The Evolution of Next-Generation Internet Services and Applications

Kevin Almeroth (almeroth@cs.ucsb.edu)

University of California—Santa Barbara

http://www.cs.ucsb.edu/~almeroth/talks/CRA-SMF.ppt

CRA Digital Government Fellow—GTC West

May 16, 2001

State of the Network

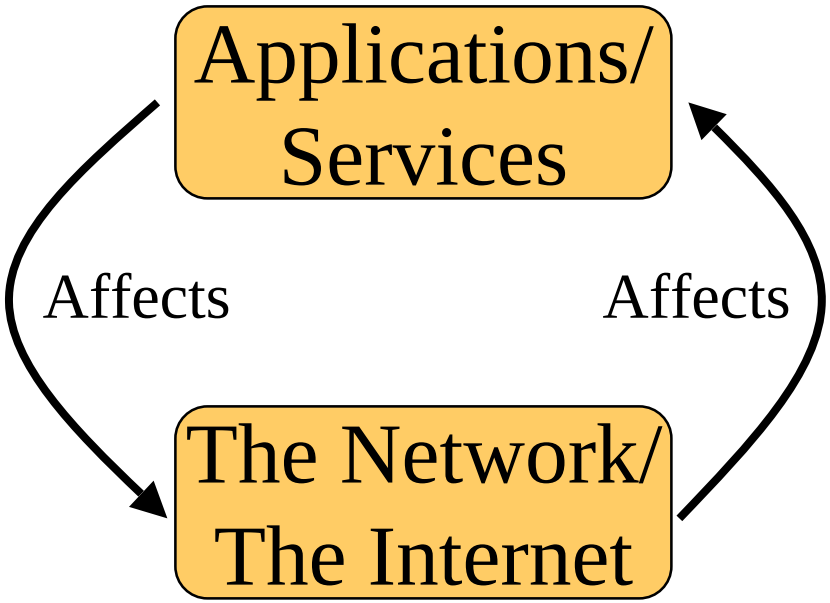
- The Internet mantra:

  "Intelligence only at the edges"

  "Best effort delivery (of IP packets)"

- But the needs have changed…

Future of the Network: "In-the-Network" Services



The Questions

- Background
  - What are some examples of these services?
  - Why are they so difficult to deploy?
- Focus on one of these services (focus of my research)
  - What does it do?
  - What are the technical issues?
  - What are the non-technical issues?
- The role of Internet2
  - What is Internet2 supposed to do?
  - What have they been able to do?

Examples of “In-the-Network” Services

- Trying to add “intelligence” into the network:
  - Next Generation IP (IPv6)
  - Quality-of-Service (QoS)
  - One-to-many communication (multicast)
  - “Active” networks

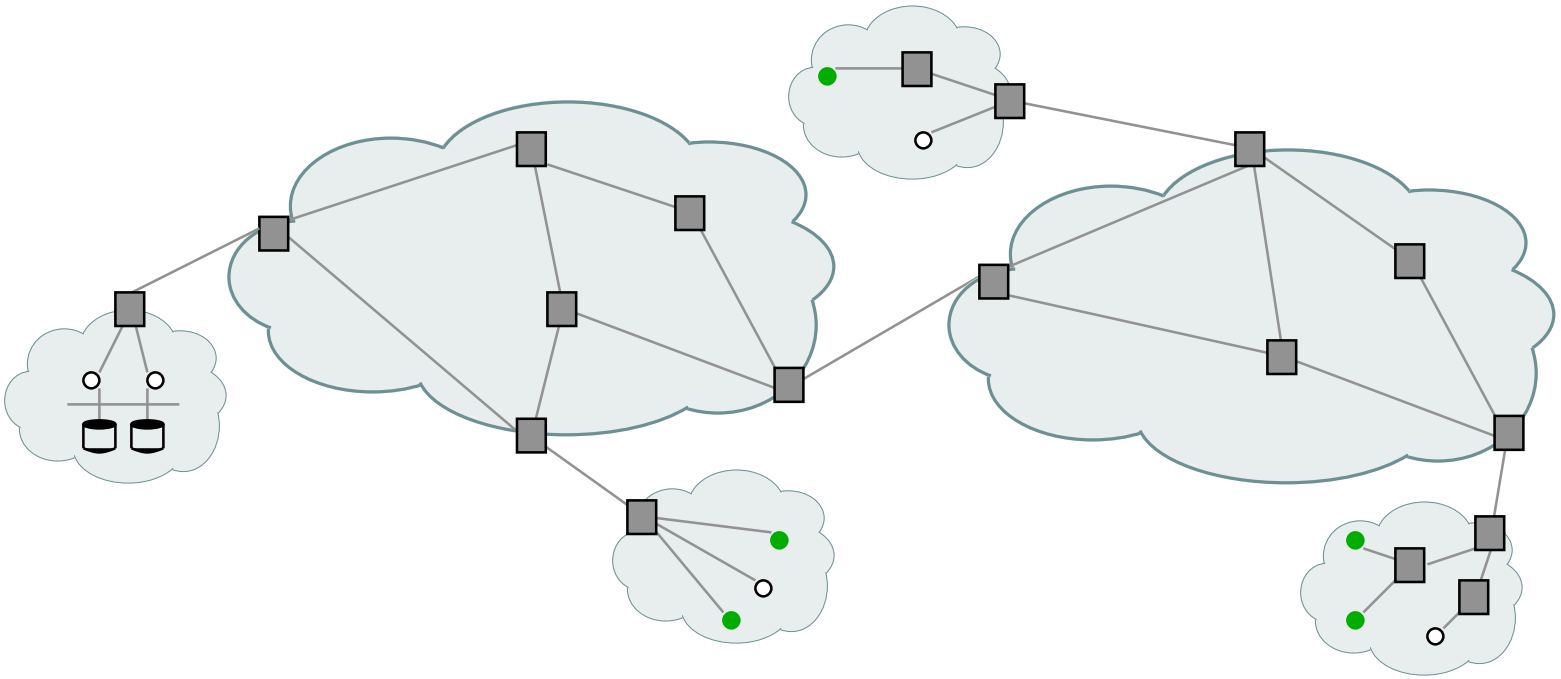
Status of "In-the-Network" Services

Service	Result
IPv6	• For all of its benefits, very little traction • Issue: deployment-for-all vs. need-for-few
QoS	• Lots of promise, but stalled each time • Hard to solve "uniform definition" problem
Multicast	• Working hard to deploy • A few technical issues & some non-technical issues
Active	• Still a research issue—very interesting! • Still *lots* of technical issues

Adopted Replacement Technology

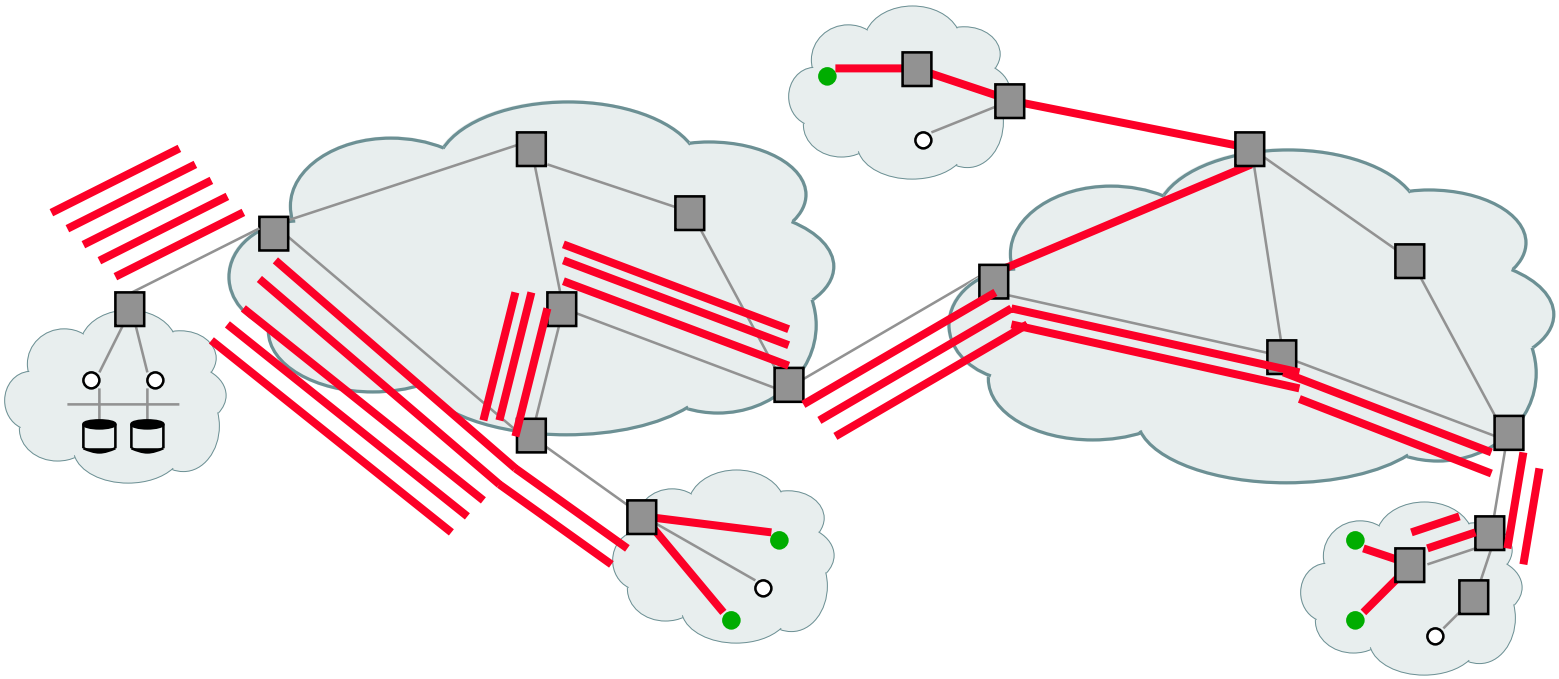
Service	The Adopted Solution
IPv6	Network Address Translation (NAT)
QoS	Over-Provisioning
Multicast	Content Delivery Networks (CDNs)
Active	Side-by-side Processing

My Favorite “In-the-Network” Service



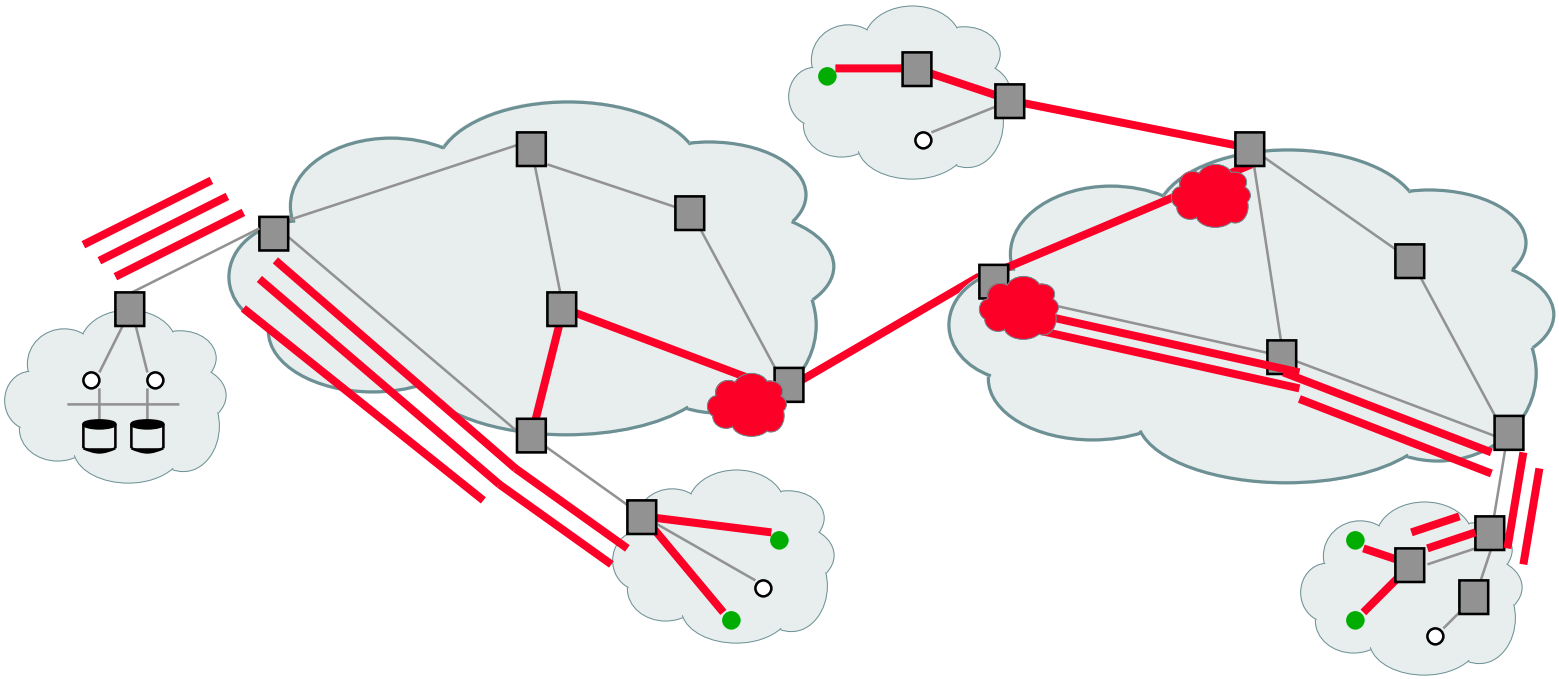
- Multicast communication: one-to-many packet delivery

Unicast Delivery



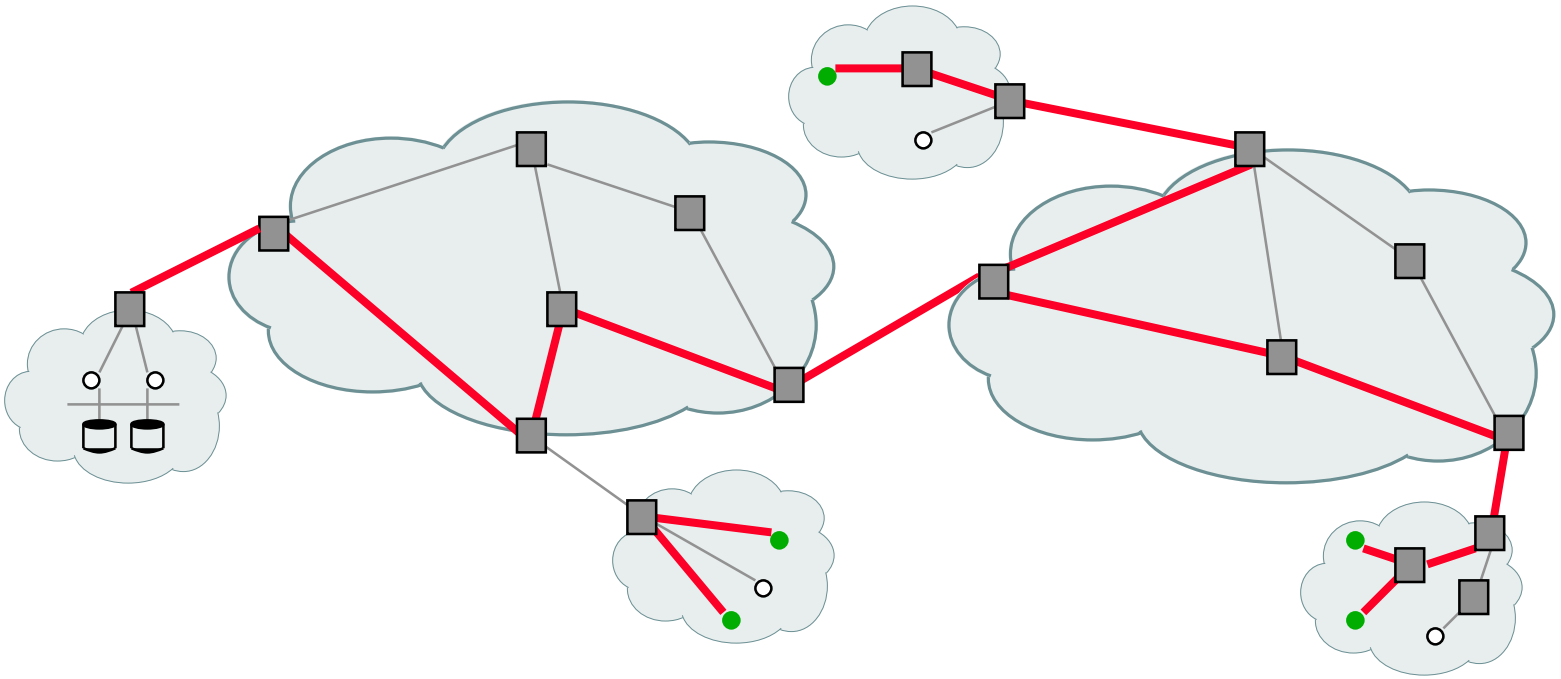
- Unicast communication: one-to-one packet delivery
  - Need to replicate each packet at the source

Content Delivery Networks



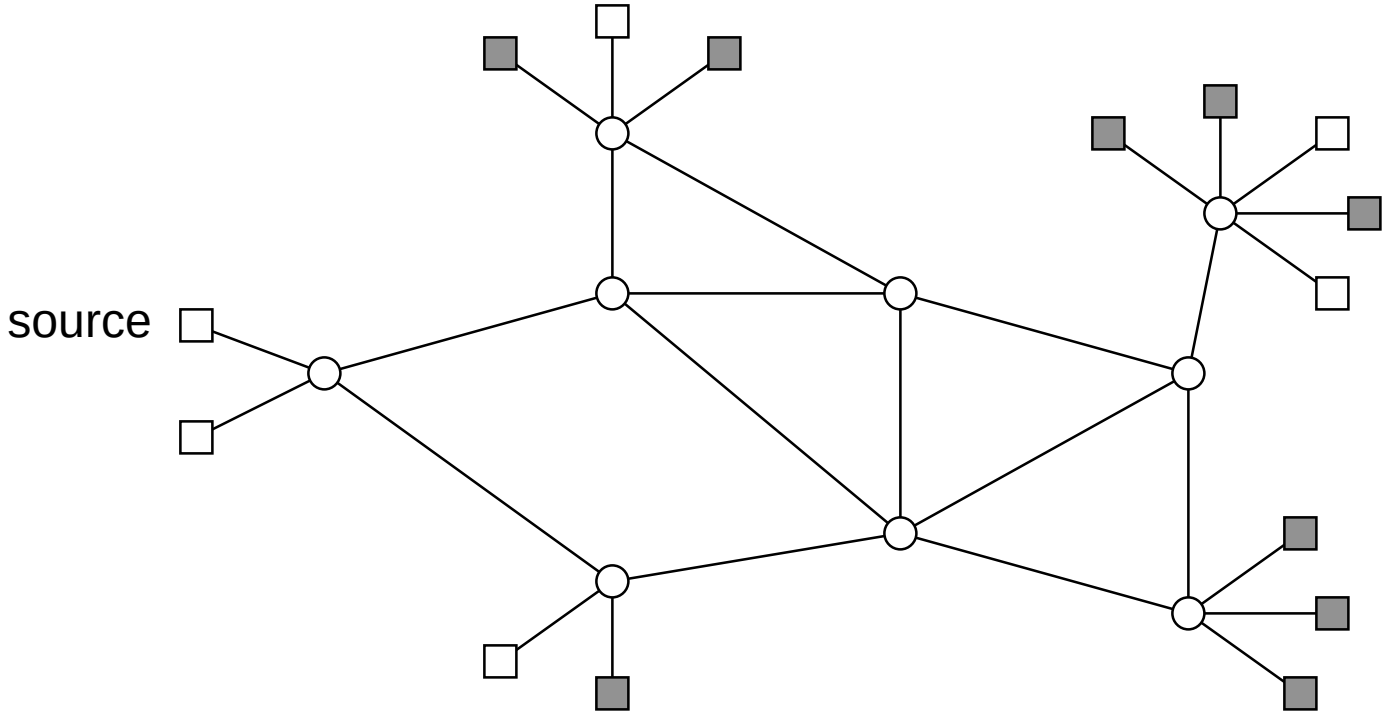
- CDNs can help, but only if they are in the right places

Multicast Communication



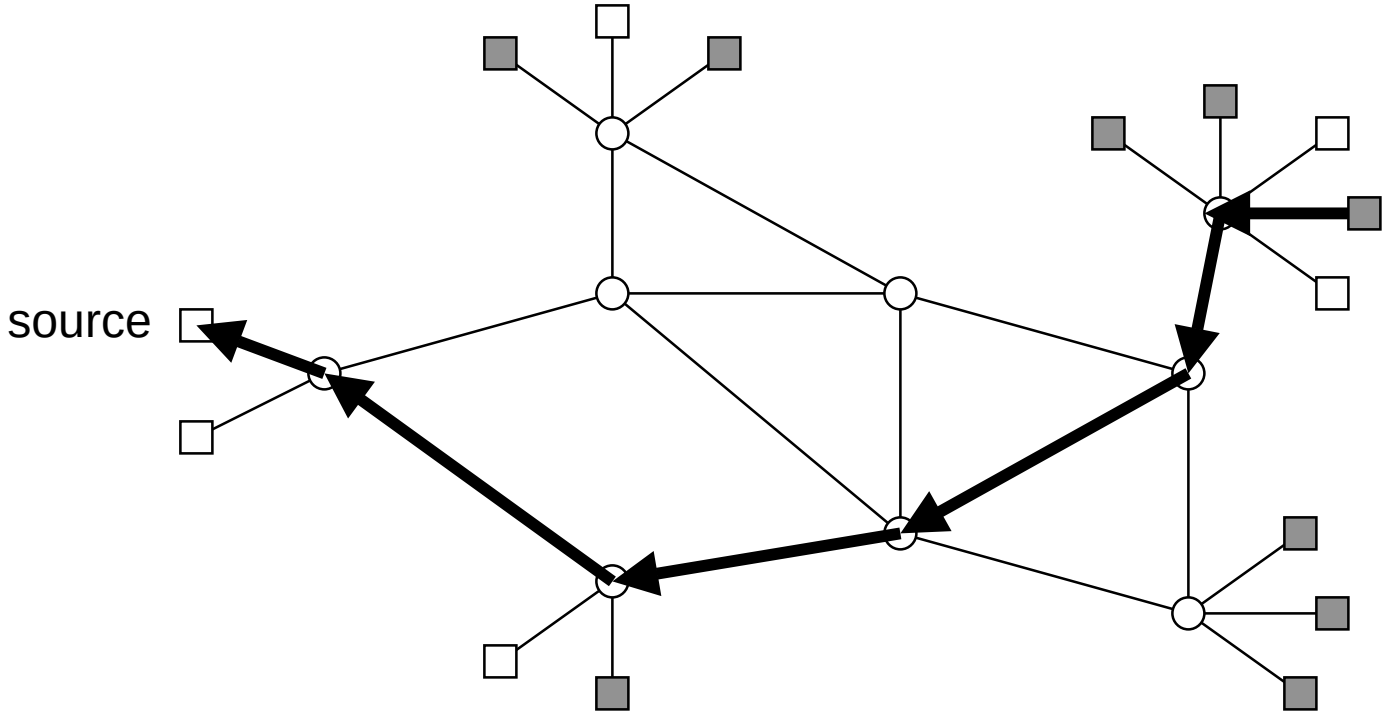
- Where CDNs are static branching points in a few places…
- Multicast has dynamic branching points everywhere

Building the Multicast “Tree”



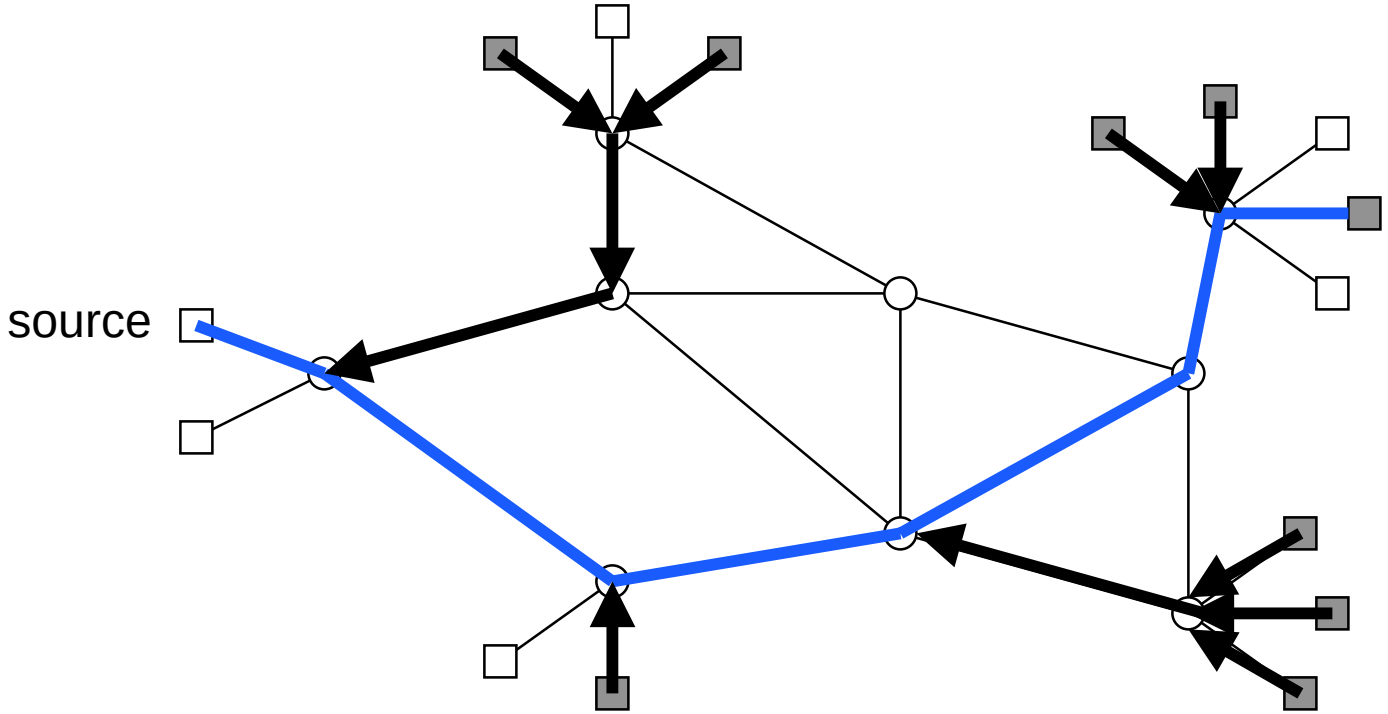
- Packets are distributed via a “tree”
  - No loops… no cycles
  - No more than one copy of each packet over a link

Tree is Built via “Reverse Paths”



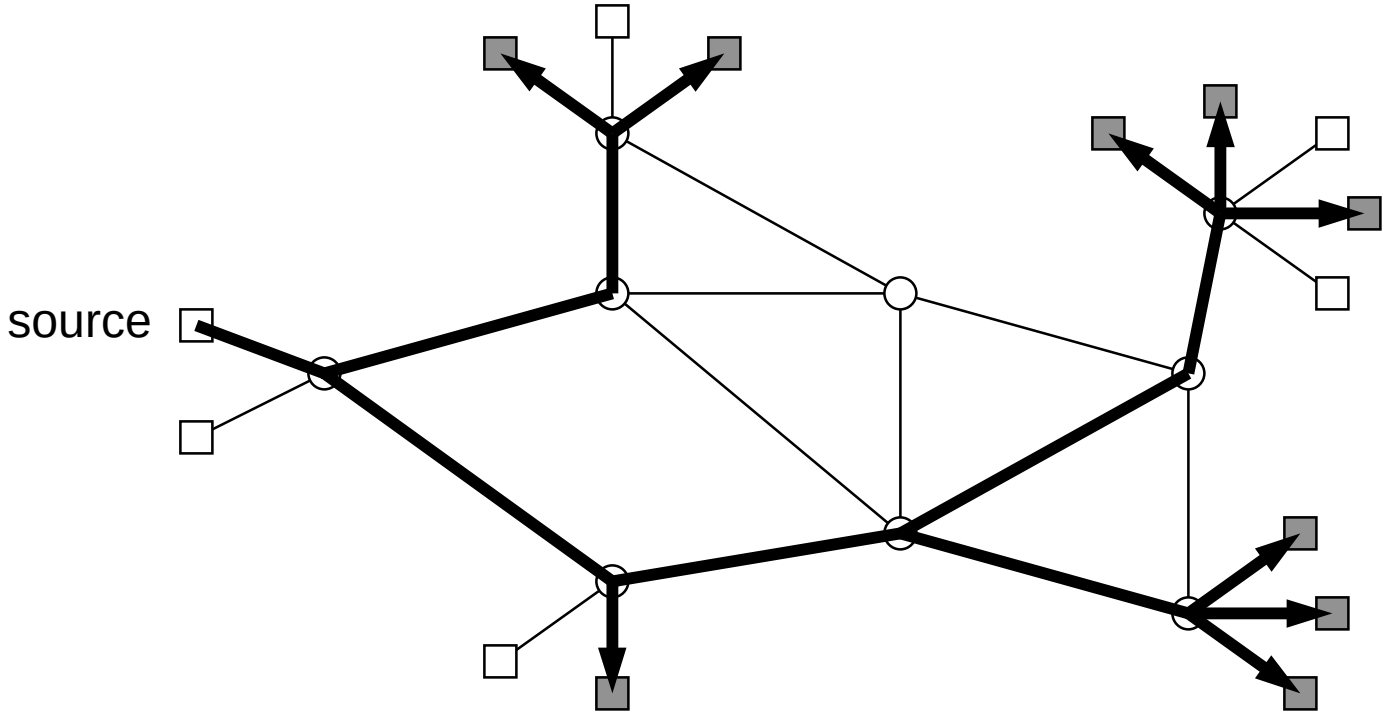
- Start from the receiver and build a path to the source
  - Routing is from the receiver to the source (reverse path)
  - Forwarding is in the source to receiver direction

Adding Receivers to the Tree



- Other group members build a reverse path to an existing point on the tree

Multicast Tree Management



- Routing (path determination) [but in the reverse direction]
- Packet forwarding and replication
- Handling dynamic membership—path pruning/grafting

What Were/Are the Technical Issues?

- How to build trees efficiently
  - Minimize complexity
  - Minimize router state and minimize message passing/processing
  - How to find the sources?
- How to connect domains together
- How to provide TCP-style services
  - Reliability
  - Congestion control

What Are the Non-Technical Issues?

- Deployment requirements
  - Hardware/software updates
  - Pricing concerns
- Monitoring/Management challenges
  - No one really knows who the sources are
  - Packets go to multiple receivers
- Security issues
  - One-to-many is powerful
  - UDP is hard to predict and control

Resync on the Questions

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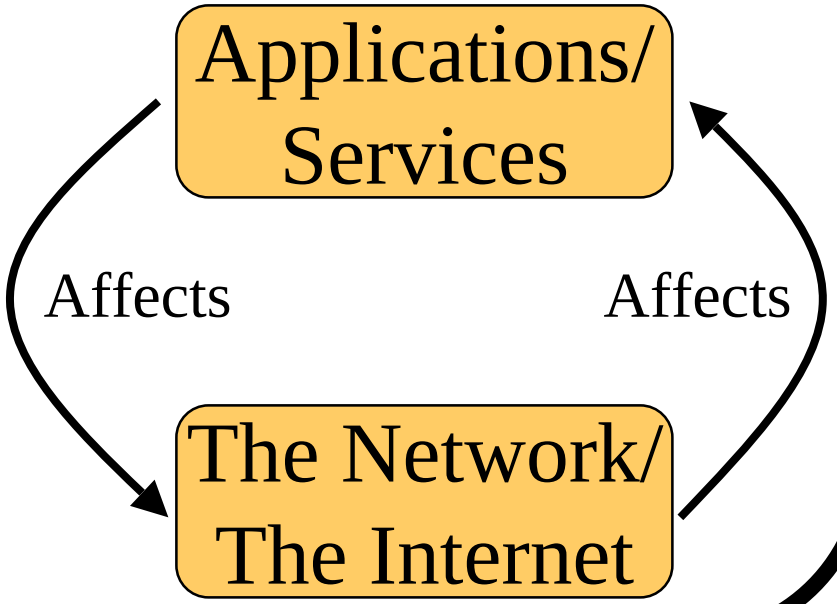
My Research

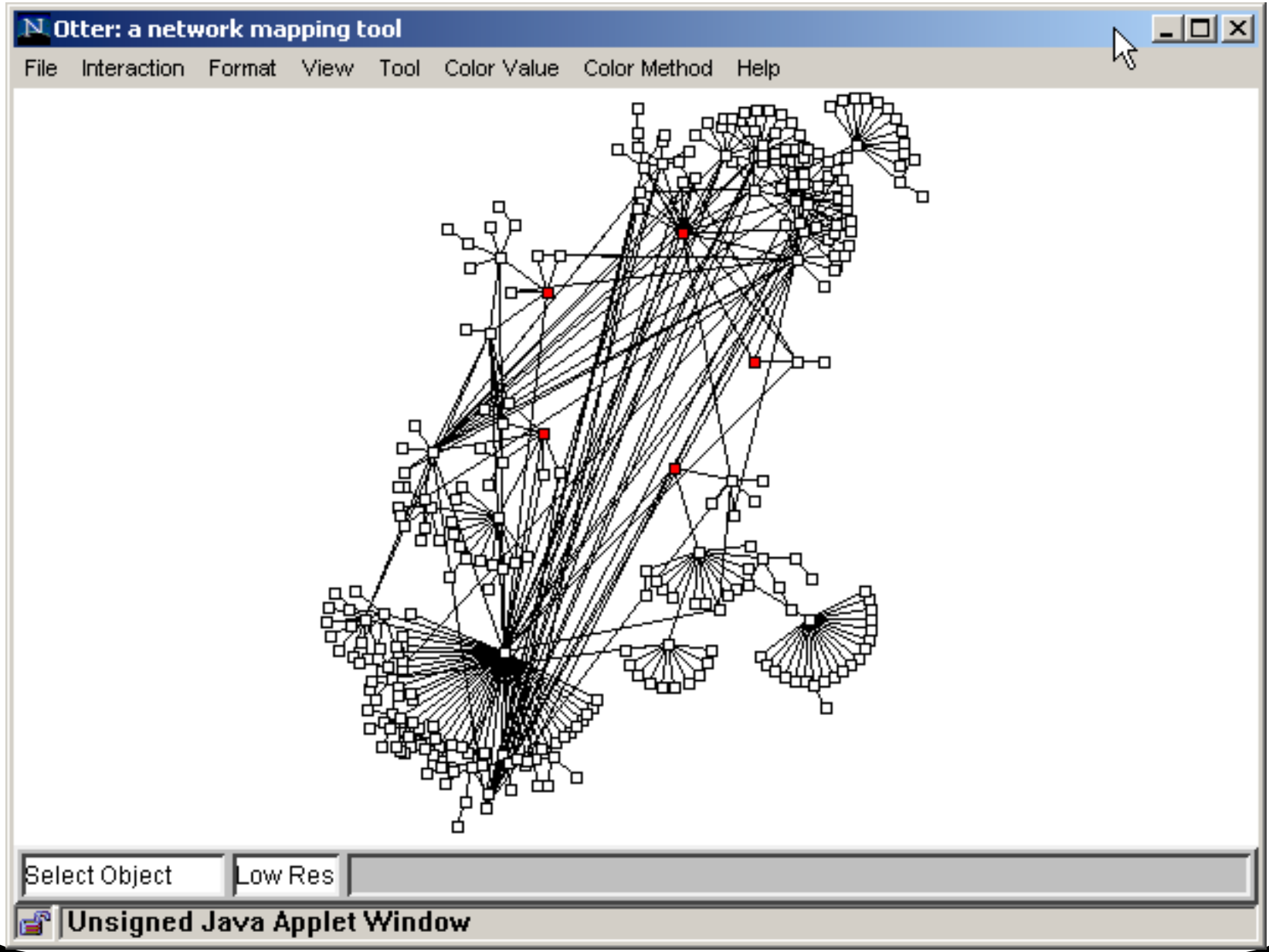
- New applications
  - (near) video-on-demand to jukebox-style delivery
  - other push-based content (loading caches & web content)
  - auctions, games, distance learning, etc
- Monitoring research
  - Monitor tree “health”
  - Visualize the topology
  - Track deployment
- Deployment efforts
  - Work with IETF and Internet2
  - Solve chicken-and-egg problems



A Word About Deployment

- some commercial ISPs…
  - but typically service is not announced and is not supported
  - issues are beginning to be only political/financial (layers 8&9)
- still, there is multicast out there…
  - and many of the most successful apps are enterprise-based
- to track multicast deployment and stats…
  - see http://imj.ucsb.edu/mantra/
  - see http://dast.nlanr.net/projects/beacon/

Latest Multicast Topology



Hardware/Software Support for Multicast

- **network:** lots of vendors support multicast routing: Cisco & Juniper then Nortel, Foundry, Lucent, others, etc.
- **OSs/kernel:** **most** kernels support group mgt functions
- **applications:**
  - MBone tools (http://www-mice.cs.ucl.ac.uk/multimedia/software/)
  - IPTV, Real, MediaPlayer, etc.
  - Lots of others are imminent

Multicast-Based Content

- **content:**
  - UofO (http://videolab.uoregon.edu/)
  - GRID (http://www-fp.mcs.anl.gov/fl/accessgrid/)
  - ICAIR CSPAN (http://cspan.icair.org/)
  - On-the-I (http://www.on-the-i.com/)
  - Yahoo (http://www.broadcast.com/broadband/)
  - NASA (http://www.nasa.gov/ntv/ntvweb.html)
  - UCSB (http://imj.gatech.edu/)
  - All the commodity traffic (sdr)

A Word About Internet2

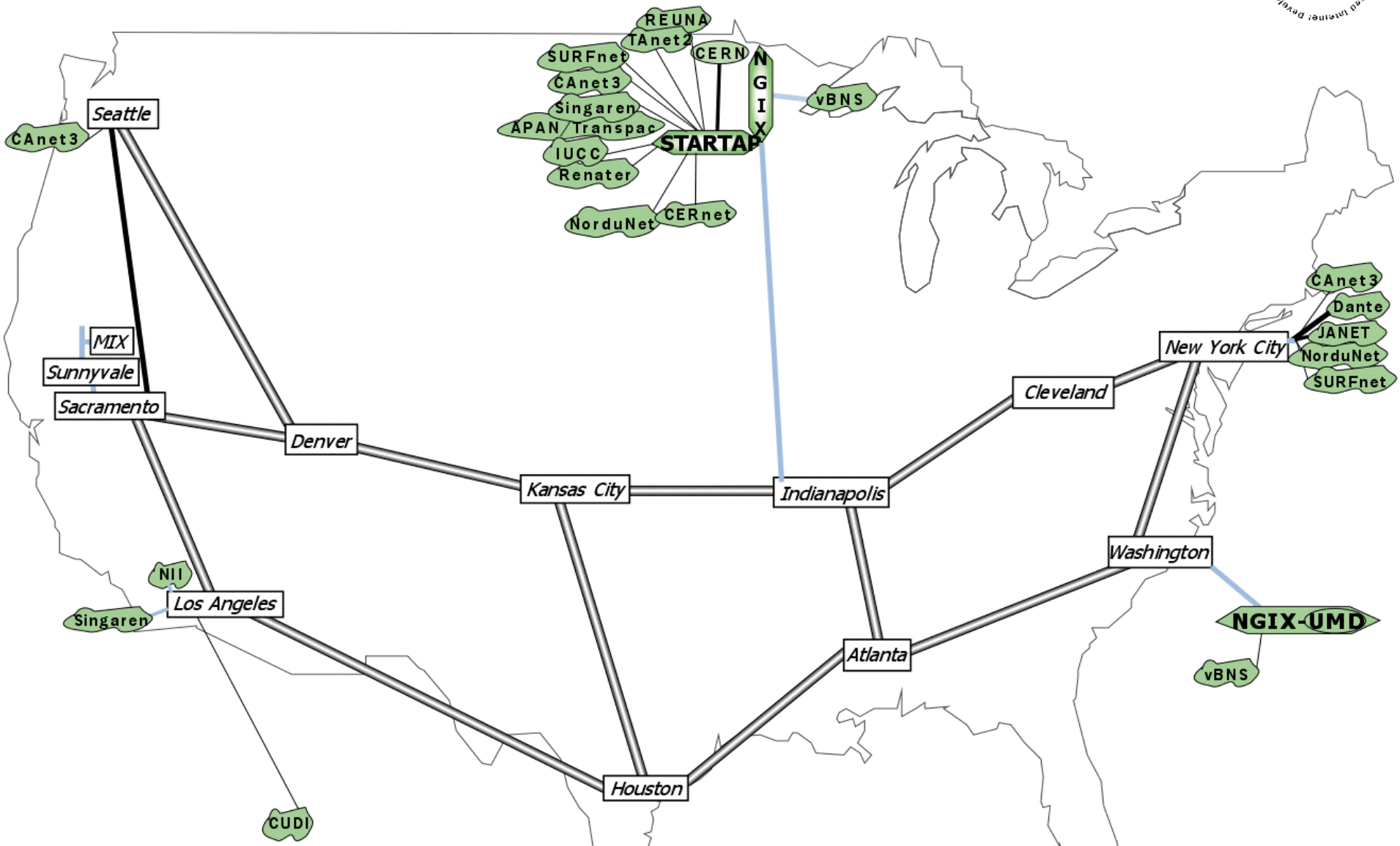
Internet2, led by over 180 universities working in partnership with industry and government, is developing and deploying advanced network applications and technologies.

- Internet2 Engineering Working Groups
  - IPv6
  - Measurement
  - Multicast
  - Quality of Service
  - Routing
  - Security
  - Topology

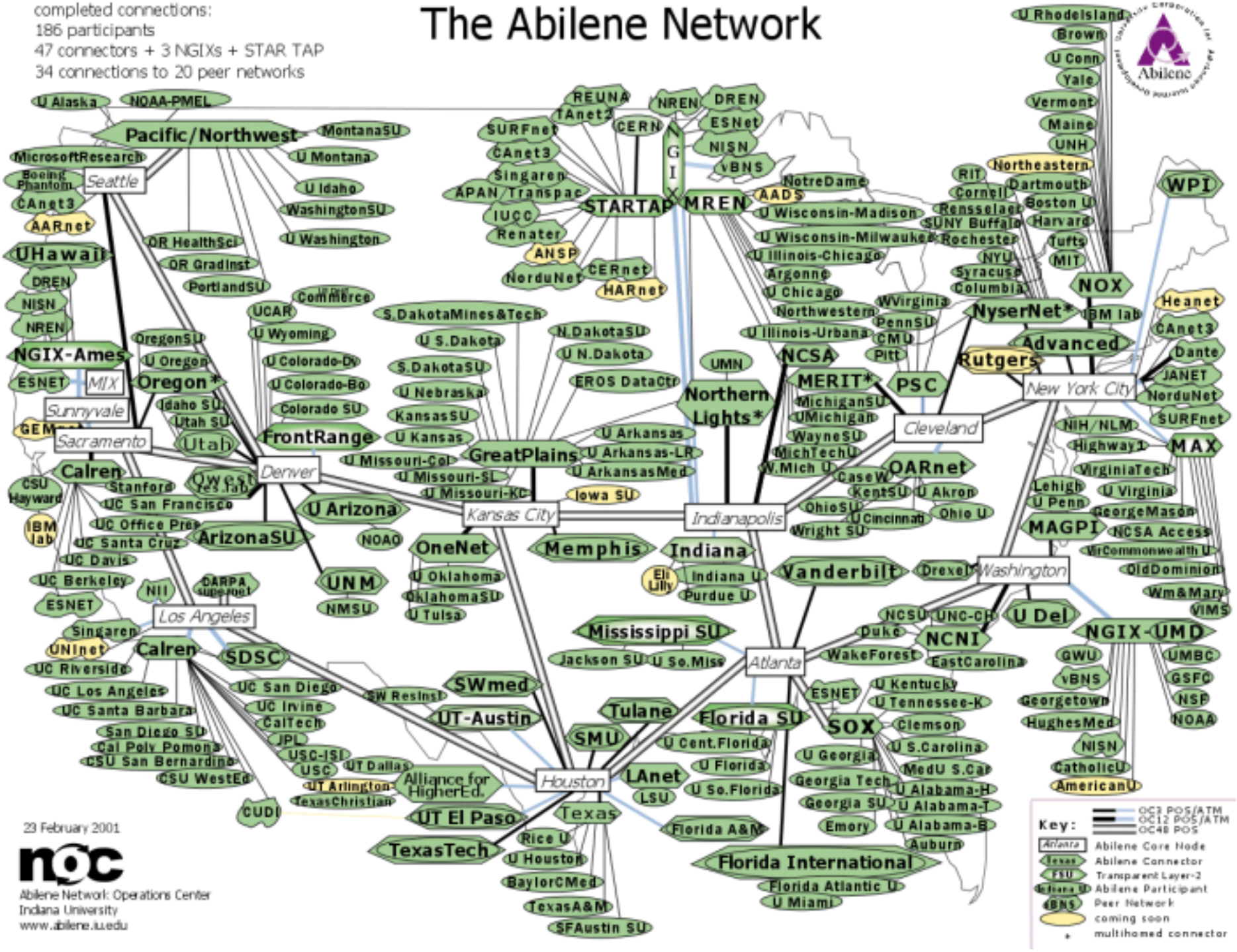
The Internet2 (Abilene) Topology

The Abilene Network

All International Peers



Abilene Network Operations Center
Indiana University
www.abilene.iu.edu


The Abilene Network
completed connections:
186 participants
47 connectors + 3 NGIXs + STAR TAP
34 connections to 20 peer networks
Abilene
U Alaska
NOAA-PMEL
Pacific/Northwest
MontanaSU
U Montana
U Idaho
WashingtonSU
U Washington
MicrosoftResearch
Boeing Phantom
Seattle
CAnet3
AARnet
UHawaii
DREN
NISN
NREN
OR HealthSci
OR GradInst
PortlandSU
NGIX-Ames
ESNET
MIX
Sunnyvale
GEMnet
Sacramento
OregonSU
U Oregon
Oregon*
Idaho SU
Utah SU
Utah
Calren
CSU Hayward
Stanford
UC San Francisco
IBM lab
UC Office Pres
UC Santa Cruz
UC Davis
UC Berkeley
ESNET
NII
Los Angeles
Singaren
UNInet
UC Riverside
UC Los Angeles
UC Santa Barbara
San Diego SU
Cal Poly Pomona
CSU San Bernardino
CSU WestEd
CUDI
Calren
SDSC
UC San Diego
UC Irvine
CalTech
JPL
USC-ISI
USC
UT Dallas
UT Arlington
TexasChristian
SW Reslnst
Qwest
Yes Lab
Denver
FrontRange
U Colorado-Dv
U Colorado-Bo
Colorado SU
U Arizona
ArizonaSU
NOAO
UNM
NMSU
DARPA supernet
Commerce
UCAR
U Wyoming
S.DakotaMines&Tech
U S.Dakota
S.DakotaSU
U Nebraska
KansasSU
U Kansas
U Missouri-Col
U Missouri-SL
U Missouri-KC
Kansas City
GreatPlains
OneNet
U Oklahoma
OklahomaSU
U Tulsa
N.DakotaSU
U N.Dakota
EROS DataCtr
U Arkansas
U Arkansas-LR
U ArkansasMed
Iowa SU
Memphis
SWmed
UT-Austin
Tulane
SMU
Houston
Alliance for HigherEd.
UT El Paso
TexasTech
Texas
Rice U
U Houston
BaylorCMed
TexasA&M
SFAustin SU
REUNA
TAnet2
CERN
SURFnet
CAnet3
Singaren
APAN/Transpac
IUCC
Renater
ANSP
NorduNet
CERnet
HARnet
NREN
DREN
ESNet
NISN
vBNS
GIX
STARTAP
MREN
UMN
Northern Lights*
NCSA
MERIT*
MichiganSU
UMichigan
WayneSU
MichTechU
W.Mich U
PSC
Cleveland
OARnet
CaseW
KentSU
U Akron
OhioSU
U Cincinnati
Ohio U
Wright SU
Indianapolis
Indiana
Indiana U
Purdue U
Eli Lilly
Vanderbilt
LANet
LSU
Florida SU
U Cent.Florida
U Florida
U So.Florida
Florida A&M
Florida International
Florida Atlantic U
U Miami
Mississippi SU
Jackson SU
U So.Miss
Atlanta
NCSU
UNC-CH
Duke
NCNI
WakeForest
EastCarolina
ESNET
SOX
U Kentucky
U Tennessee-K
Clemson
U S.Carolina
U Georgia
Georgia Tech
Georgia SU
Emory
MedU S.Car
U Alabama-H
U Alabama-T
U Alabama-B
Auburn
U Rhodelsland
Brown
U Conn
Yale
Vermont
Maine
UNH
Northeastern
Dartmouth
Boston U
Harvard
Tufts
MIT
RIT
Cornell
Rensselaer
SUNY Buffalo
Rochester
NYU
Syracuse
Columbia
NOX
IBM lab
WPI
Heanet
CAnet3
Dante
JANET
NorduNet
SURFnet
NyserNet*
WVirginia
PennSU
CMU
Pitt
U Illinois-Urbana
Northwestern
U Chicago
Argonne
U Illinois-Chicago
U Wisconsin-Milwaukee
U Wisconsin-Madison
AADS
NotreDame
Advanced
Rutgers
New York City
NIH/NLM
Highway1
MAX
VirginiaTech
U Virginia
GeorgeMason
NCSA Access
VrCommonwealth U
OldDominion
Wm&Mary
VIMS
Lehigh
U Penn
MAGPI
Drexel
Washington
U Del
NGIX-UMD
UMBC
GSFC
NSF
NOAA
GWU
vBNS
Georgetown
HughesMed
NISN
CatholicU
AmericanU
23 February 2001
noc
Abilene Network Operations Center
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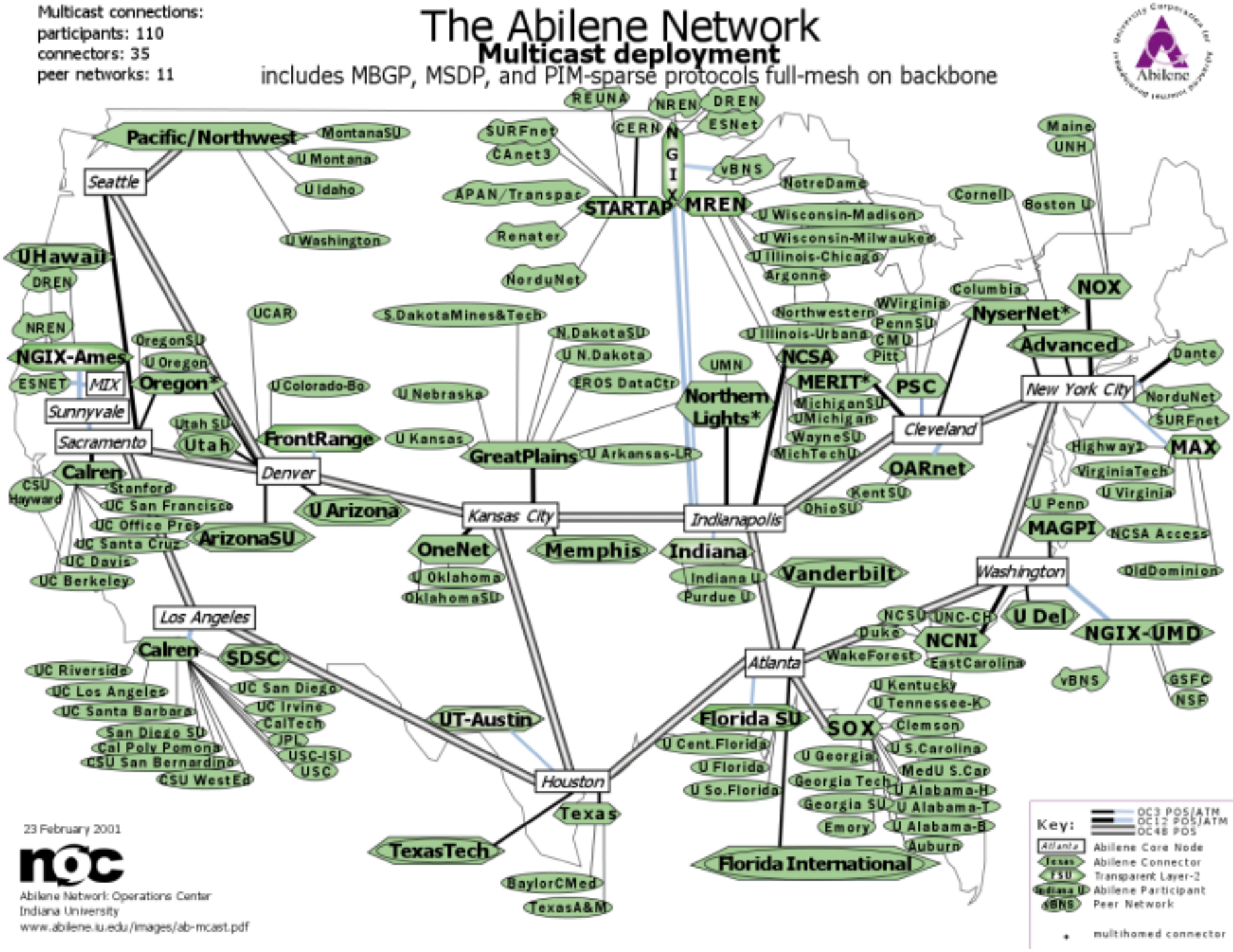
Key:
OC3 POS/ATM
OC12 POS/ATM
OC48 POS
Atlanta
Abilene Core Node
Texas
Abilene Connector
FSU
Transparent Layer-2
Abilene U
Abilene Participant
vBNS
Peer Network
coming soon
multihomed connector


Multicast connections:
participants: 110
connectors: 35
peer networks: 11
The Abilene Network
Multicast deployment
includes MBGP, MSDP, and PIM-sparse protocols full-mesh on backbone
Abilene
REUNA
NREN
DREN
ESNet
CERN
NGIX
SURFnet
CAnet3
vBNS
APAN/Transpac
STARTAP
MREN
NotreDame
Renater
U Wisconsin-Madison
U Wisconsin-Milwaukee
U Illinois-Chicago
Argonne
NorduNet
Pacific/Northwest
MontanaSU
U Montana
U Idaho
U Washington
Seattle
UHawaii
DREN
NREN
NGIX-Ames
ESNET
MIX
Sunnyvale
OregonSU
U Oregon
Oregon*
UCAR
U Colorado-Bo
Utah SU
Utah
Sacramento
FrontRange
Denver
Calren
CSU Hayward
Stanford
UC San Francisco
UC Office Pres
UC Santa Cruz
UC Davis
UC Berkeley
U Arizona
ArizonaSU
Los Angeles
Calren
SDSC
UC Riverside
UC Los Angeles
UC Santa Barbara
San Diego SU
Cal Poly Pomona
CSU San Bernardino
CSU WestEd
UC San Diego
UC Irvine
CalTech
JPL
USC-ISI
USC
UT-Austin
Houston
Texas
TexasTech
BaylorCMed
TexasA&M
S.DakotaMines&Tech
N.DakotaSU
U N.Dakota
EROS DataCtr
U Nebraska
U Kansas
GreatPlains
U Arkansas-LR
Kansas City
OneNet
U Oklahoma
OklahomaSU
Memphis
UMN
Northern Lights*
U Illinois-Urbana
NCSA
MERIT*
MichiganSU
UMichigan
WayneSU
MichTechU
PSC
Pitt
CMU
Northwestern
WVirginia
PennSU
Cleveland
OARnet
KentSU
OhioSU
Indianapolis
Indiana
Indiana U
Purdue U
Vanderbilt
Atlanta
Florida SU
U Cent.Florida
U Florida
U So.Florida
Florida International
SOX
U Kentucky
U Tennessee-K
Clemson
U S.Carolina
U Georgia
Georgia Tech
Georgia SU
Emory
MedU S.Car
U Alabama-H
U Alabama-T
U Alabama-B
Auburn
NCSU
UNC-CH
Duke
WakeForest
NCNI
EastCarolina
Washington
U Del
NGIX-UMD
vBNS
GSFC
NSF
Maine
UNH
Cornell
Boston U
Columbia
NyserNet*
NOX
Advanced
Dante
New York City
NorduNet
SURFnet
Highway1
MAX
VirginiaTech
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U Penn
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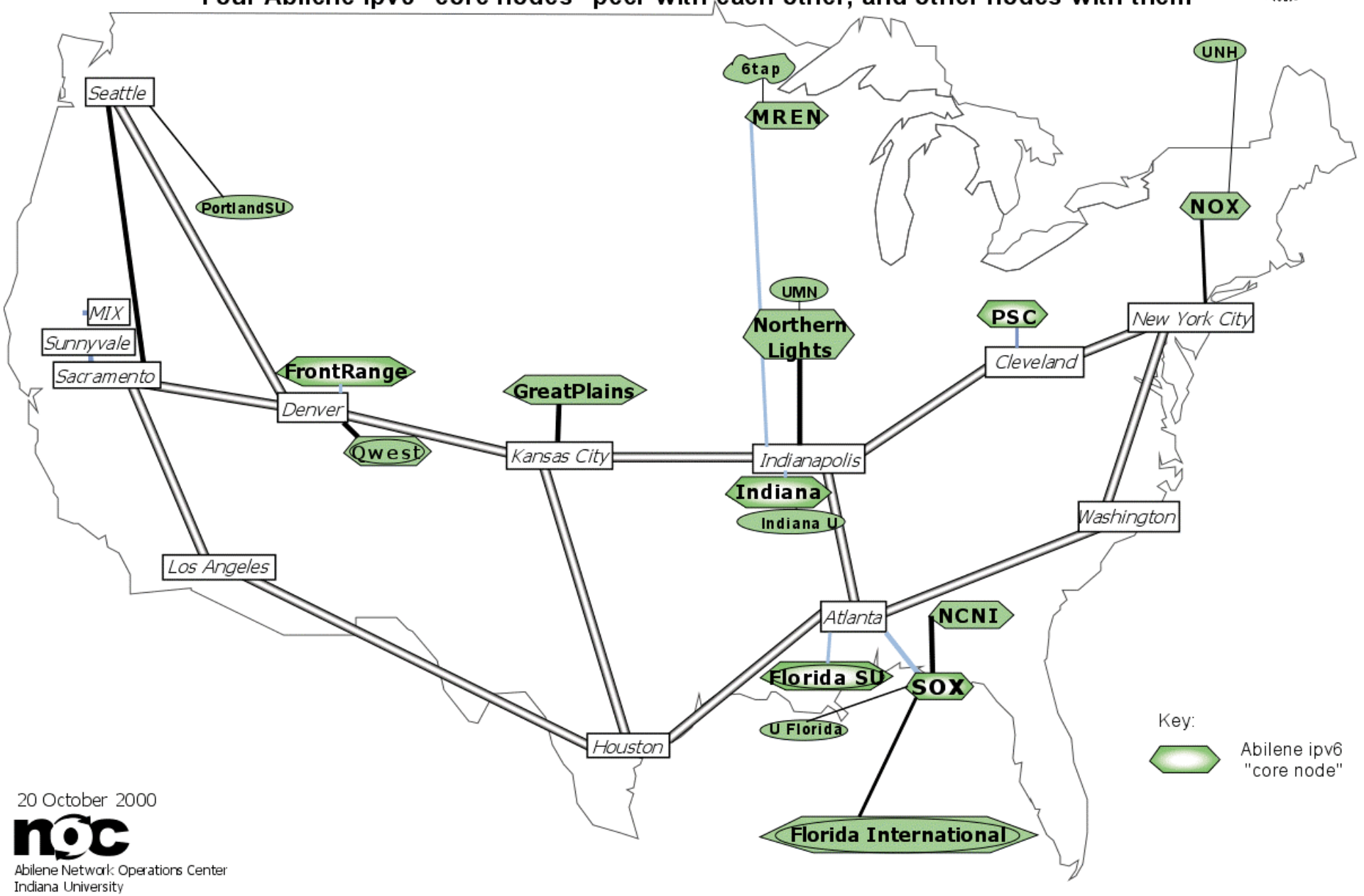
Abilene Core Node
Texas
Abilene Connector
FSU
Transparent Layer-2
Indiana U
Abilene Participant
vBNS
Peer Network
*
multihomed connector

The Abilene Network

IPv6 deployment

Four Abilene ipv6 "core nodes" peer with each other, and other nodes with them



20 October 2000

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Questions… Answered(?)

http://www.cs.ucsb.edu/~almeroth/talks/CRA-SMF.ppt

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