Advanced Computer Networks

Network Characterization

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Summer 2007

Network characterization

- Topology
  - graph model: G(N,E)
  - node
    - routers, AS domains
  - edge
    - communication links, AS connectivities
- Traffic
  - packet level
  - session level
  - application level

Network traffic observations

- TCP accounts for most of the packet traffic on the Internet
- Traffic flows are bidirectional, but often asymmetric
- Most TCP conversations are short-lived
- The packet arrival process is not Poisson
- The session arrival process is Poisson

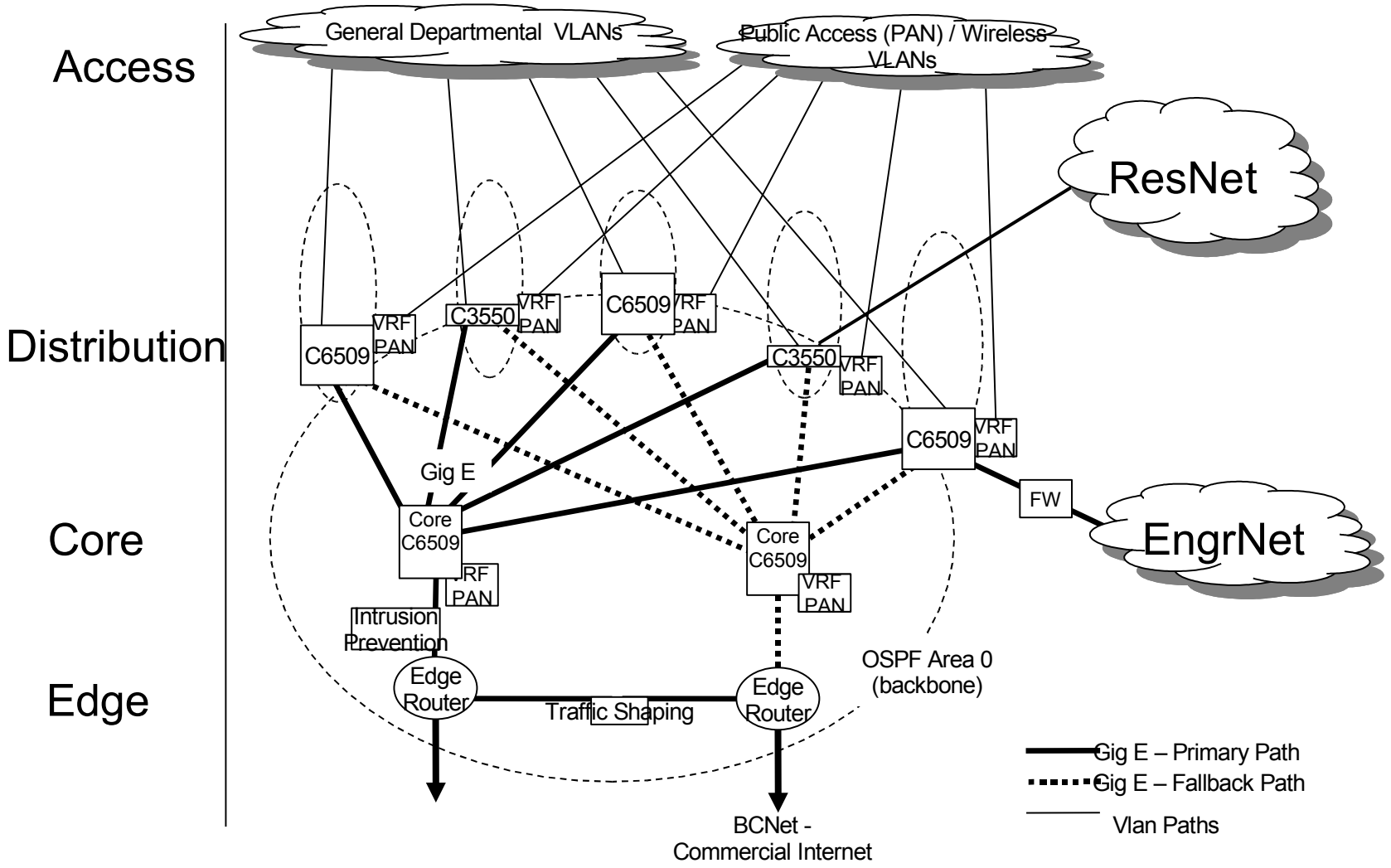
Q: why?

http://pages.cpsc.ucalgary.ca/~carey/papers/2001/measurements.pdf

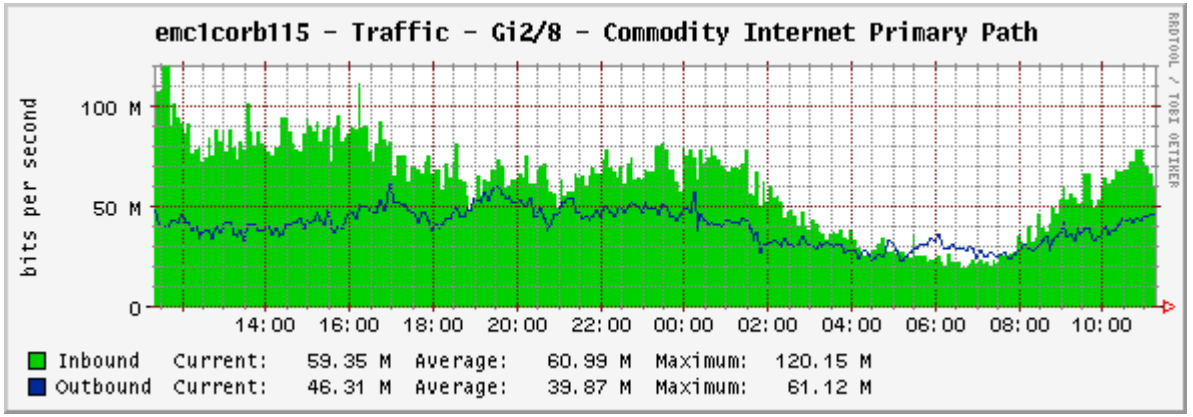
Network traffic observations: more

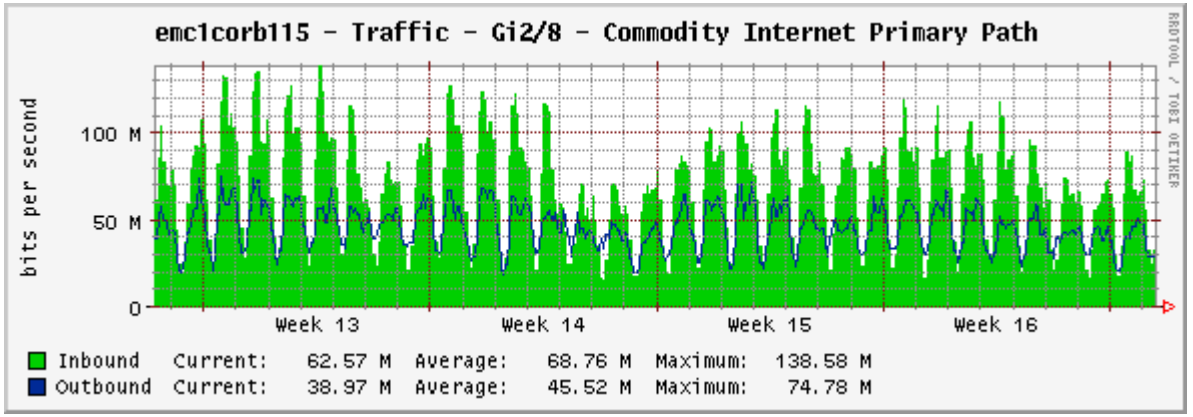
- Packet sizes are bimodally distributed
- Packet traffic is non-uniformly distributed
- Network traffic exhibits "locality" properties
- Aggregate network traffic is multi-fractal in nature
- Internet traffic continues to change

UVicNet


Access
Distribution
Core
Edge
General Departmental VLANs
Public Access (PAN) / Wireless VLANs
ResNet
C6509
VRF PAN
C3550
VRF PAN
C6509
VRF PAN
C3550
VRF PAN
C6509
VRF PAN
FW
EngrNet
Gig E
Core C6509
Core C6509
VRF PAN
Intrusion Prevention
Edge Router
Traffic Shaping
Edge Router
OSPF Area 0 (backbone)
BCNet - Commercial Internet
Gig E – Primary Path
Gig E – Fallback Path
Vlan Paths

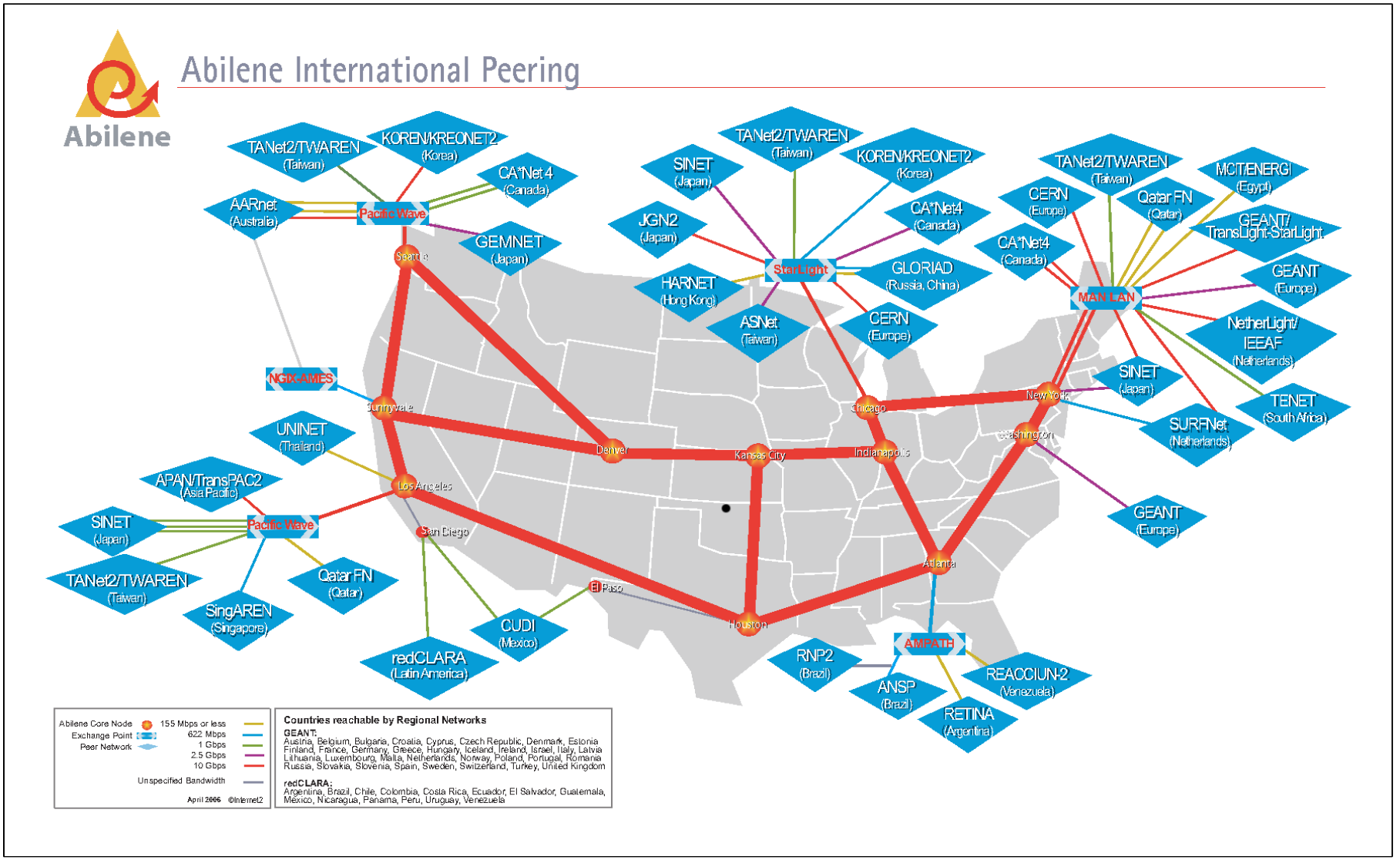
UVicNet traffic



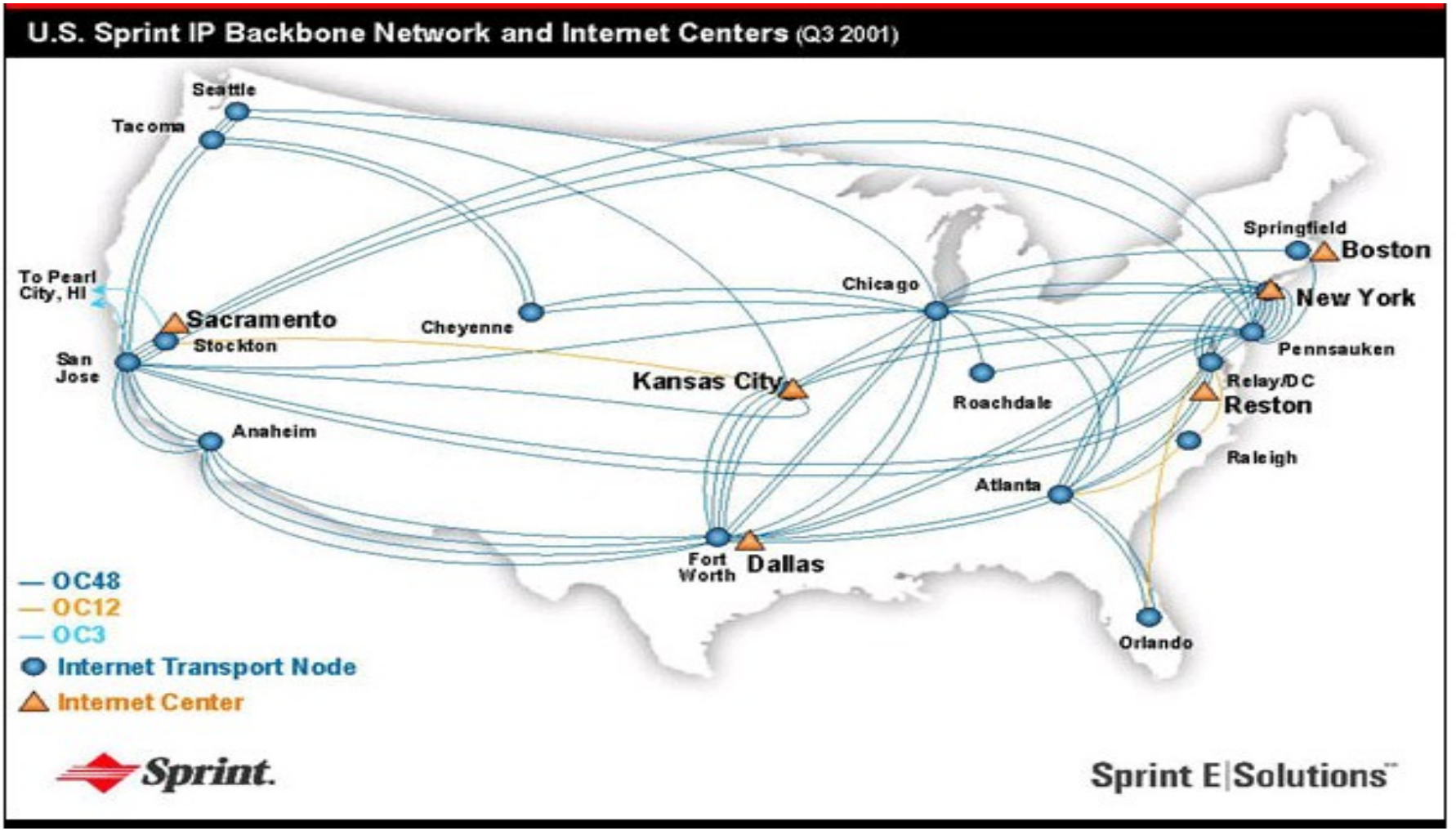


BCNet/CA*Net4

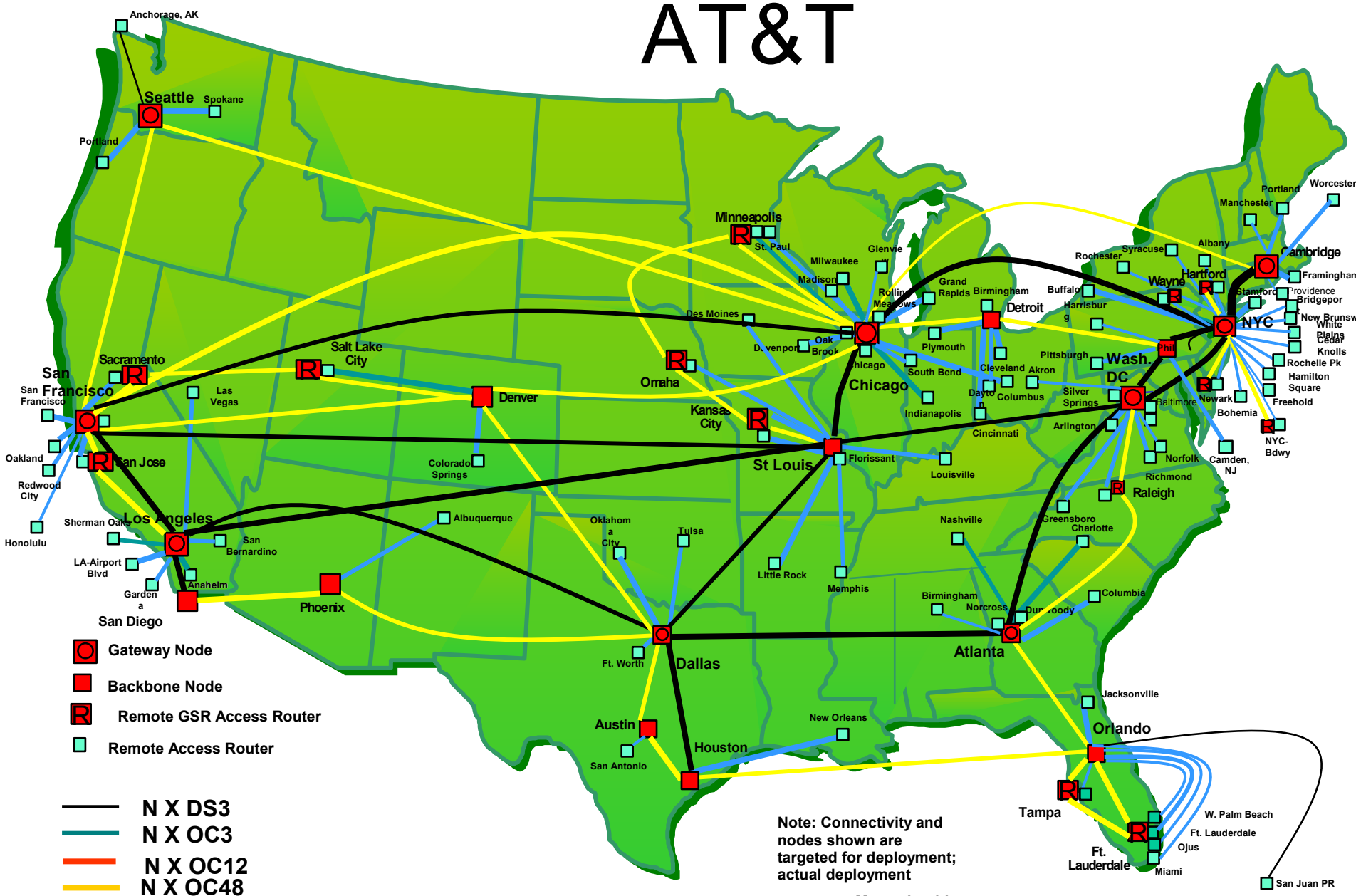
Internet2


Abilene
Abilene International Peering
TANet2/TWAREN (Taiwan)
KOREN/KREONET2 (Korea)
CA*Net 4 (Canada)
AARnet (Australia)
Pacific Wave
GEMNET (Japan)
Seattle
SINET (Japan)
TANet2/TWAREN (Taiwan)
KOREN/KREONET2 (Korea)
JGN2 (Japan)
CA*Net4 (Canada)
HARNET (Hong Kong)
StarLight
GLORIAD (Russia, China)
ASNet (Taiwan)
CERN (Europe)
TANet2/TWAREN (Taiwan)
MCIT/ENERGI (Egypt)
CERN (Europe)
Qatar FN (Qatar)
GEANT/ TransLight-StarLight
CA*Net4 (Canada)
GEANT (Europe)
MAN LAN
NetherLight/ IEEAF (Netherlands)
SINET (Japan)
TENET (South Africa)
SURFNet (Netherlands)
NGIX-AMES
Sunnyvale
Chicago
New York
Washington
UNINET (Thailand)
Denver
Kansas City
Indianapolis
APAN/TransPAC2 (Asia Pacific)
Los Angeles
SINET (Japan)
Pacific Wave
San Diego
GEANT (Europe)
Atlanta
TANet2/TWAREN (Taiwan)
Qatar FN (Qatar)
El Paso
SingAREN (Singapore)
CUDI (Mexico)
Houston
redCLARA (Latin America)
RNP2 (Brazil)
AMPATH
REACCIUN-2 (Venezuela)
ANSP (Brazil)
RETINA (Argentina)
Abilene Core Node
Exchange Point
Peer Network
155 Mbps or less
622 Mbps
1 Gbps
2.5 Gbps
10 Gbps
Unspecified Bandwidth
April 2006 ©Internet2
Countries reachable by Regional Networks
GEANT:
Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Israel, Italy, Latvia Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Romania Russia, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey, United Kingdom
redCLARA:
Argentina, Brazil, Chile, Colombia, Costa Rica, Ecuador, El Salvador, Guatemala, Mexico, Nicaragua, Panama, Peru, Uruguay, Venezuela

Sprint

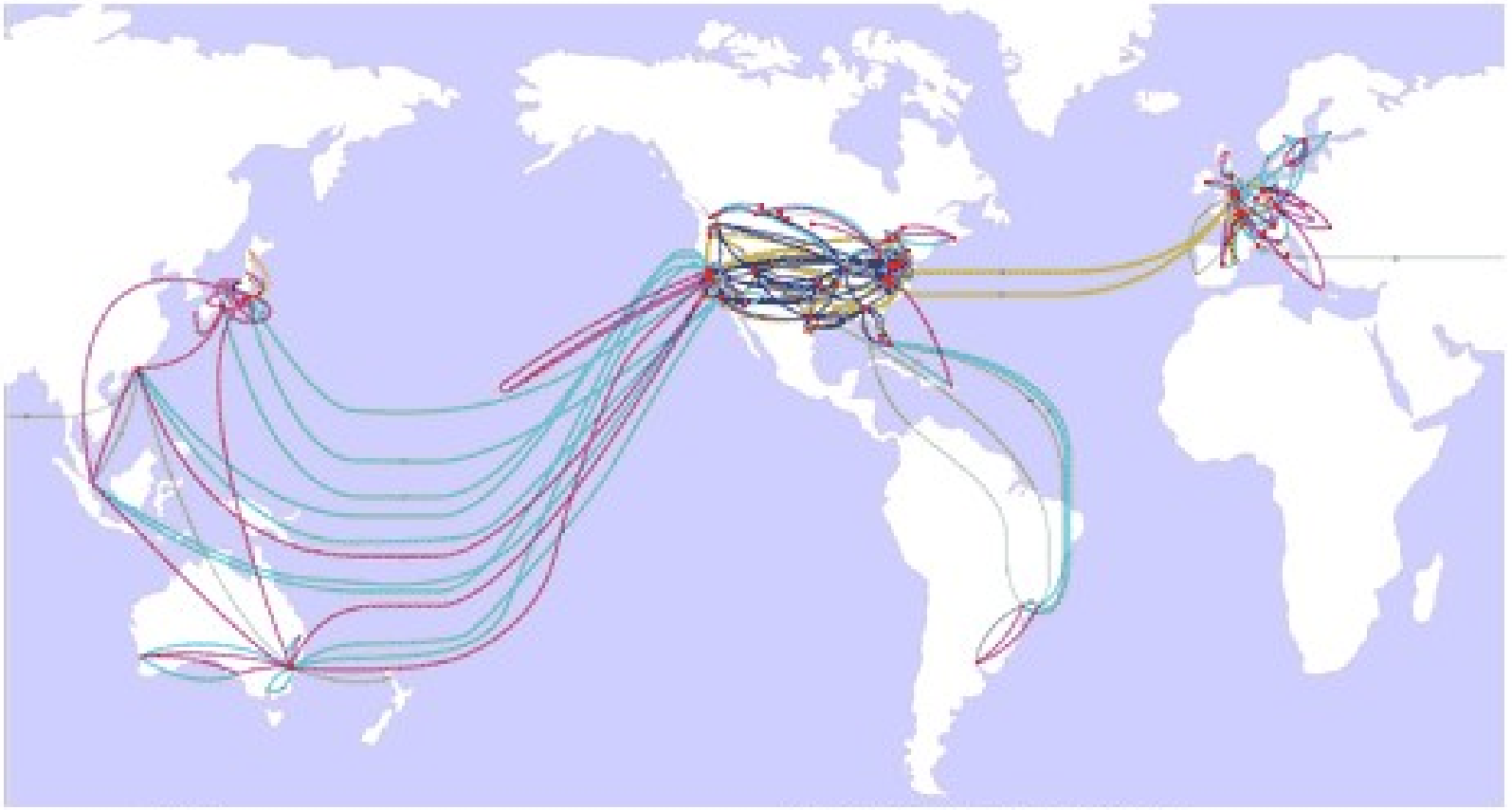

U.S. Sprint IP Backbone Network and Internet Centers (Q3 2001)
Seattle
Tacoma
To Pearl City, HI
Sacramento
Stockton
San Jose
Anaheim
Cheyenne
Kansas City
Chicago
Roachdale
Springfield
Boston
New York
Pennsauken
Relay/DC
Reston
Raleigh
Atlanta
Fort Worth
Dallas
Orlando
OC48
OC12
OC3
Internet Transport Node
Internet Center
Sprint.
Sprint E|Solutions

AT&T

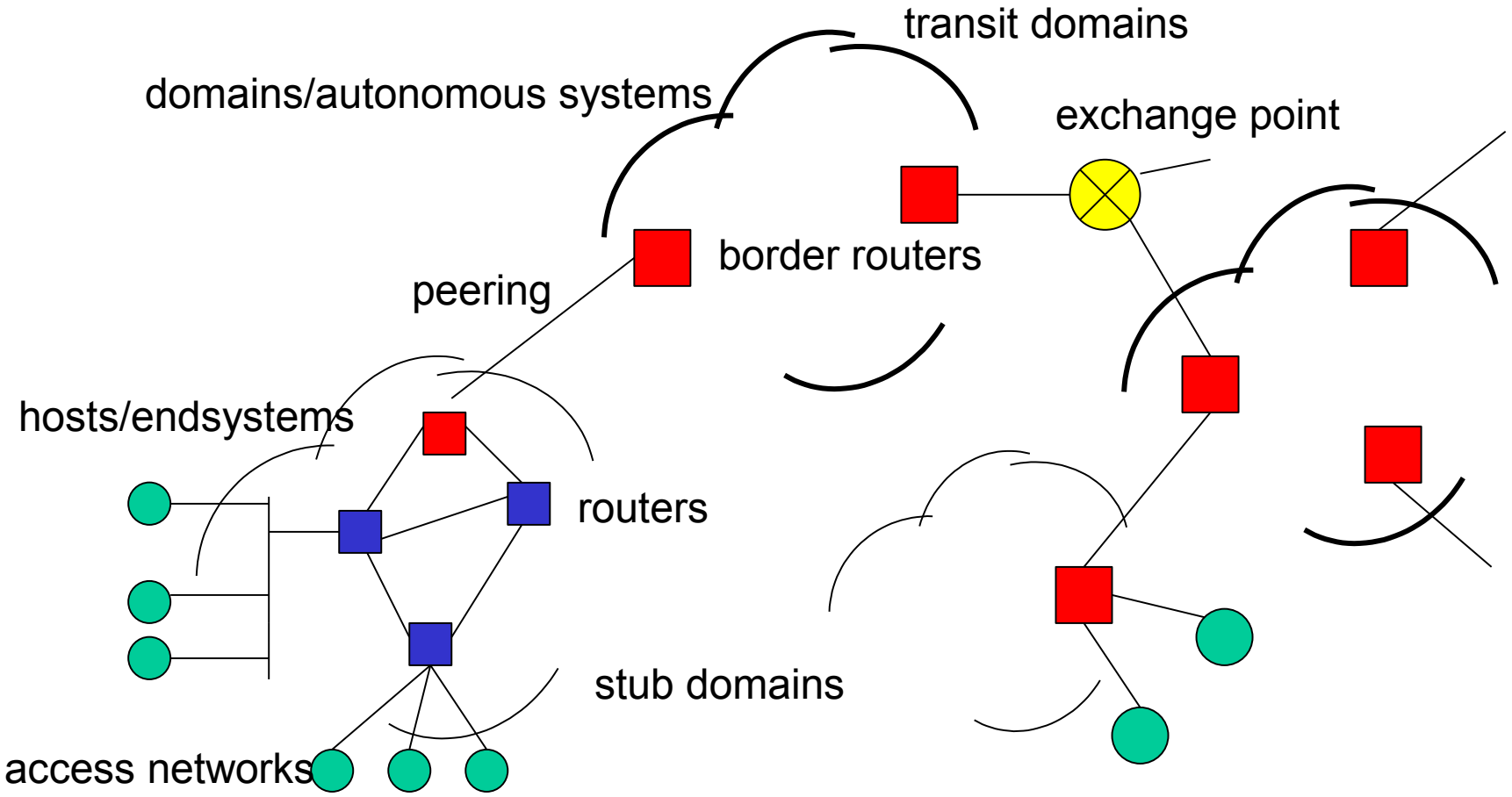

Anchorage, AK
Seattle
Spokane
Portland
Minneapolis
St. Paul
Milwaukee
Madison
Glenview
Rollin Meadows
Grand Rapids
Birmingham
Detroit
Buffalo
Harrisburg
Rochester
Syracuse
Albany
Portland
Manchester
Worcester
Cambridge
Framingham
Providence
Bridgepor
New Brunswick
White Plains
Cedar Knolls
Rochelle Pk
Hamilton Square
Freehold
NYC
Wayne
Hartford
Stamford
Phil
Wash. DC
Baltimore
Newark
Bohemia
NYC-Bdwy
Camden, NJ
Norfolk
Richmond
Raleigh
Greensboro
Charlotte
Nashville
Arlington
Silver Springs
Pittsburgh
Cleveland
Akron
Columbus
Dayton
Indianapolis
Cincinnati
Louisville
Florissant
St Louis
Chicago
South Bend
Plymouth
Oak Brook
Davenport
Des Moines
Omaha
Kansas City
Denver
Colorado Springs
Salt Lake City
Las Vegas
Sacramento
San Francisco
San Francisco
Oakland
Redwood City
San Jose
Honolulu
Sherman Oaks
Los Angeles
San Bernardino
LA-Airport Blvd
Garden a
Anaheim
San Diego
Albuquerque
Phoenix
Oklahoma City
Tulsa
Little Rock
Memphis
Ft. Worth
Dallas
Austin
San Antonio
Houston
New Orleans
Birmingham
Norcross
Dunwoody
Columbia
Atlanta
Jacksonville
Orlando
Tampa
W. Palm Beach
Ft. Lauderdale
Ojus
Miami
Ft. Lauderdale
San Juan PR
Gateway Node
Backbone Node
Remote GSR Access Router
Remote Access Router
N X DS3
N X OC3
N X OC12
N X OC48
NX OC192
Note: Connectivity and nodes shown are targeted for deployment; actual deployment may vary. Maps should not be used to predict service availability.

Rev. 6-4-01

WorldCom


64 Kbps
T1/E1 (1.5 Mbps/2 Mbps)
E3/T3/DS3 (35 Mbps/45 Mbps)
T2 (6 Mbps)
OC3c/STM1 (155 Mbps)
OC12c/STM4 (622 Mbps)
OC48c/STM16 (2.5 Gbps)
OC192c/STM64 (10 Gbps)
Single Hub City
Multiple Hubs City
Data Center Hub

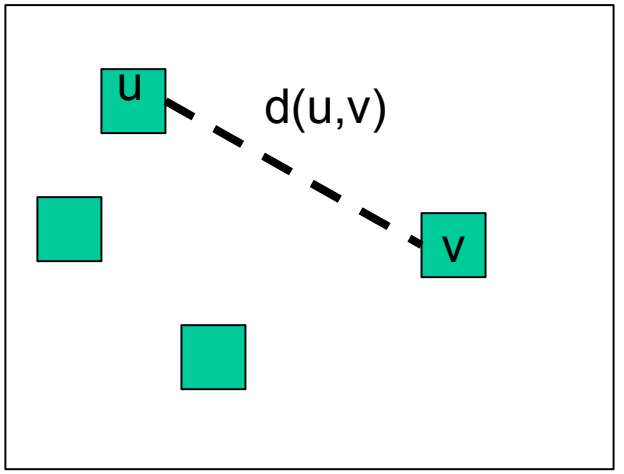
Topology modeling



http://www.ipam.ucla.edu/publications/cntut/cntut_1547.ppt

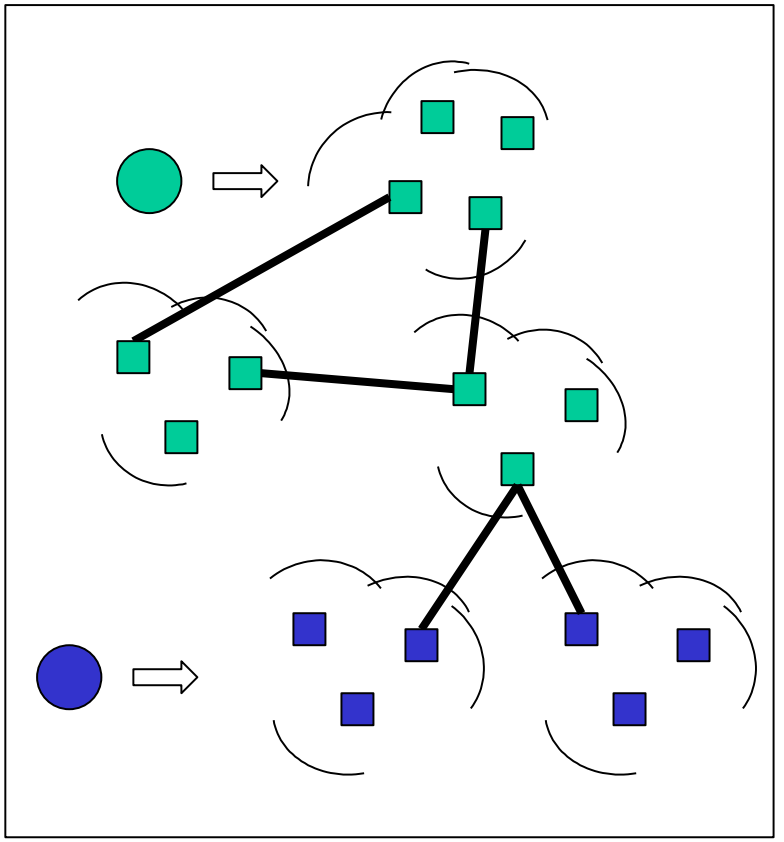
Waxman model (Waxman 1988)

- Router level model
- Nodes placed at random in 2-d space with dimension L
- Probability of edge (u,v):
  - ae^{-d/(bL)}, where d is Euclidean distance (u,v), a and b are constants
- Models *locality*



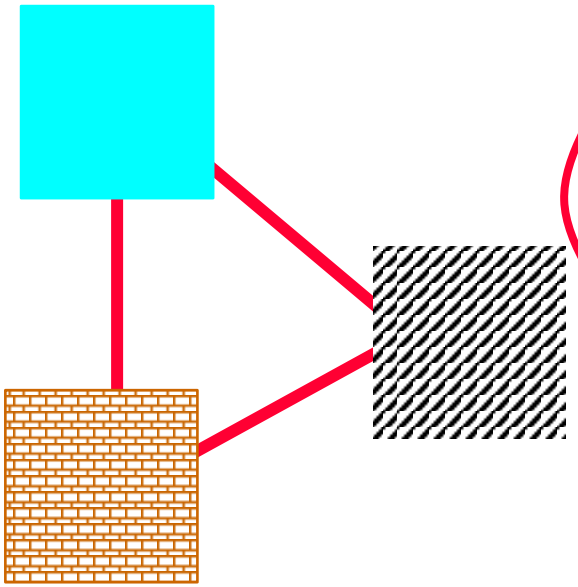
Transit-stub model (Zegura 1997)

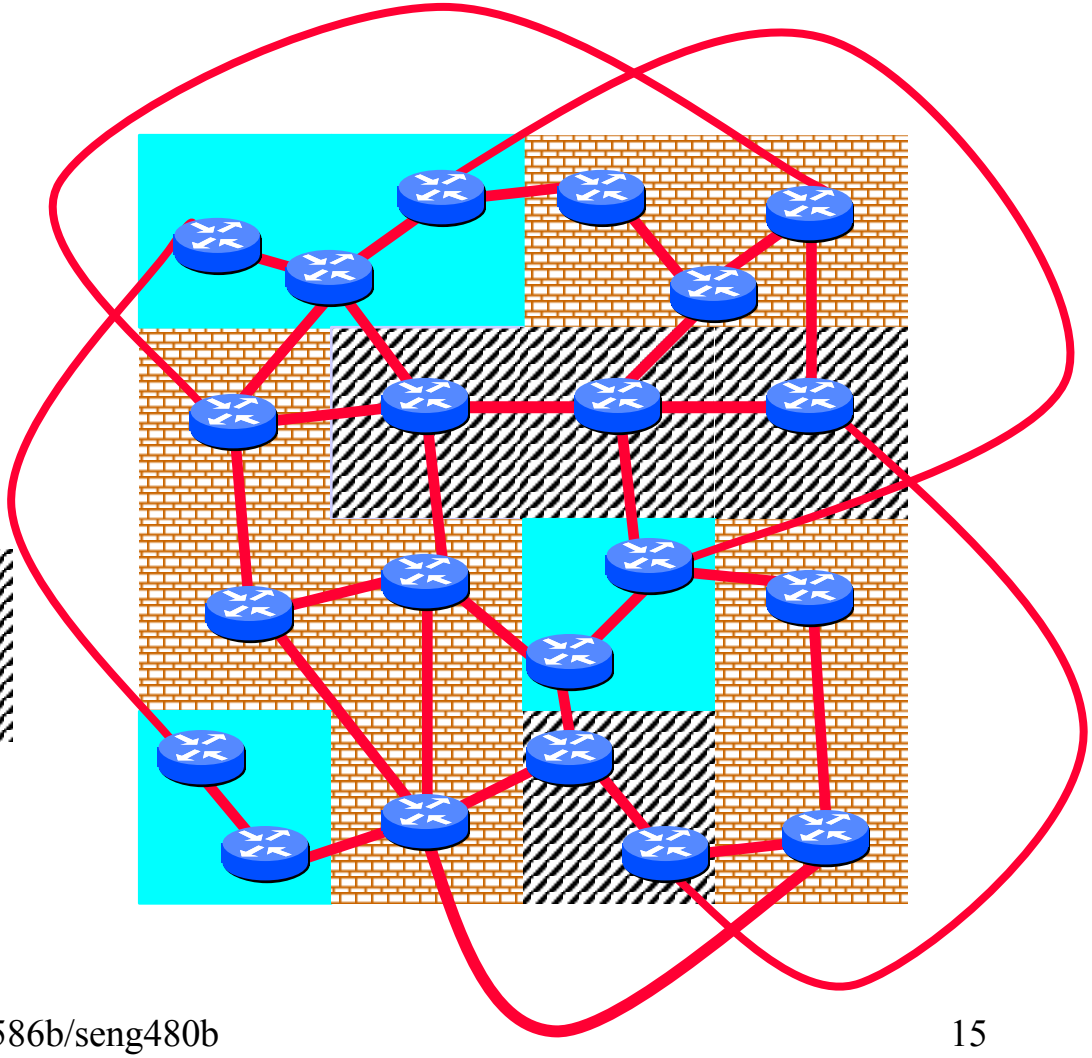
- Router level model
- Transit domains
  - placed in 2-d space
  - populated with routers
  - connected to each other
- Stub domains
  - placed in 2-d space
  - populated with routers
  - connected to transit domains
- Models *hierarchy*



Topology measurement

- Router-level topology
  - traceroute
- AS-level topology
  - BGP





The AS graph may look like this.

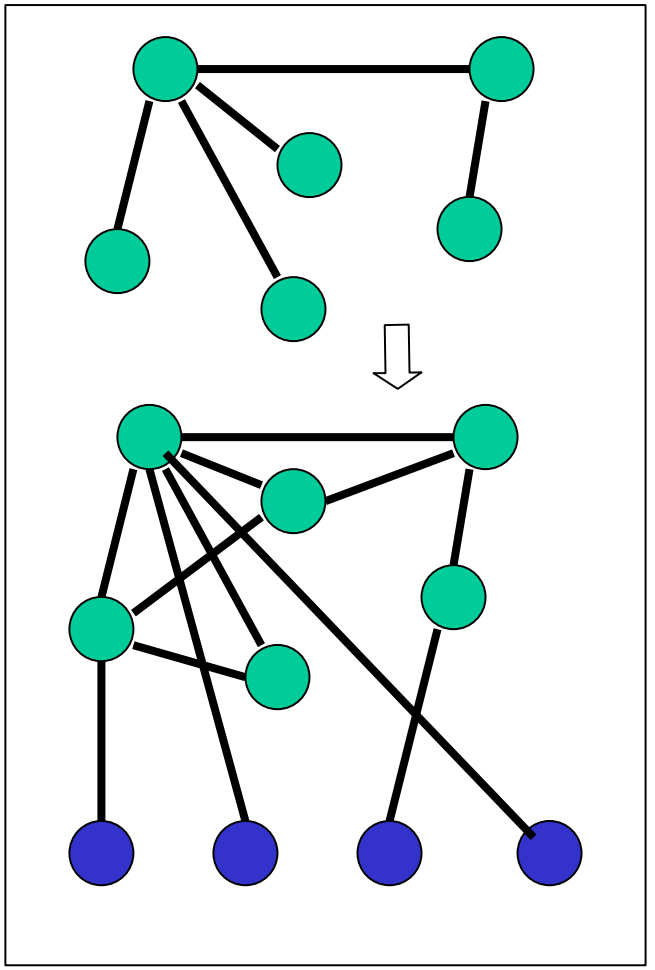
Reality may be closer to this…

Student presentation

- Dandan Huang
  - [FFF99] Michalis Faloutsos, Petros Faloutsos, and Christos Faloutsos, "On Power-Law Relationships of the Internet Topology". In Proceedings of SIGCOMM '99

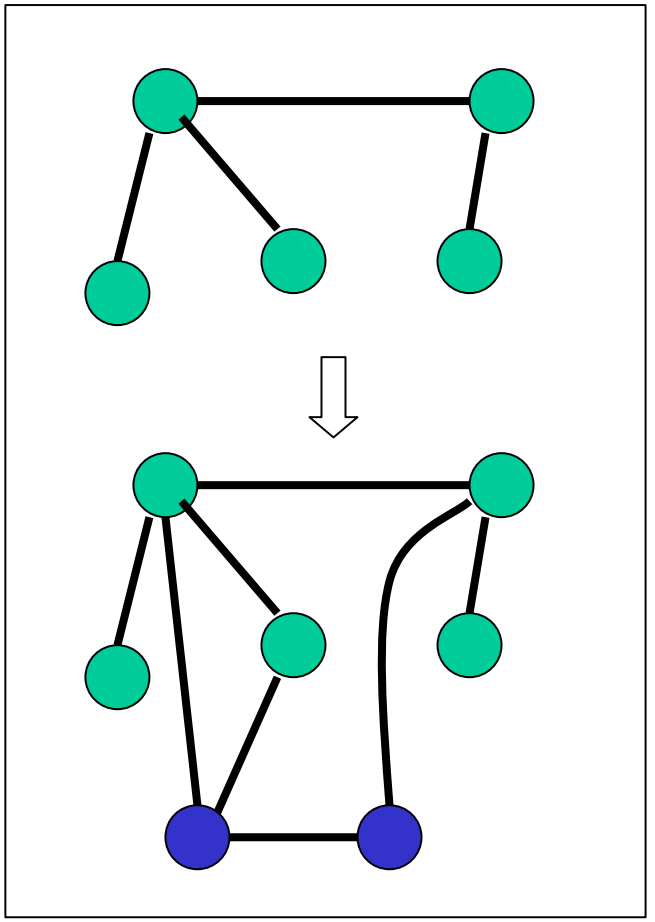
Inet (Jin 2000)

- Generate degree sequence
- Build spanning tree over nodes with degree larger than 1, using preferential connectivity
  - randomly select node u not in tree
  - join u to existing node v with probability d(v)/Σd(w)
- Connect degree 1 nodes using preferential connectivity
- Add remaining edges using preferential connectivity



BRITE (Medina 2000)

- Generate small backbone, with nodes placed:
  - randomly or
  - concentrated (skewed)
- Add nodes one at a time (incremental growth)
- New node has constant # of edges connected using:
  - preferential connectivity and/or
  - locality



This lecture

- Internet characterization
  - network traffic
  - network topology
- Explore further
  - Routeviews
  - Rocketfuel

Next lectures

- July 18: more on reality check
  - [LAWD04] Lun Li, David Alderson, Walter Willinger, John Doyle. A First-Principles Approach to Understanding the Internet's Router-Level Topology. In SIGCOMM 2004.
- July 23: guest lecture by Mr Michael Chan
  - Director of Product Development at MCK Advanced Technology and CitiWide Broadband
    - “A technology company is going to great heights to broadcast an Internet signal over much of Victoria.” --- Times Colonist

Course projects presentation

- July 25
  - Justyn Bussey and Dale Lyons; Ryan Chen; Hong-Yi Wang
- July 30
  - Andy Yu and Chun-Hung Chiu; Emad Shihab; Ming Lu
- August 1
  - Leo Gong and Ching-Chang Chen; Haoling Ma; Dandan Huang