



Is the Internet a Railway or an Autobahn? Issues for Research

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The Internet as an Infrastructure

- Most research on the Internet has looked at its nodes rather than its links
- The difficulties:
 - The Internet is an amalgam of many separate networks
 - There is no data source with comprehensive information
 - Deregulation has compounded these difficulties



A Brief Look at Nodes on Internet Backbones in the USA

- A top group of 7 urban areas consistently leads as the nodes most connected
 - True from 1997 through 2001
 - 2001 total bandwidth: Chicago, Washington, San Francisco, New York, Los Angeles, Atlanta, Dallas
- These suggest some shake-up in the urban hierarchy
 - “New network cities” surpass larger cities

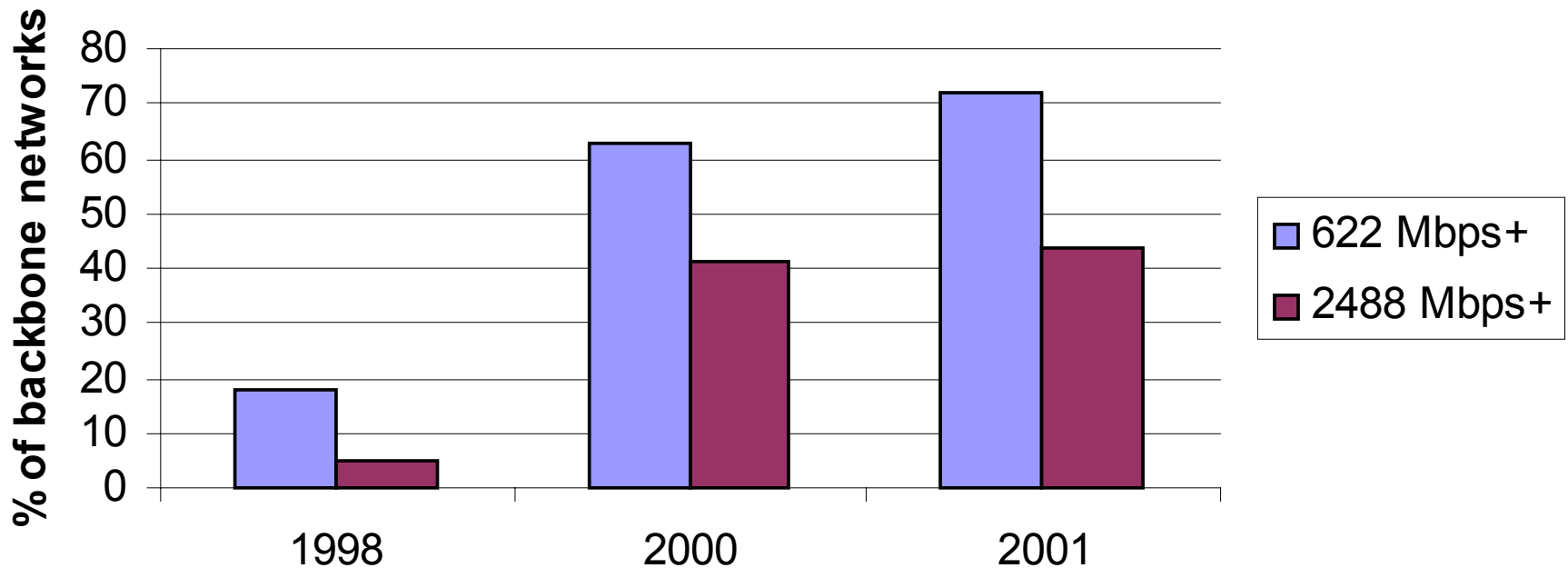


The Internet is a Work in Progress

- New links on backbone networks
- Upgrades of bandwidth and technology on existing links
 - The new bandwidth added from 2000 to 2001 connecting Los Angeles and San Francisco is enough to make it rank 5th in the USA

New Routes Have More Bandwidth

Bandwidth 622 Mbps and higher and 2488 and higher on US Internet backbone networks 1998-2001



New Bandwidth on Backbones 2000-2001



Most New Bandwidth “Added Lanes” on Existing Routes (2000 Bandwidth)





New Investment on Internet Backbones 2000-2001

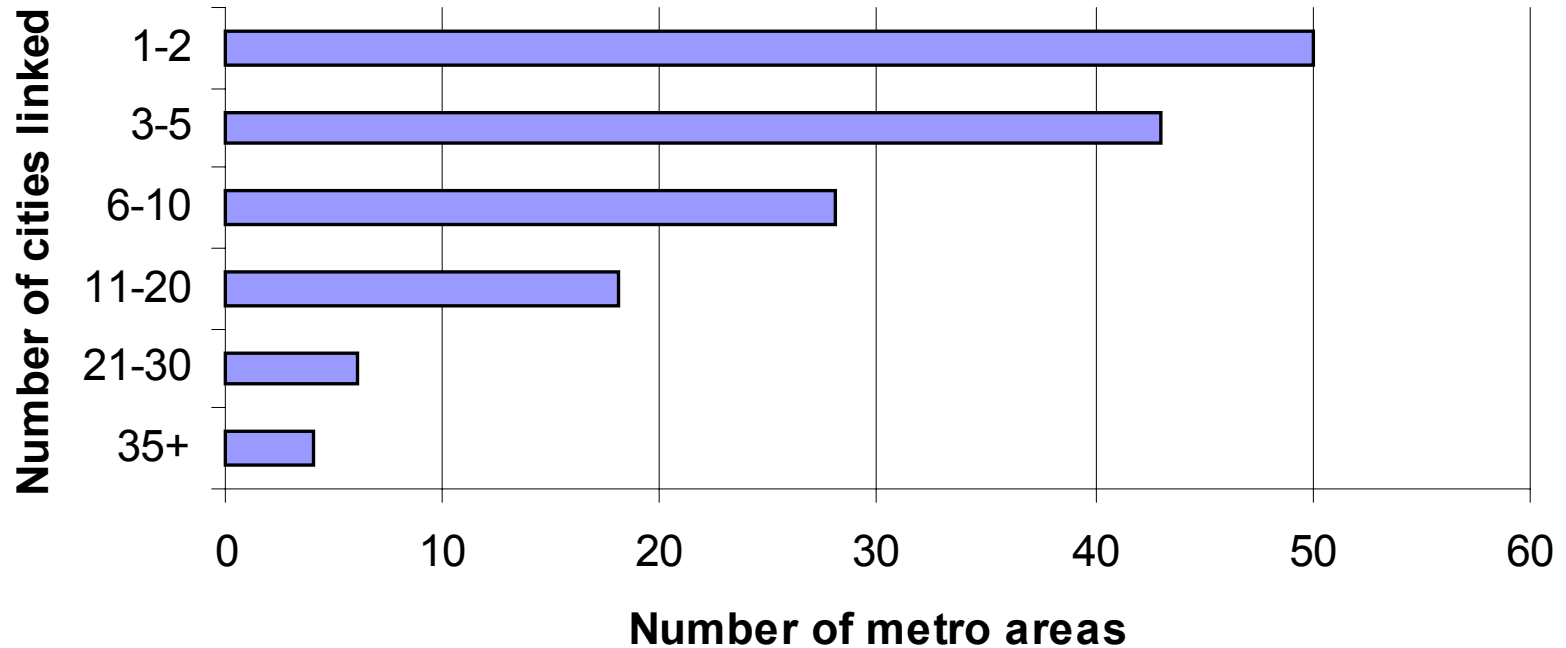
- The ten routes with the greatest additional bandwidth 2000-2001
- Most new bandwidth is on short-haul routes
 - Los Angeles-San Francisco, New York-Washington, Portland-Seattle, San Francisco-Sacramento, Boston-New York, and Los Angeles-San Diego
- But also some longer-haul routes from major hubs
 - Chicago-New York, Chicago-San Francisco, Chicago-Washington, and Atlanta-Washington

The “Information Superhighway” in 2001



Few Cities Are Connected to Many Other Cities

Number of Other Cities Linked via Internet Backbones to Metro Areas, 2001





Ten Cities Are Linked to Over 20 Other Places

- Atlanta, Chicago, Washington - 40
- Dallas - 37
- San Francisco - 30
- Kansas City, New York - 26
- Denver - 25
- Houston - 24
- St. Louis - 21
 - This list includes coastal places with NAPs (Washington, New York, San Francisco)
 - The list of well-connected places is mainly central locations that serve as network hubs for private interconnection



18 Third-Tier Hubs (11-20 city links)

- Los Angeles - 20
- Cleveland - 19
- Seattle - 17
- Phoenix, Salt Lake City - 16
- Columbus OH, Detroit - 15
- Boston, Miami, New Orleans, Sacramento - 14
- Charlotte, Tampa - 13
- Indianapolis, Orlando, San Diego – 12
- Cincinnati, Minneapolis - 11



The Most Linked Places

- Only 8 cities have over 100 distinct backbone links to other cities. Only 2 have over 200.
 - Chicago - 224
 - Washington - 215
 - Dallas - 189
 - Atlanta - 185
 - San Francisco - 182
 - New York - 169
 - Los Angeles - 144
 - Houston -106



The Best-Connected Places Have the “Big Pipes”

Metro areas with over 50 networks links of 2488 Mbps or over:

- Chicago - 91
- San Francisco - 77
- Washington - 72
- Dallas - 70
- New York - 66
- Los Angeles - 62
- Atlanta - 62
- Houston - 55

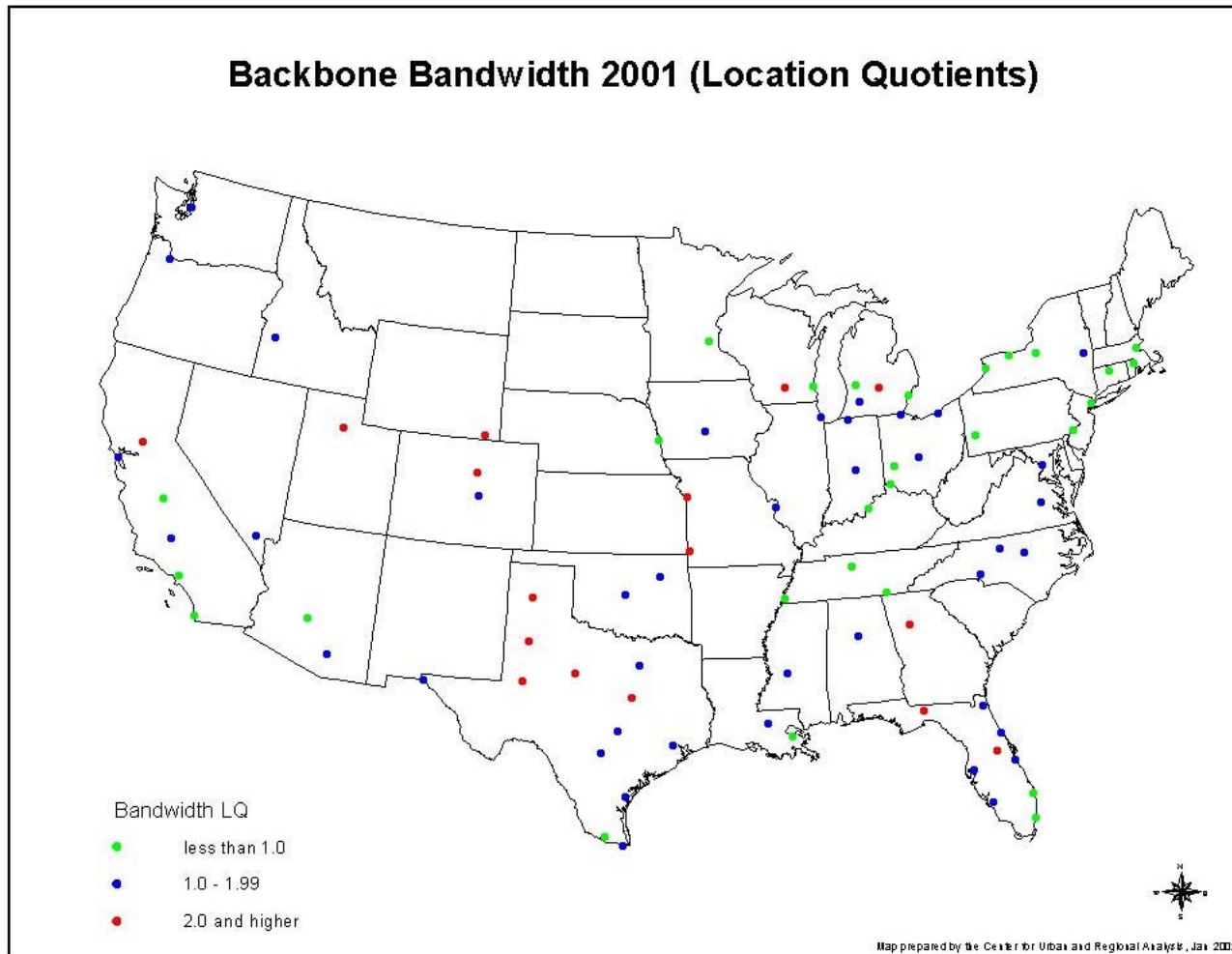


The Urban Hierarchy Lives:

Backbone Connections by MSA/CMSA Size Class

MSA Size Range	n	Average Total Bandwidth (Mbps)	Mean Number of Cities Linked	Mean Bandwidth/Pop
Over 5 million	9	373,419	25.6	40.0
2-5 million	13	165,588	17.8	53.3
1-2 million	27	67,489	9.4	49.2
500,000-1 million	30	20,704	4.5	29.7
250,000-500,000	40	12,702	2.7	33.8
Under 250,000	30	9,040	2.8	50.5

Bandwidth Concentrates at “Funnel Points”





What is the Internet?

- An Autobahn?

- Traceroutes suggest that few packets travel long distances directly
- There are both “local” routes and long-haul routes

- A Railway?

- Local routes are needed by smaller cities that connect to few other places



Conclusion

- Maybe the Internet is an airport system
 - Some network links approximate long-distance, non-stop flights
 - Other messages take the “local” service, stopping off at several hub interconnection points
- The complexity of private interconnection suggests that no transport analogy can apply



Research Needs

- Needed: research on Internet traffic flows
 - What routes do packets take?
- Needed: research on the “middle mile”
 - The links between backbones and the last-mile connections to users
 - Regional, local and metro fiber networks
- Needed: a focus on demand, not supply (e.g. backbone links)
 - ISPs and their connections will reflect local demand and network responses to it



Research Needs

- Needed: research on the effects of competition
 - Are there monopolies are some Internet hubs?
 - Where is redundancy (connection to multiple networks) possible? And where is it not possible?
- What can policy or public/private action so?
 - Entrepreneurial cities and towns work to improve their connections, but where? And how?