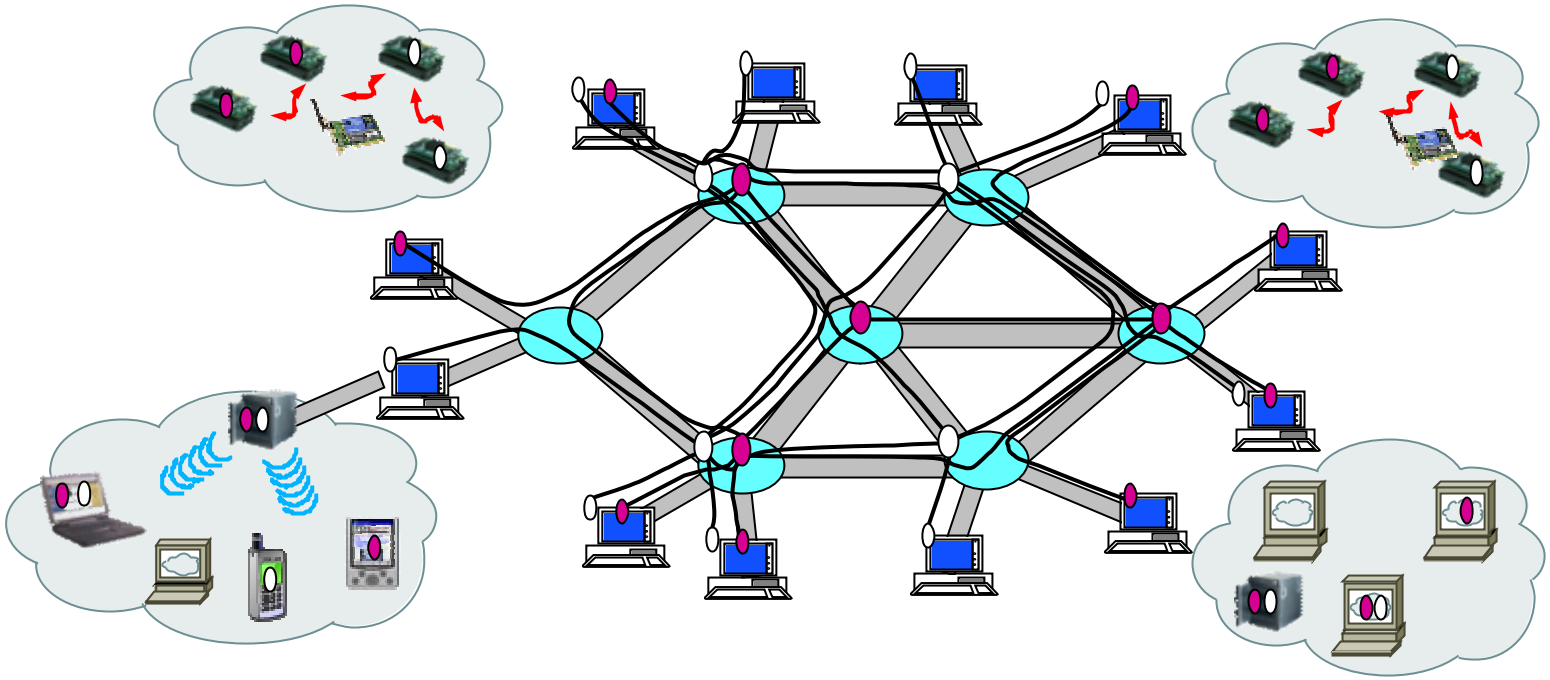
GENI Features

- Virtualization
- Programmability
- Federation
  - Three synergistic concepts that when combined provide the unique power of an experimental infrastructure at scale

Virtualization

Substrate → Virtual Substrate → Virtual Networks

From Bandwidth on Demand to Network on Demand!

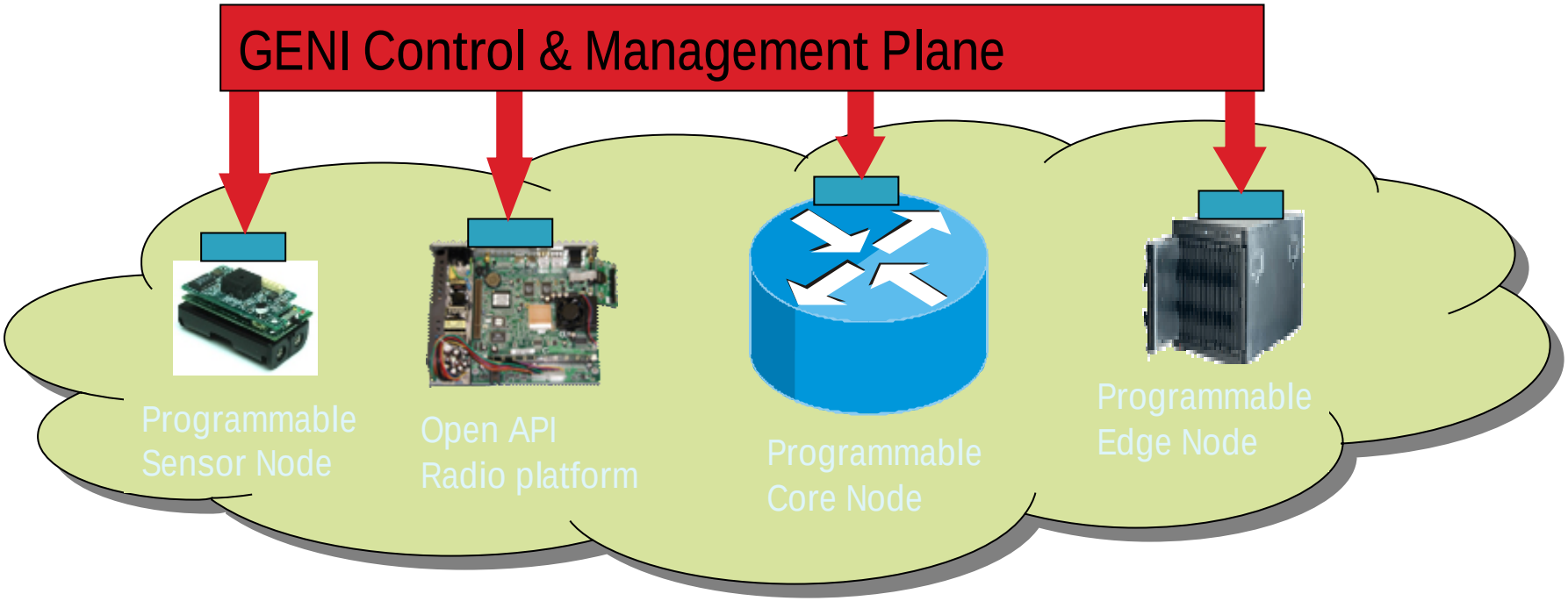


Edge Site

Share resources to support many simultaneous experiments

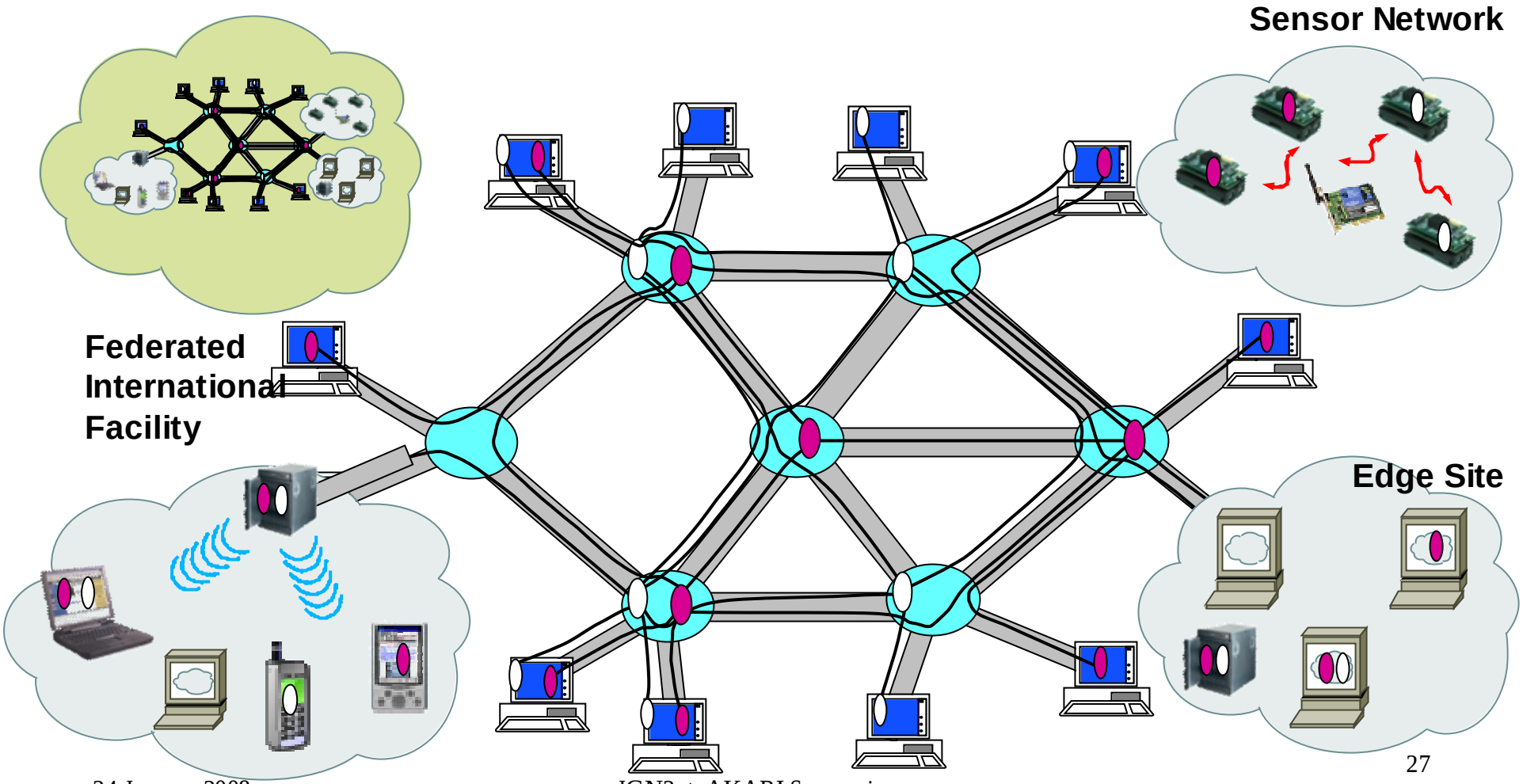
Programmability

All network elements programmable via open interfaces and/or downloadable user code



Federation

GENI grows by gluing together heterogeneous facilities over time.



Global Collaboration

"Global collaboration – among scientists, engineers, educators, industry and governments – can speed the transformation of new knowledge into new products, processes and services, and in their wake produce new jobs, create wealth, and improve the standard of living and quality of life worldwide. "

Arden L. Bement, Jr.
NSF Director
Cancun, Mexico
August 2005

Overarching Guiding Principles

- Research in Computer Science (CS) and Computer Engineering (CE) has had and will continue to have significant societal impact in the US and throughout the world
- CS/CE research is global in reach and, therefore, international cooperation, communication and collaboration are critical to the success of US CS/CE Research and Education (R&E)

CISE Overarching Guiding Principles

- CISE has a responsibility to proactively seek out and foster international relationships and cooperative activities that support its mission and maximize the strategic value of its international investments
- CISE has a national leadership role in advising the US government on national and international policies related to CS/CE R&E
- CISE has a national leadership role in representing US interests, as they relate to CS/CE R&E, to counterpart organizations within foreign agencies.
- CISE has a national leadership role in representing the US CS/CE disciplines and the CS/CE R&E academic community in international scientific and policy forums
- CISE has a national leadership role in working with counterpart organizations within foreign agencies to identify, encourage and support bi-lateral and multi-lateral CS/CE R&E collaborations

Conclusions

- The future of the Internet is too important to be left to chance or random developments
  - Network Science – Best way to predict the future is to invent it!
  - True experimentation is needed.
    - The GENI project intends to provide the basic infrastructure to enable, understanding, implementation and deployment of socio-technical networked systems of the future

More Information

- Visit the CISE Web site at:
- http://www.nsf.gov/dir/index.jsp?org=CISE
- Visit the CRA CCC web site at:
- http://www.cra.org/ccc

Thank you!