

# InterTubes: A Study of the US Long-haul Fiber-optic Infrastructure

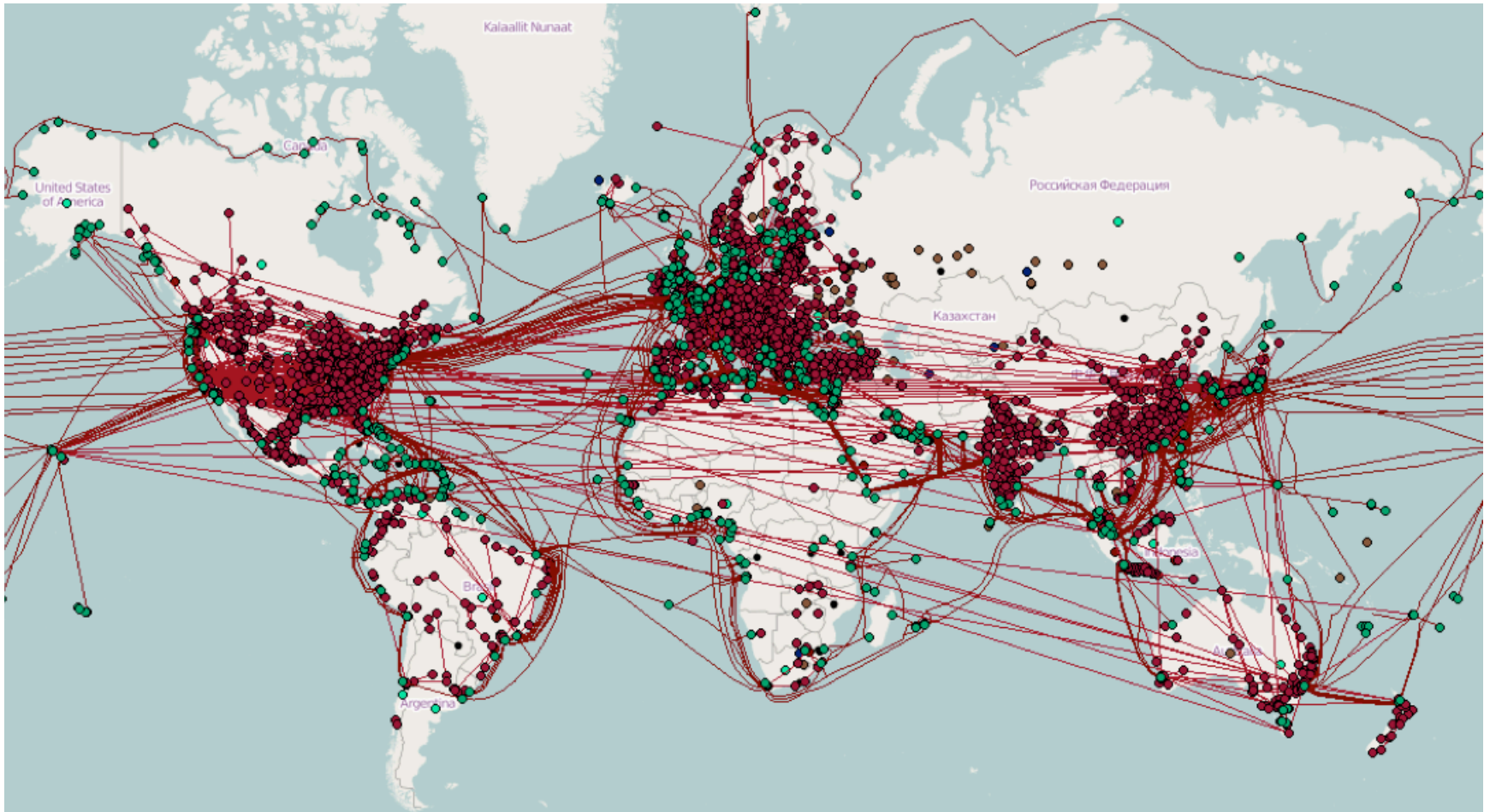
**Ram Durairajan**  
University of Wisconsin-Madison

**Paul Barford**  
University of Wisconsin-Madison &  
comScore, Inc.

**Joel Sommers**  
Colgate University

**Walter Willinger**  
NIKSUN, Inc.

# A view of the Internet



Source: Internet Atlas  
© <http://internetatlas.org>

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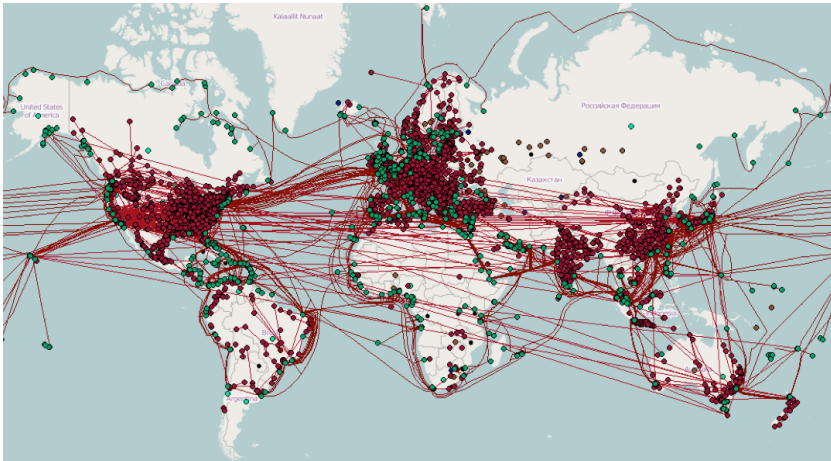
What does the Internet's underlying **physical infrastructure** look like?

How **resilient** is this infrastructure?

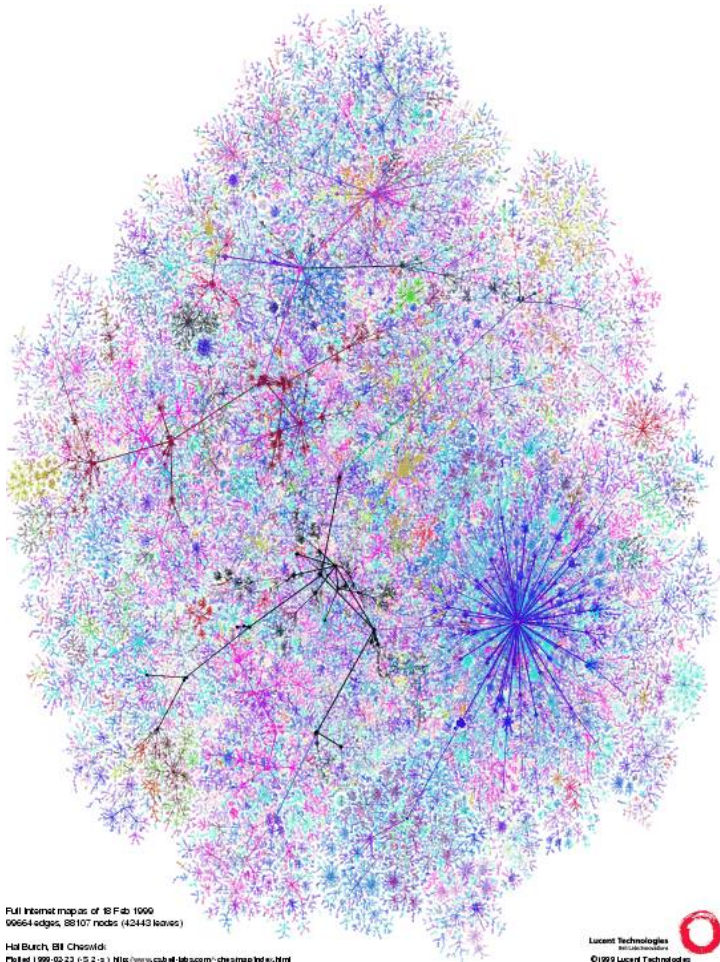
How can I broaden my perspective on risks in my network?

What are all the right (and wrong) conduit **deployment practices** and **policies**?

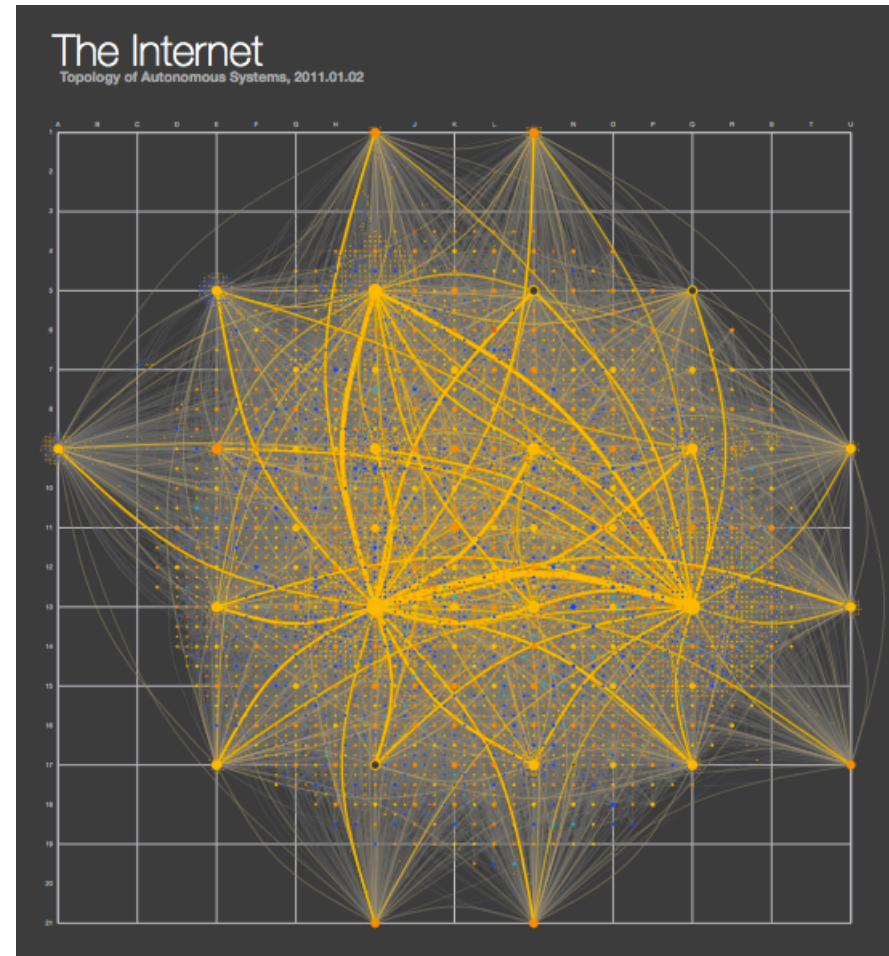
How can I **improve robustness** and/or **performance**?



# No one has a complete view of Internet at the *physical* level

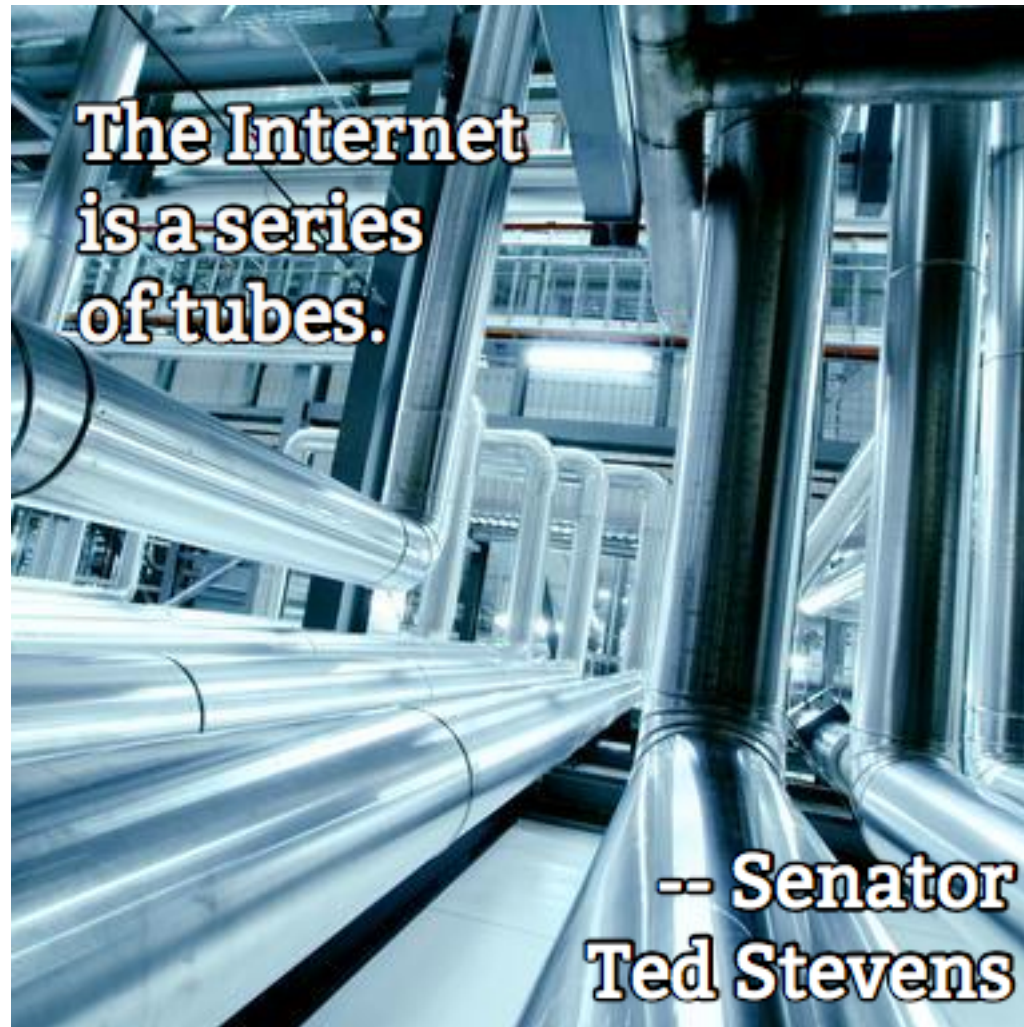


Source: Lumeta



Source: Peer1

Some are quite confused...



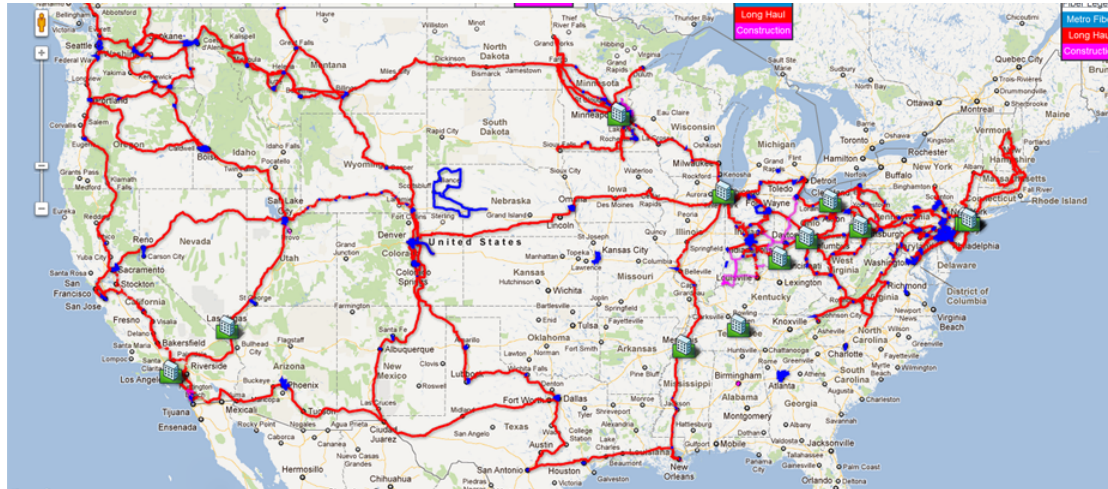
# InterTubes outline

- Introduction and Motivation
- Process for constructing a map
- Assessment of infrastructure sharing
- Robustness suggestions
- Implications

# Process for constructing a map

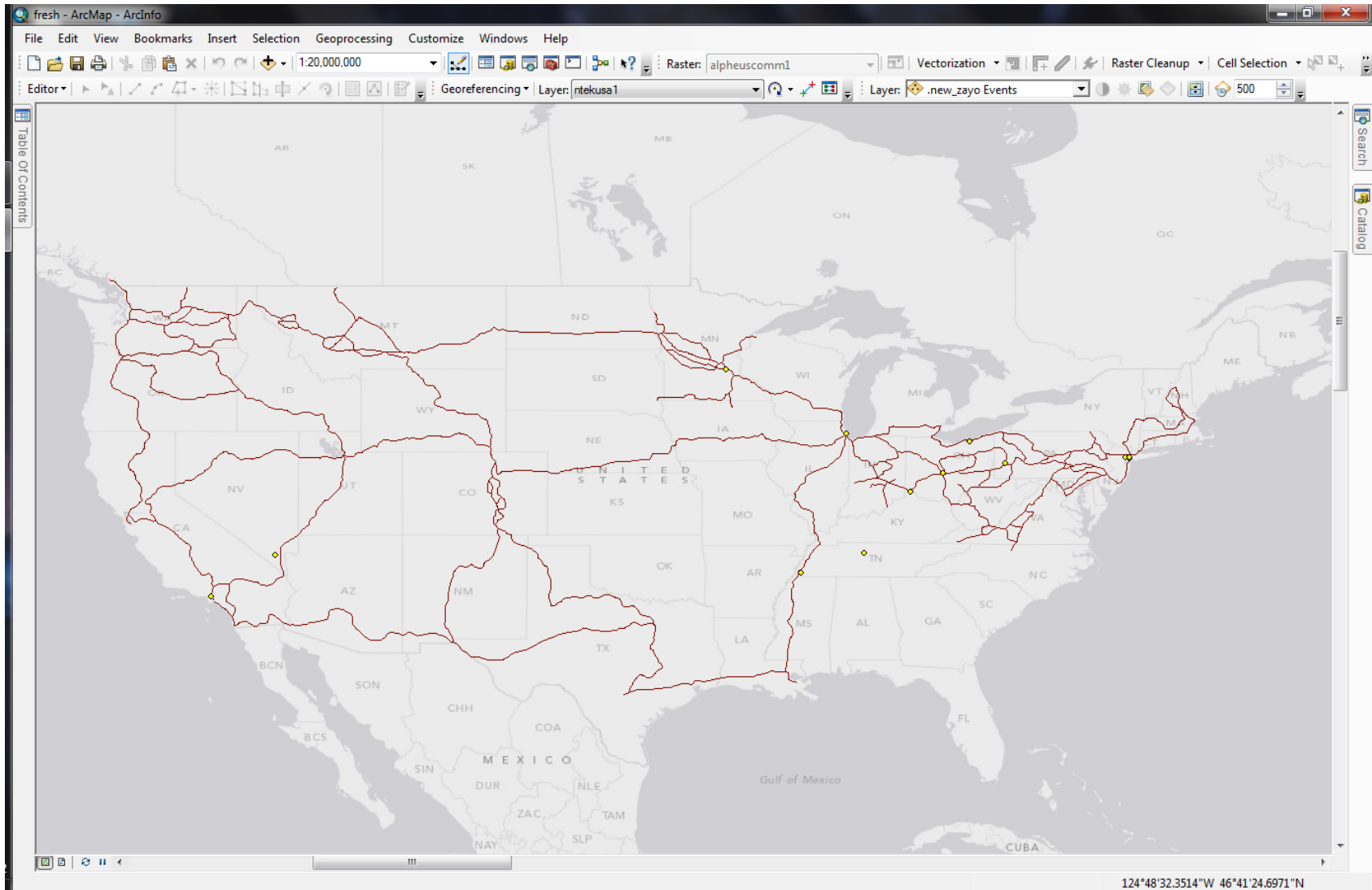
- Step #1: Building an initial map
  - Utilize (geocoded) maps of tier-1 ISPs and major cable providers found by web search
- Step #2: Consistency check with public records
  - Rights of Way, agency filings, etc.
- Step #3: Add links from ISPs that are ‘not’ geocoded
  - E.g., the Sprint network map
- Step #4: Infer conduit sharing

# Map construction

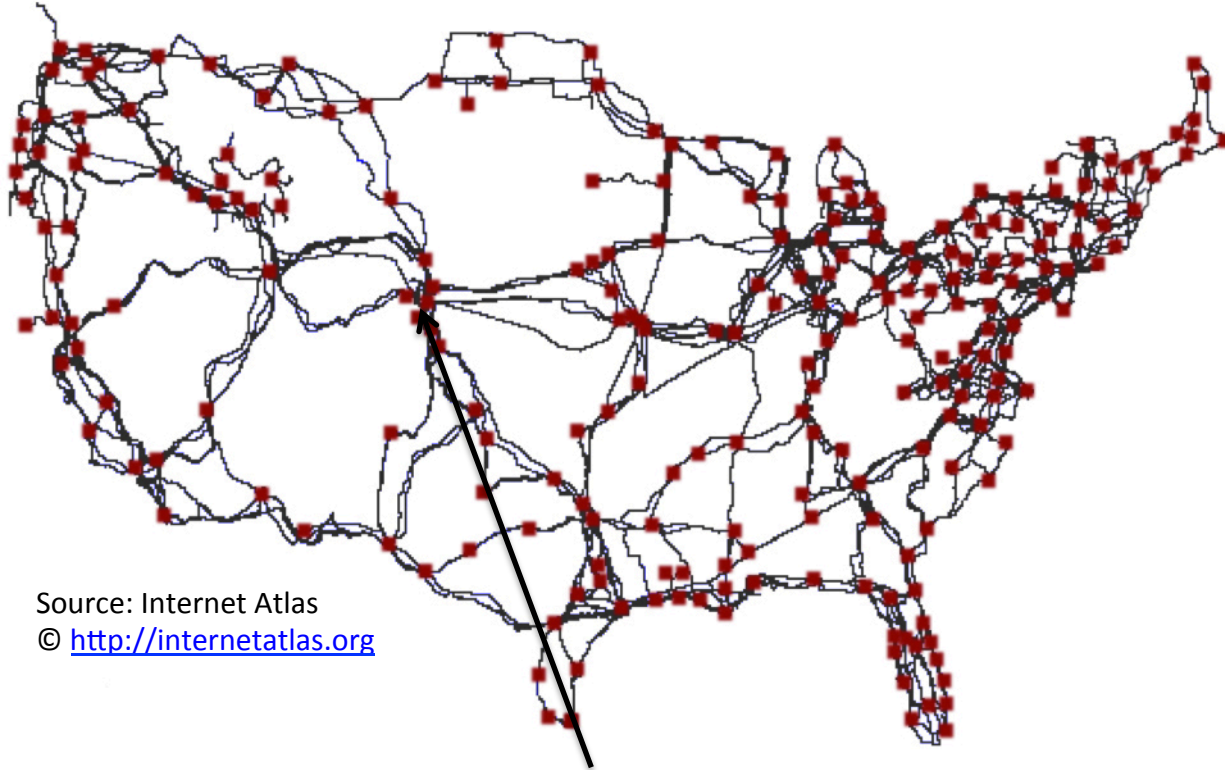




# Geo-specific link encoding



# Map of US long-haul fiber

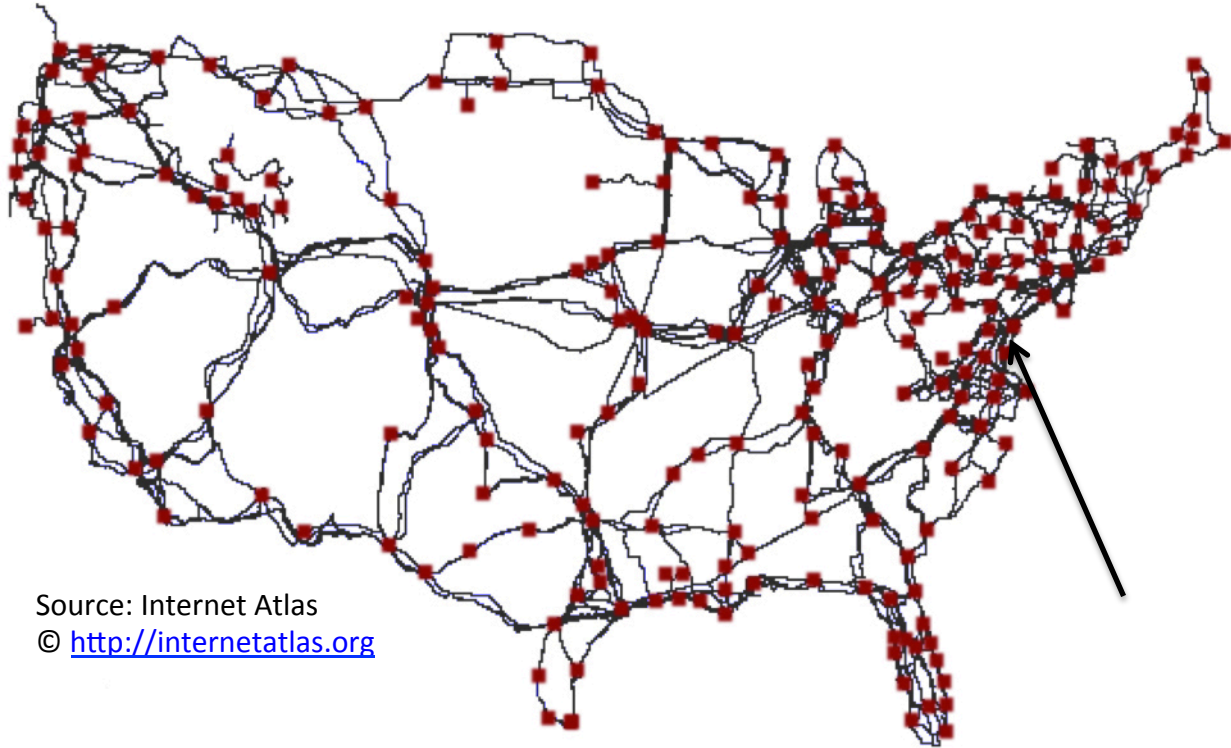


Source: Internet Atlas  
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Repair of Damages. Zayo agrees to promptly repair all damage caused by Zayo or its contractors to the City Duct System or to any existing fiber optic cable owned by the City, Level 3, BRAN, Qwest, Comcast, or any other fiber optic cable owner located within the City Duct System or the City Unused Conduit. If such damage poses a threat to the health, safety or welfare of the public or individuals, the City may cause repairs to be made at Zayo's expense and Zayo shall reimburse the City within thirty days of its receipt of an invoice for the repairs.

Source: branfiber.net

# Map of US long-haul fiber - details

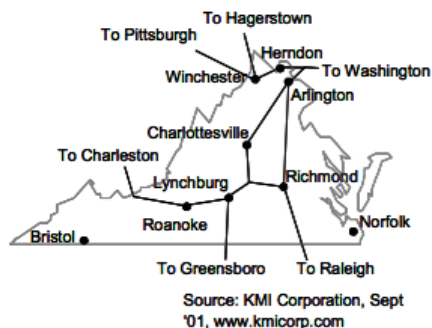


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# Consistency check via public records

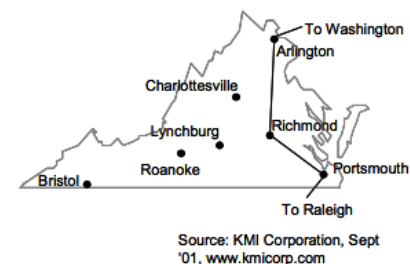
## AT&T

Address: 13630 Solstice Street  
Midlothian VA 23113  
Telephone: 804-897-1734  
Contact Person: Chester Porter  
Title: Client Business Manager for VA  
e-mail: cdporter@att.com  
Internet URL: www.att.com  
Offering: "Full range of voice and data services, IT and professional services"



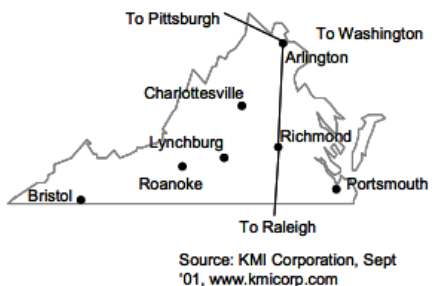
## Qwest

Address: 1306 Concourse Drive  
Suite 400  
Linthicum MD 21090  
Telephone: 410-694-4848  
Contact Person: Joel Prescott  
Title: National Account Manager  
e-mail: joel.prescott@qwest.com  
Internet URL: www.qwest.com  
Offering: "Private line services, Internet, collocation, fiber leasing, engineering, construction, hosting, VPNs"



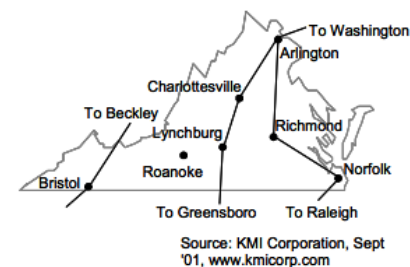
## Level 3

Address: 8270 Greensboro Drive  
Suite 900  
McLean VA 22102  
Telephone: 571-382-7427  
Contact Person: Laura Spining  
Title: Account Director  
e-mail: Laura.spining@level3.com  
Internet URL: www.level3.com  
Offering: "Private line transport services, optical waves, managed services for construction, engineering, fiber leasing, collocation, MPLS transport product"



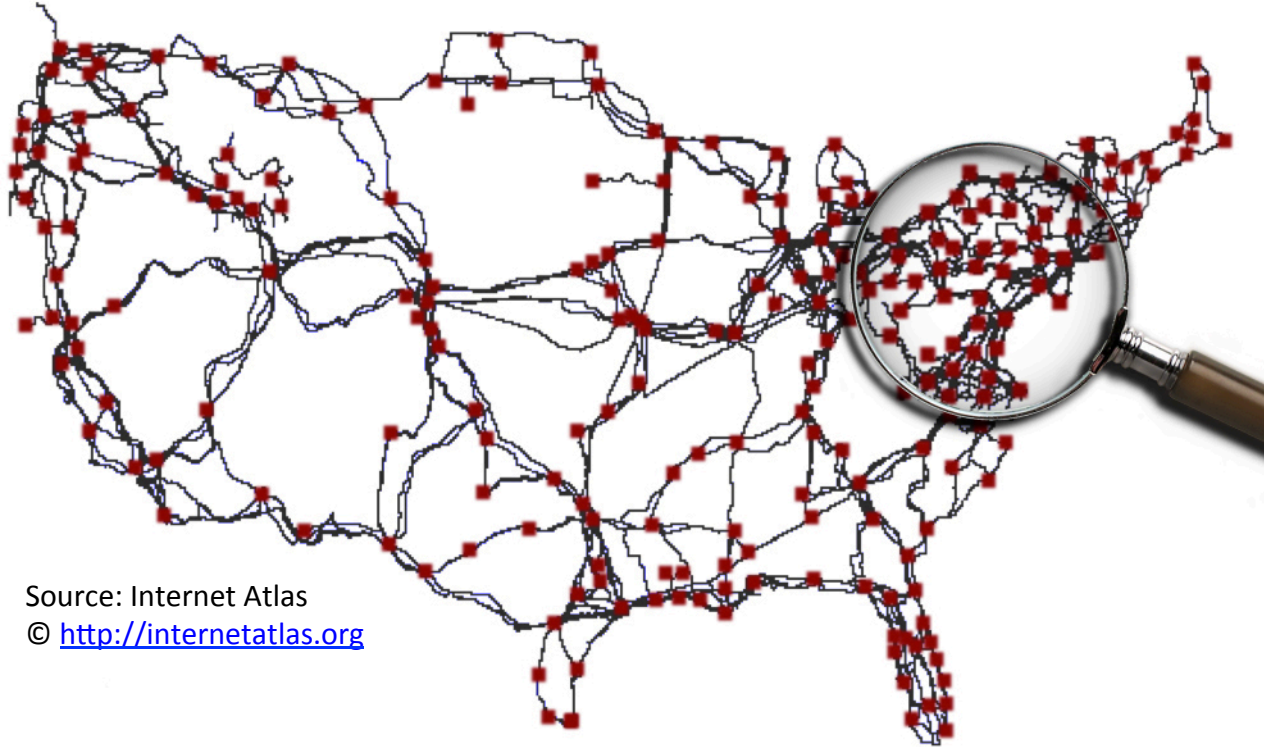
## Worldcom

Address: 4951 Lake Brooke Drive  
Glen Allen VA 23060  
Telephone: 804-527-6338  
Contact Person: Jim Nystrom  
Title: Director  
e-mail: Jim.nystrom@wcom.com  
Internet URL: www.wcom.com  
Offering: "Full array of voice and data services including private line, frame relay, ATM, Internet, Network Engineering and Managed Services, Worldcom is currently the enterprise service provider for the Commonwealth of Virginia including agencies, local and county government"



Source: Virginia County Archive

# Map of US long-haul fiber - details



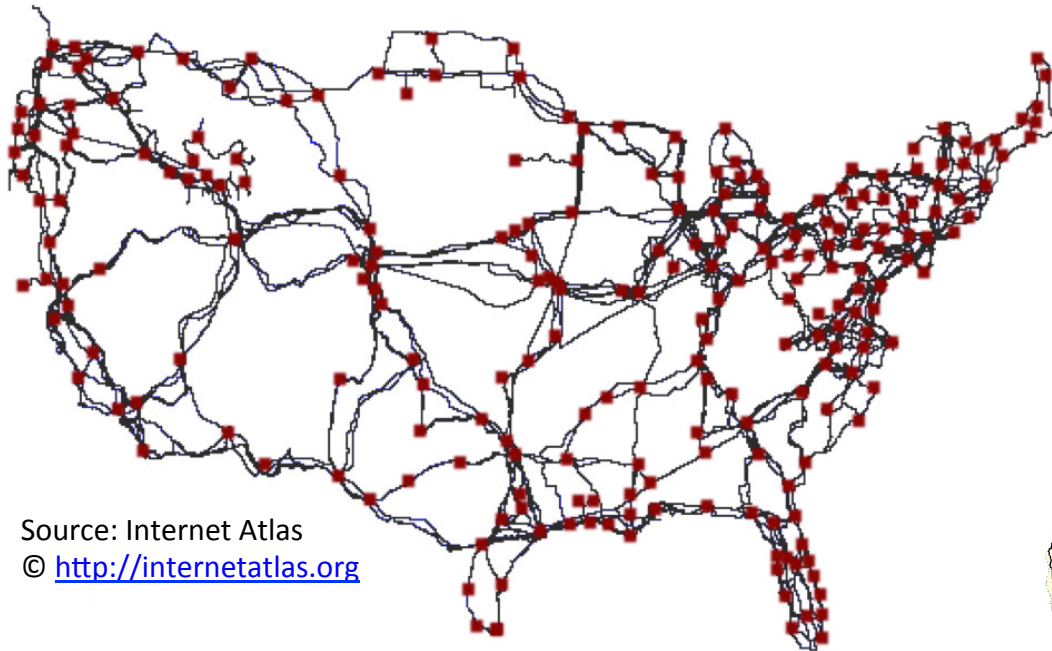
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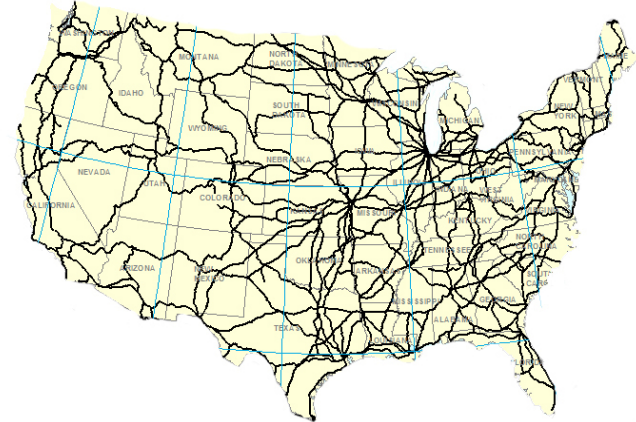


Source: Internet Atlas  
© <http://internetatlas.org>

# Internet vs. other infrastructure



Source: Internet Atlas  
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Railway infrastructure



Roadway infrastructure

# Assessing infrastructure sharing

- Striking characteristic of constructed maps is conduit sharing





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- Striking characteristic of constructed maps is conduit sharing
- Analyze shared risk using **risk matrix**

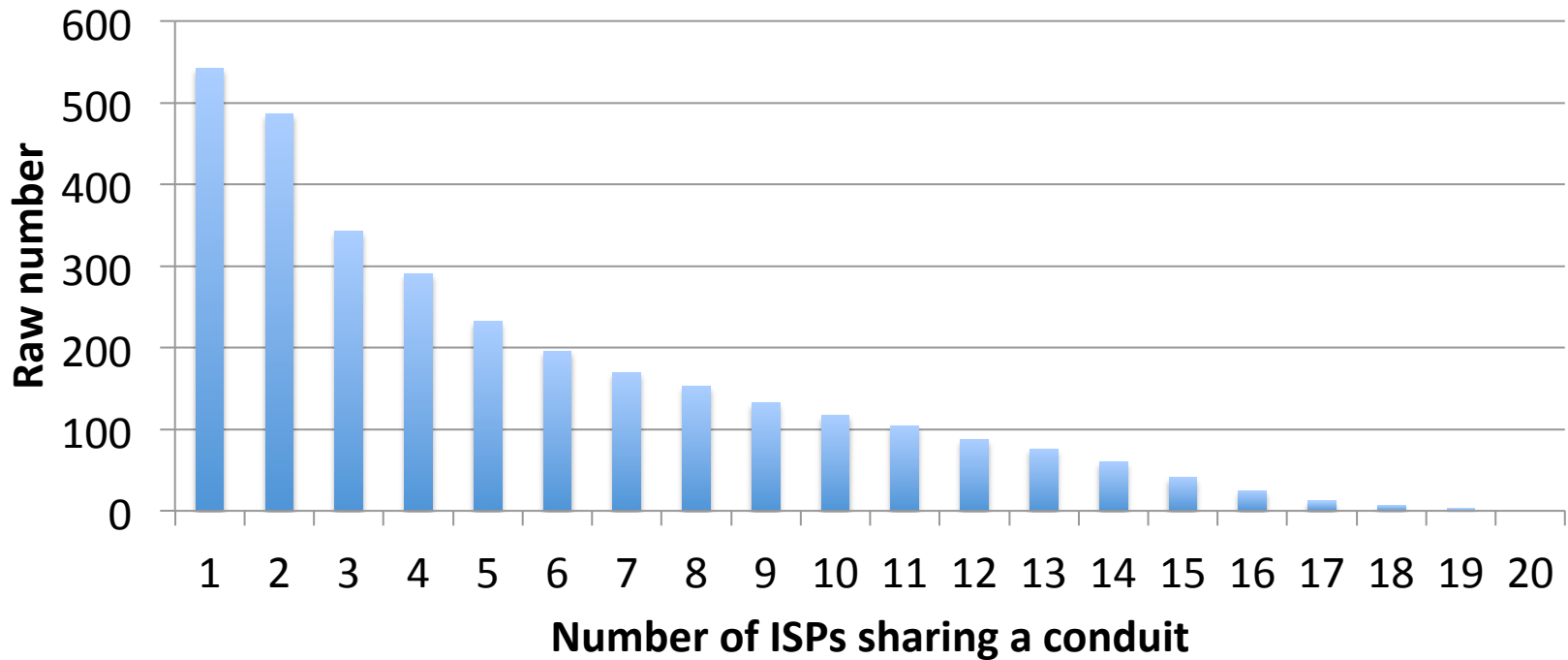
	c1	c2	c3
Level 3	2	2	1
Sprint	2	2	0

- Two notions of risk
  - Connectivity-only
  - Connectivity plus inferred traffic volumes **Visualization!**

# Connectivity-only shared risk

- How many ISPs share a conduit?

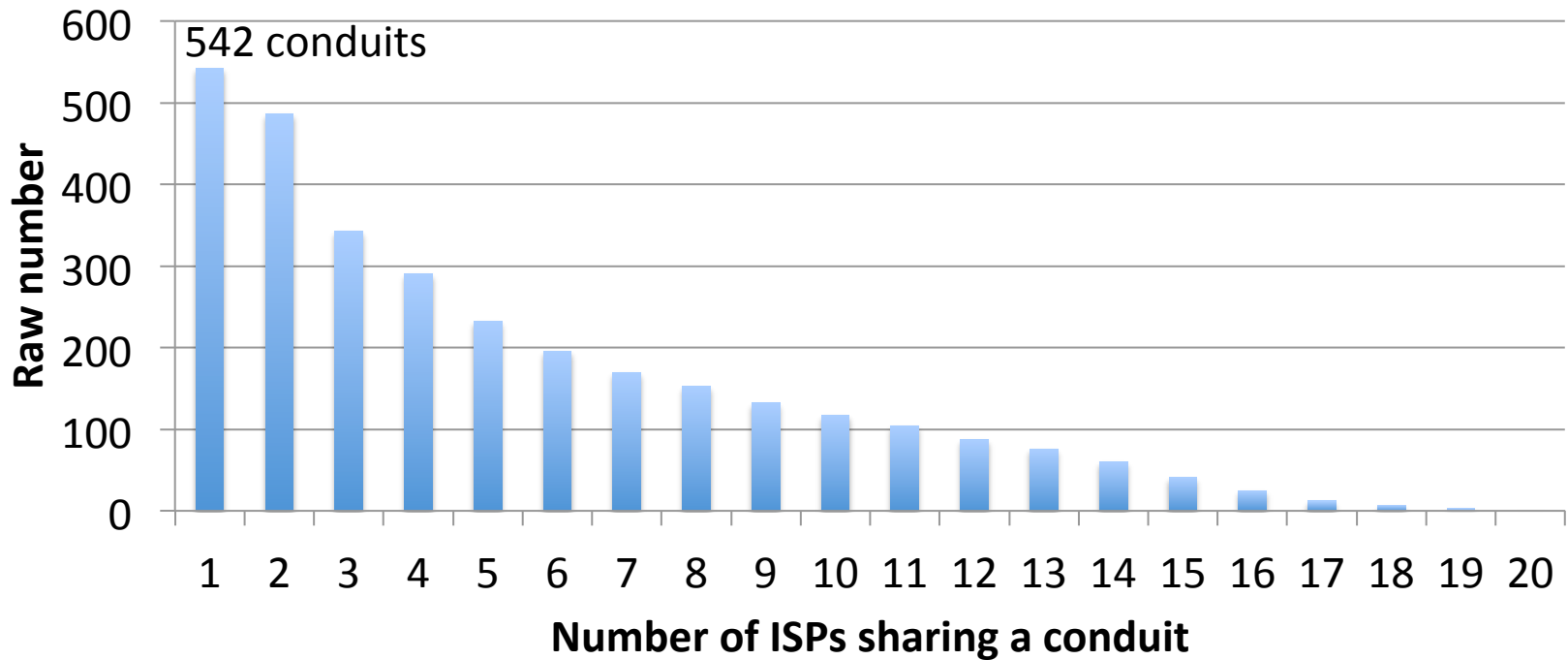
Number of conduits shared by ISPs



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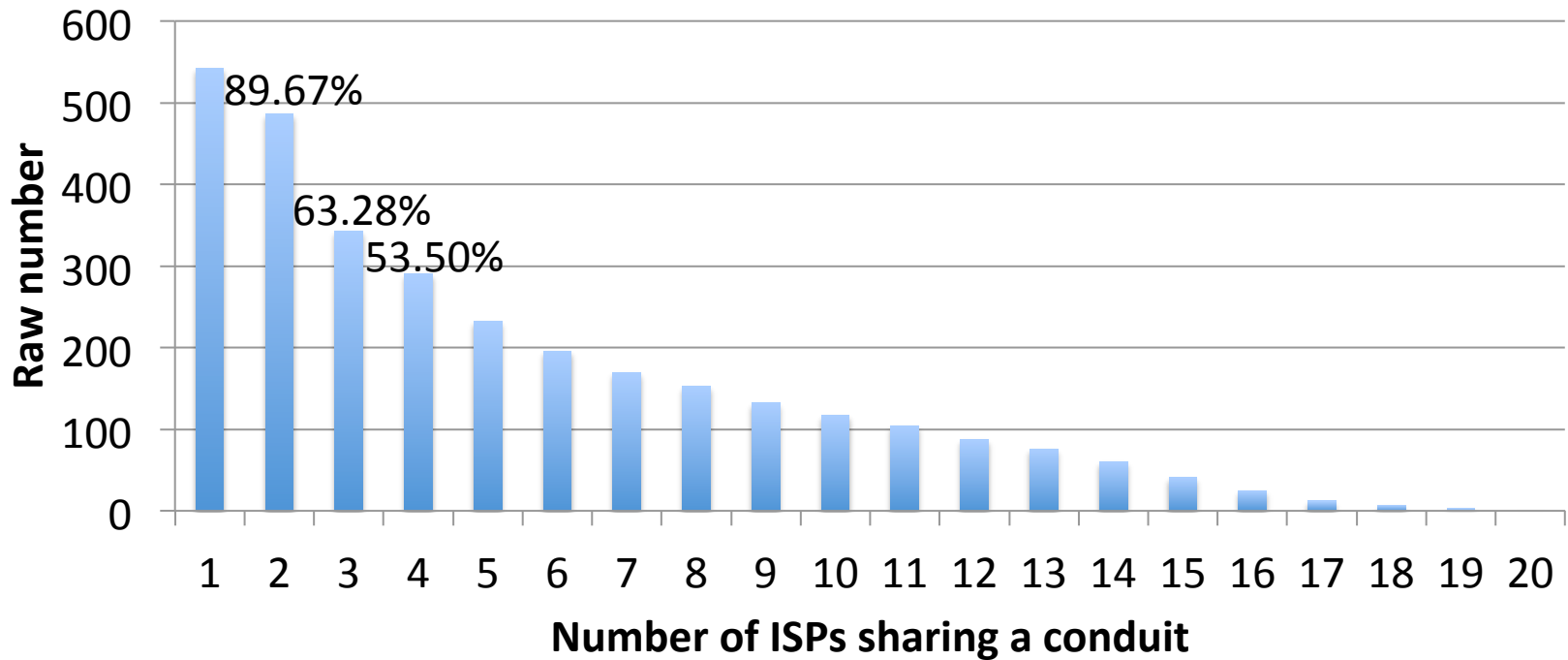
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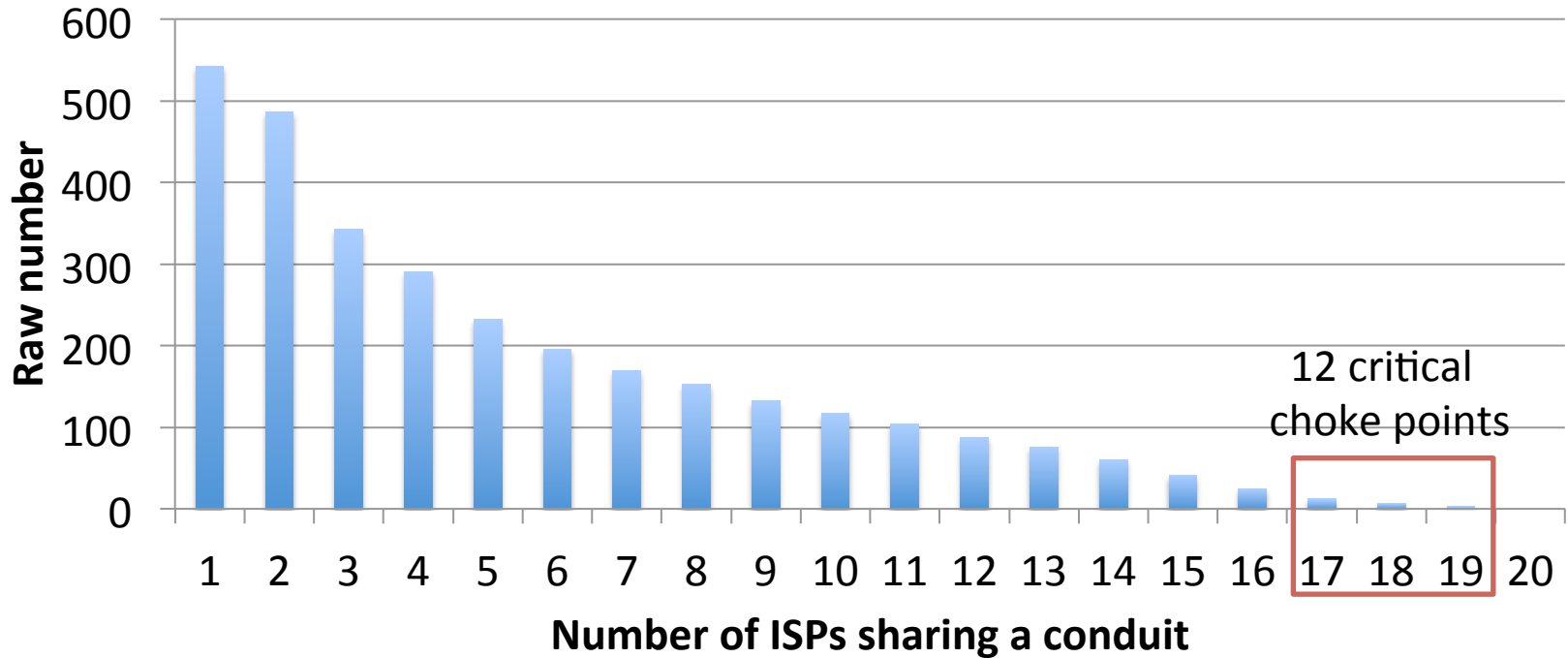
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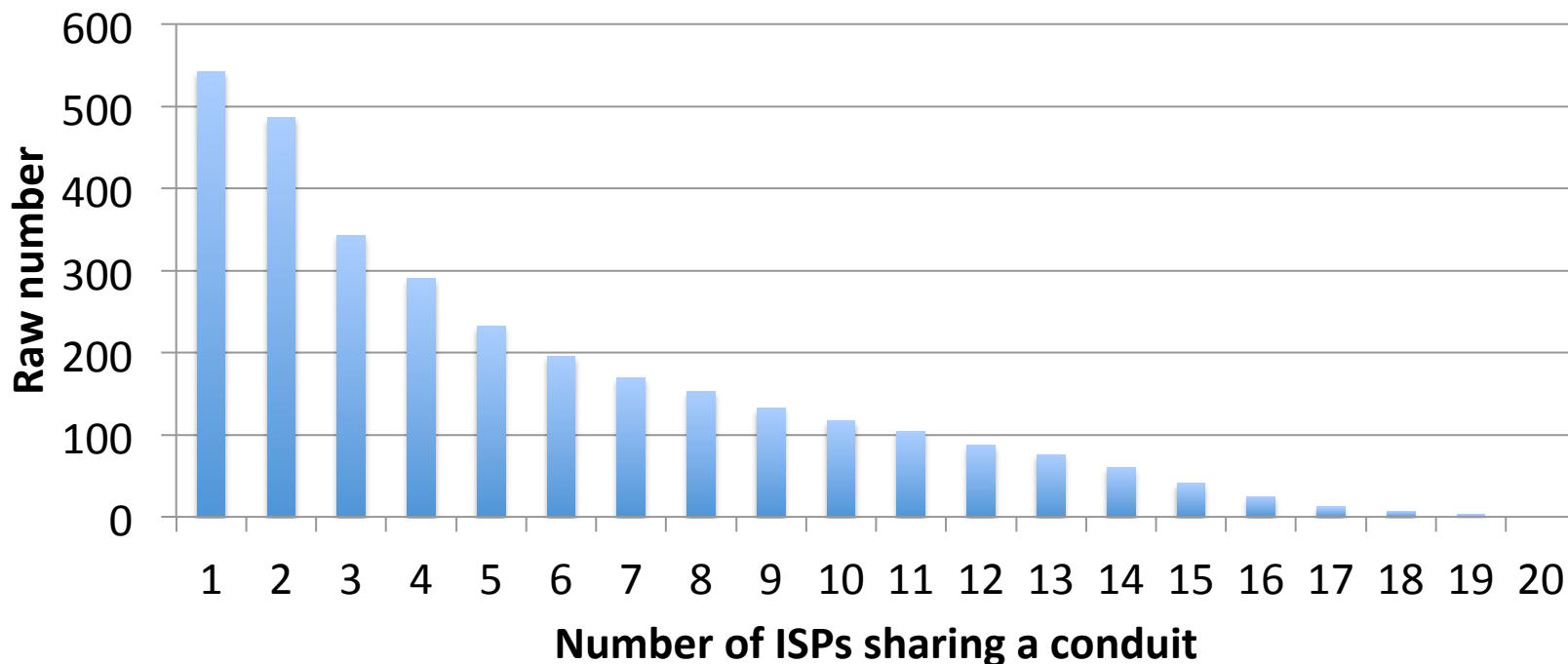
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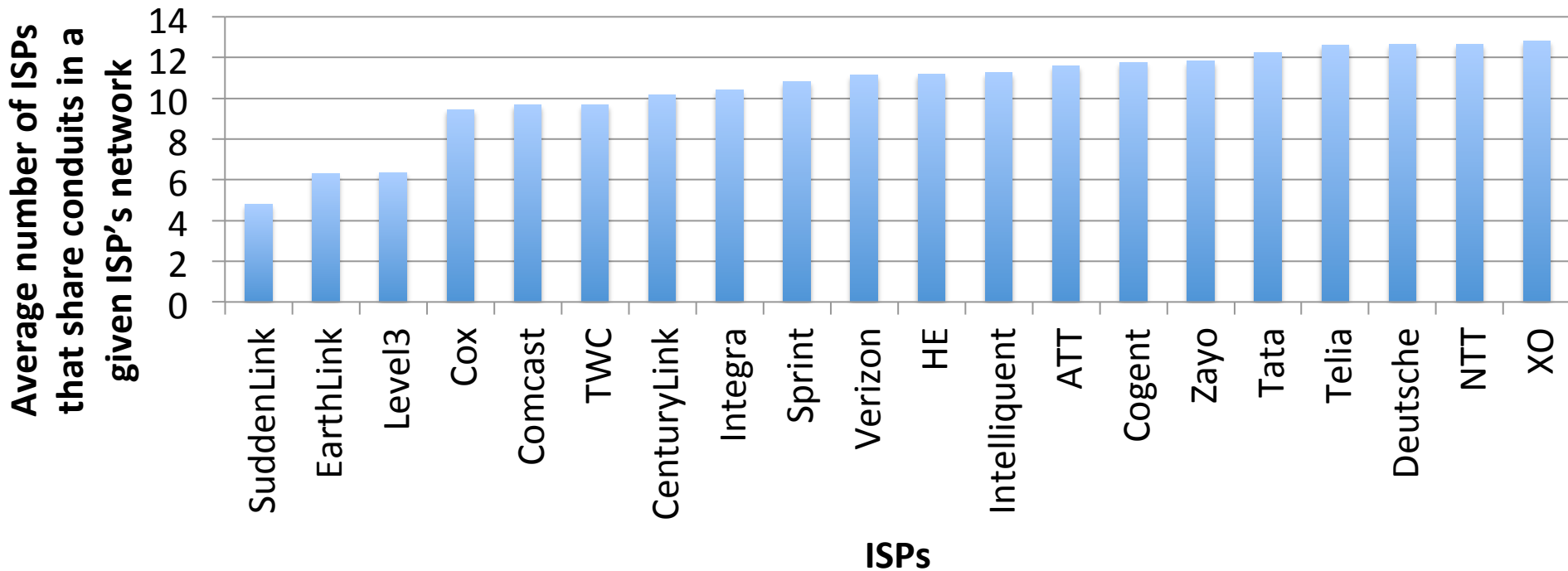


Physical connectivity lacks much diversity that is a hallmark of commonly-known models.

# Connectivity-only shared risk

- Which ISPs do the most infrastructure sharing?

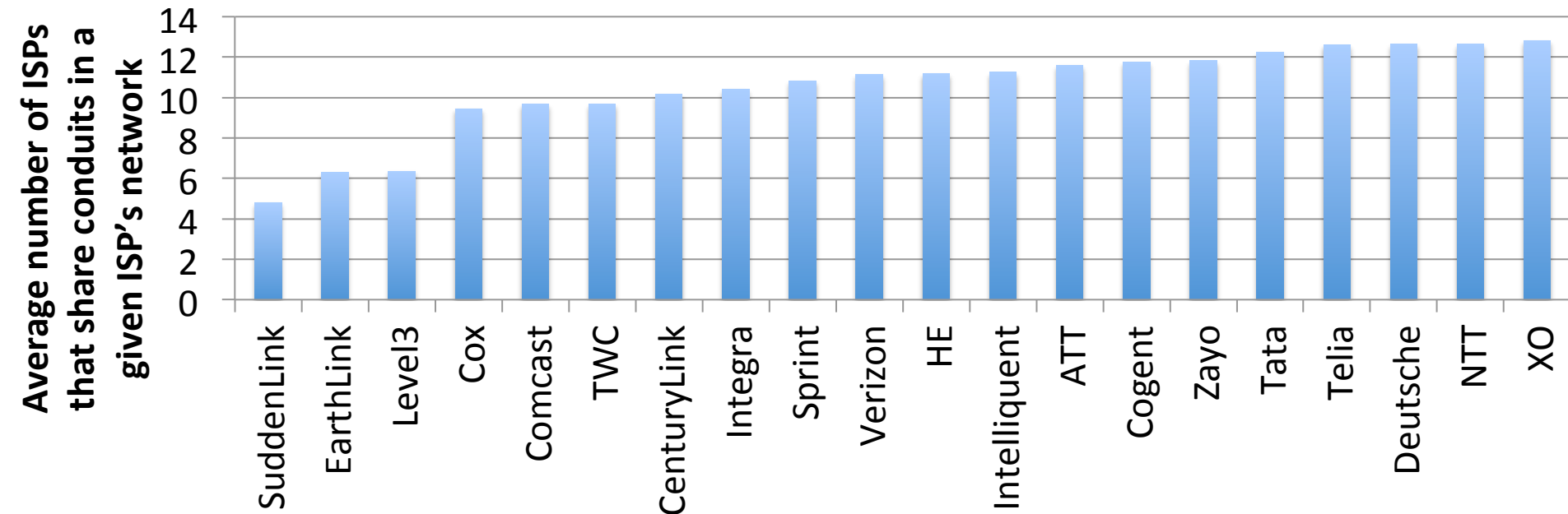
Average sharing



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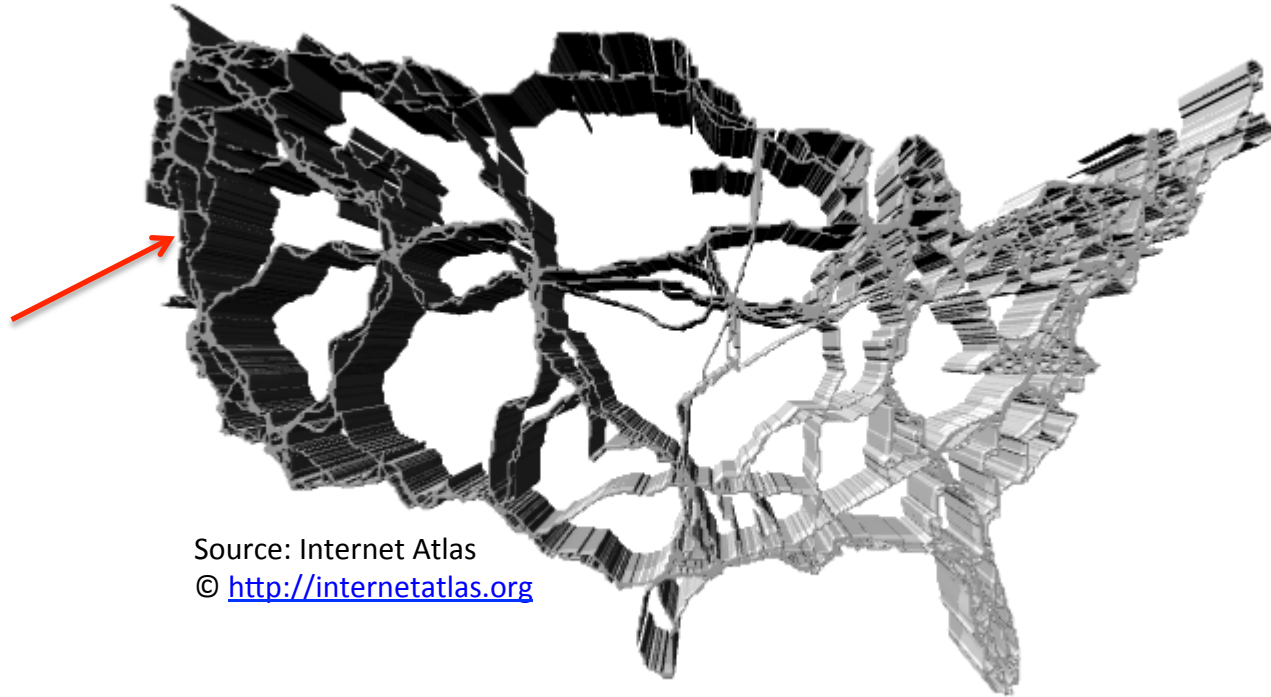
Average sharing



A majority of the ISPs is trading off lower deployment cost for increased resilience.



# Connectivity plus inferred traffic volume



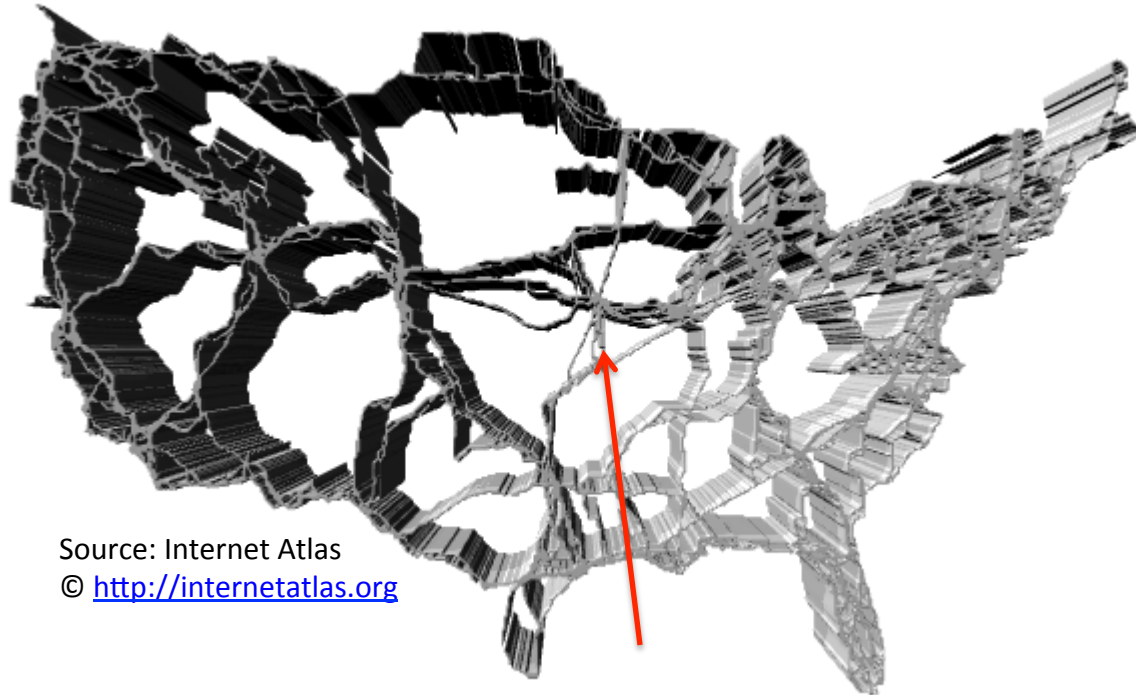
Source: Internet Atlas  
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**Dataset:** Ono from Jan. 01, 2014 to Mar. 31, 2014; stratified into ten 9-day parts

**Thickness**  $\alpha$  number of probes traversing a conduit

**Color**  $\alpha$  number of ISPs

# Connectivity plus inferred traffic volume



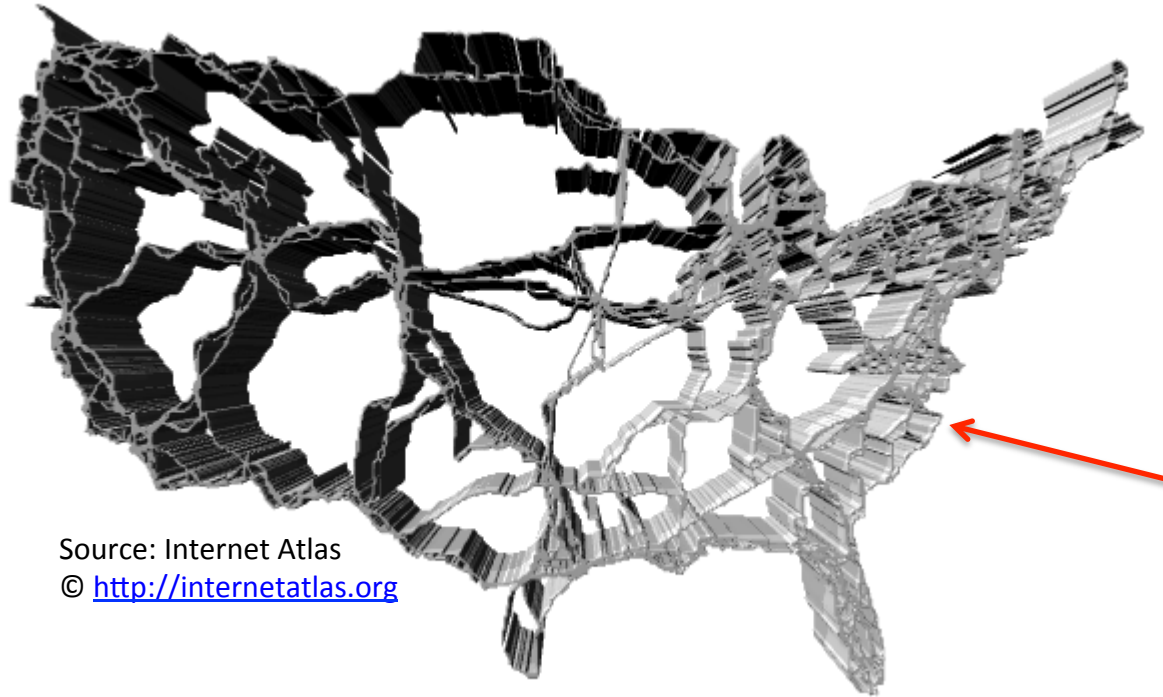
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# Robustness suggestions

- Goal: increase robustness of infrastructure to fiber cuts, or to minimize propagation delay
- Increase network robustness
  - without adding new conduits
  - by adding new conduits
- Minimize propagation delay
  - without adding new conduits
  - by adding new conduits

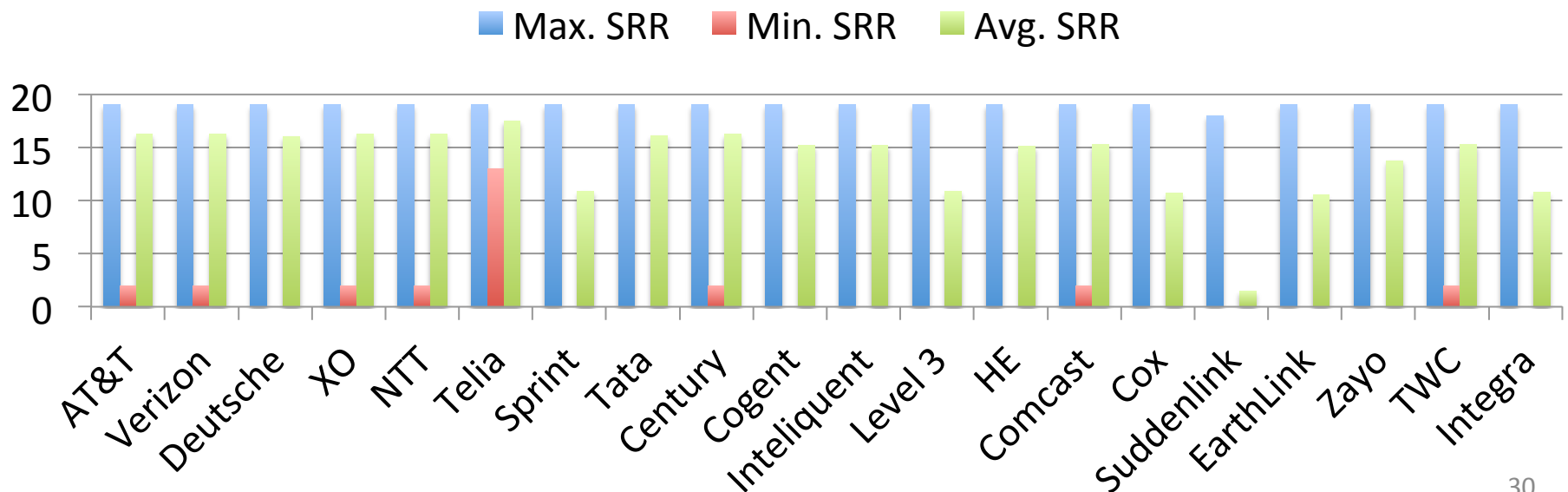
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More results in the paper!

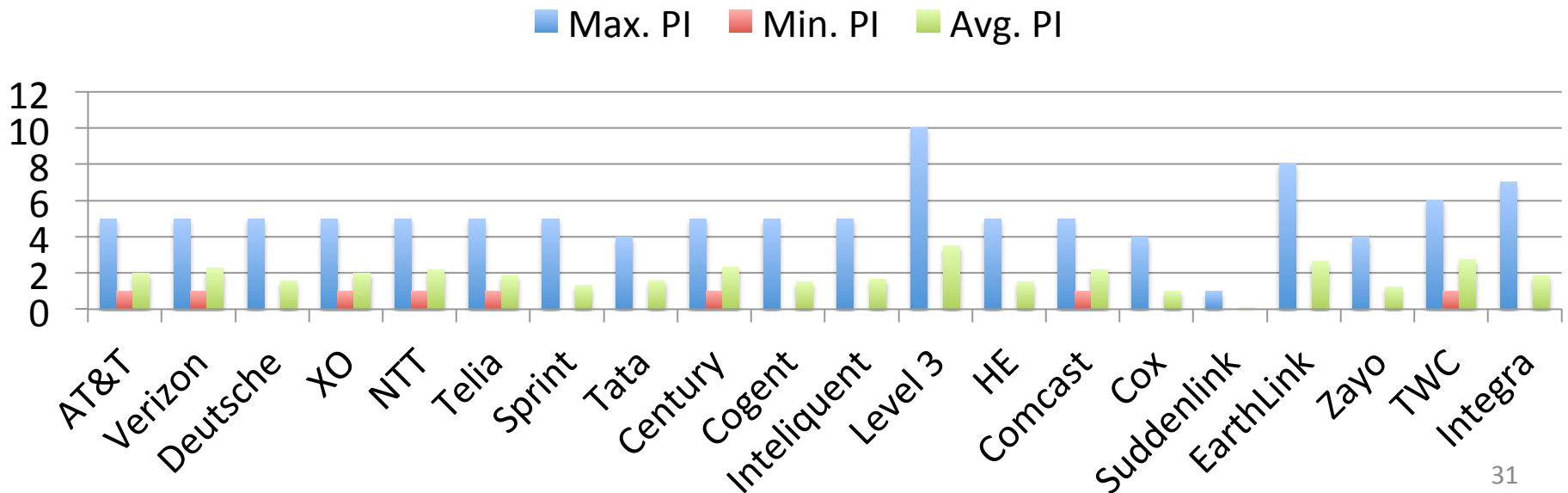
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  - Shared Risk Reduction (SRR)



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- Increasing network robustness without adding new conduits
  - Shared Risk Reduction (SRR)
  - Path Inflation (PI)



# Implications for policy makers

- Robustness suggestions conflict with currently-discussed policies
  - Title II enables FCC to specify providers as “common carriers”
  - Recent decision: reclassify broadband providers as common carriers
  - Provider’s infrastructure will be available to third parties



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If Title II classification is upheld, there will be a significant *increase* in shared risk.

# Other implications

- For ISPs
  - Provisioning and deployment
  - Competitive advantage
  - Safest physical communication backup
- For Researchers
  - How to deploy the identified conduits
  - Link Exchanges?
- More in the paper

# Thank you!

Datasets are available to the community at [www.predict.org](http://www.predict.org)

## Questions?

Acknowledgement:

Thank you Edgescope project (Northwestern Univ.) for Ono dataset!