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

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Outline

- Definition
- Building a Map
- Risks
- Mitigating risks
- Discussion
- Future Work

Definitions

Long-haul link

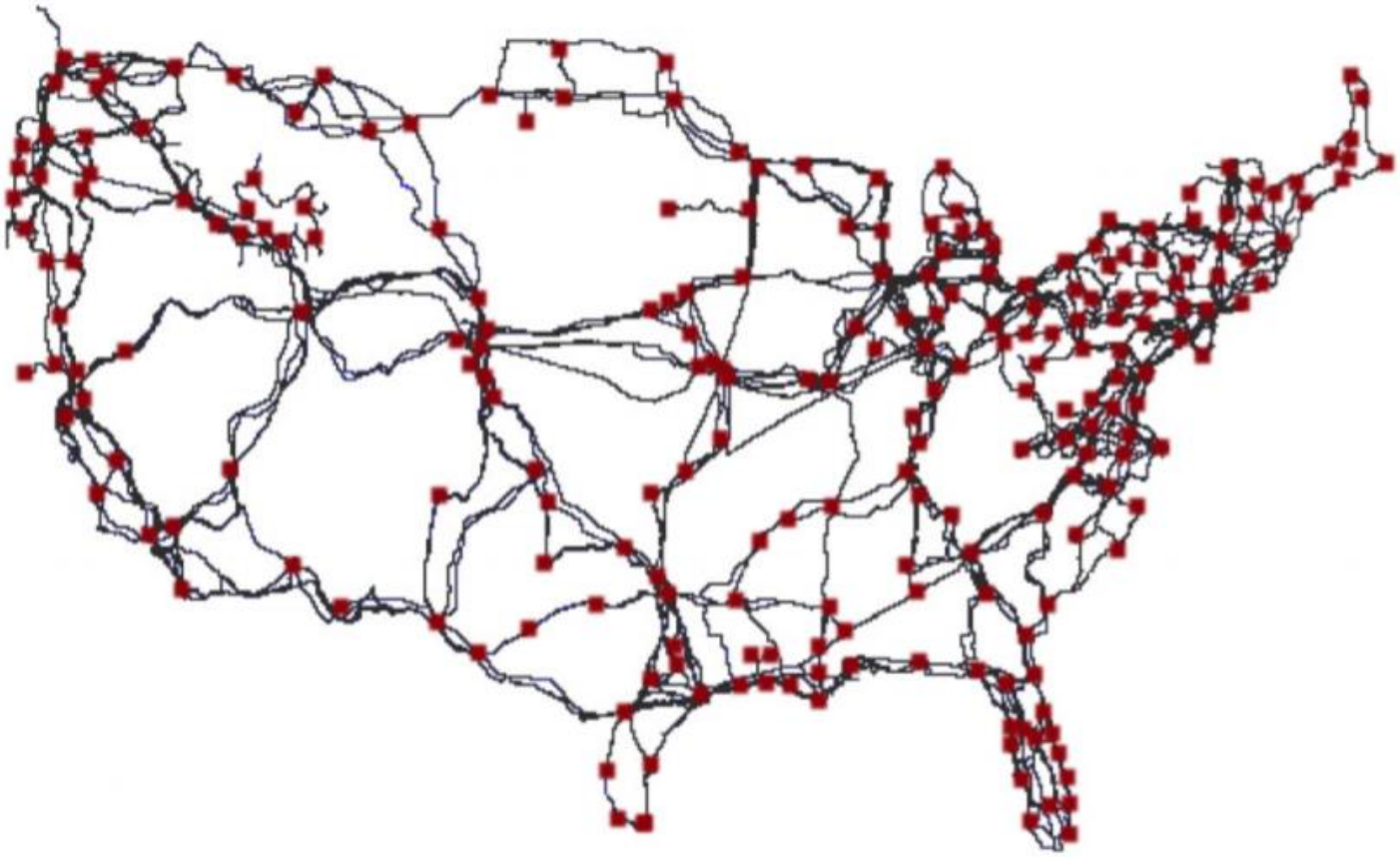
Link that spans at least 30 miles,
or that connects population centers of at least 100,000 people,
or that is shared by at least 2 providers.

Building a US Long-haul Fiber Map

Methodology

1. Build an Initial Map using Internet Atlas Project
2. Checking the Initial Map for conduit sharing
3. Build an Augmented Map with no explicit geocoding
4. Validate the Augmented Map conduit sharing

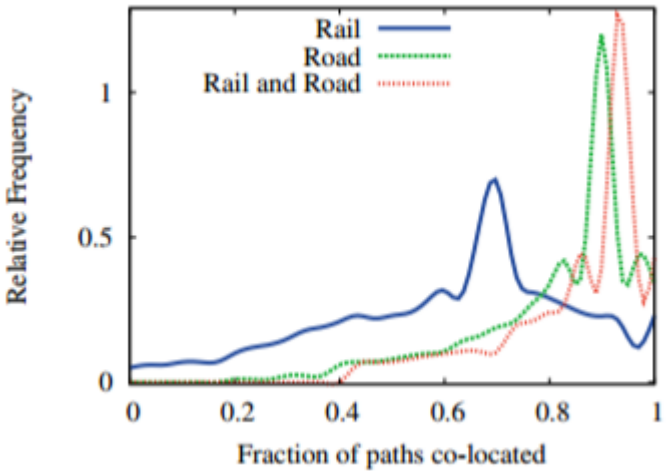
US Long-haul Fiber Map



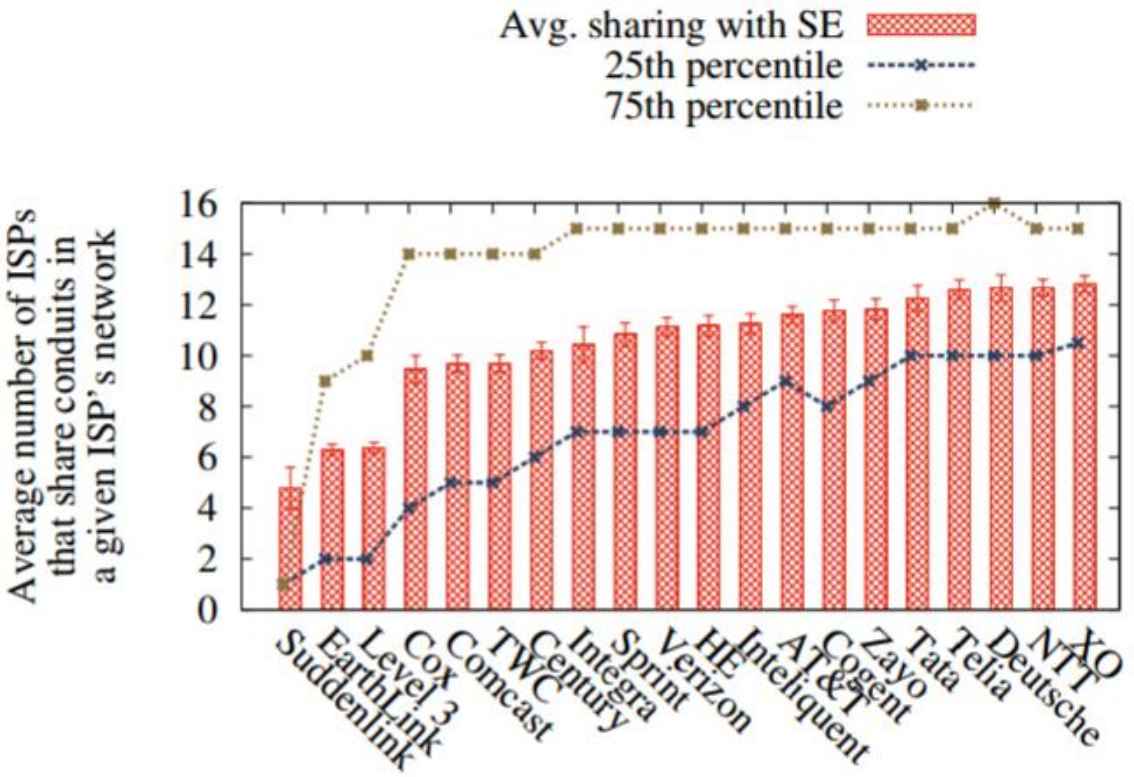
Infrastructure and Correlation with physical links

Figure 2: NationalAtlas roadway infrastructure locations.

Figure 3: NationalAtlas railway infrastructure locations.

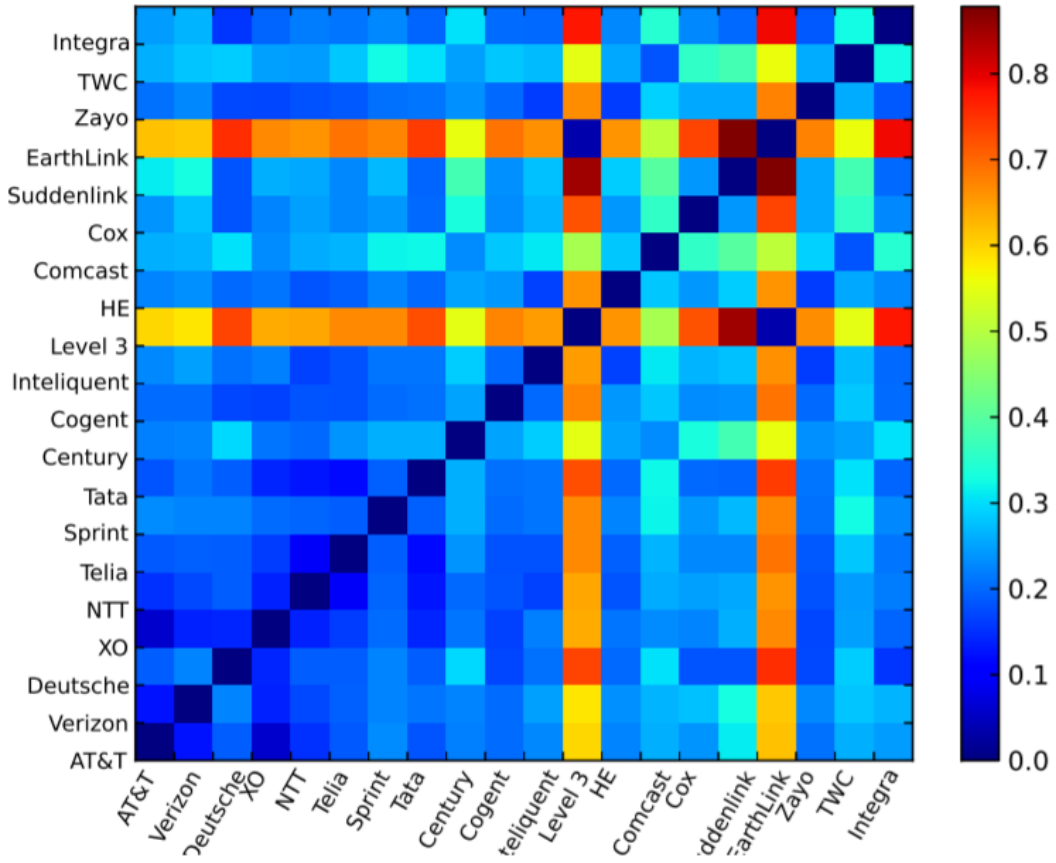


Raw Number of shared conduits by ISPs



Similarity of risk profiles of ISPs

fiber deployment, level of infrastructure sharing



Traffic

Edgescope Project data - 4,908,223 Traceroute from diverse locations

4,908,223 Traceroute from diverse locations

Location	Location	# Probes
West Palm Beach, FL	Boca Raton, FL	155774
Lynchburg, VA	Charlottesville, VA	155079
Sedona, AZ	Camp Verde, AZ	54067
Bozeman, MT	Billings, MT	50879
Billings, MT	Casper, WY	50818
Casper, WY	Cheyenne, WY	50817
White Plains, NY	Stamford, CT	25784
Amarillo, TX	Wichita Falls, TX	16354
Eugene, OR	Chico, CA	12234
Phoenix, AZ	Dallas, TX	9725
Salt Lake City, UT	Provo, UT	9433
Salt Lake City, UT	Los Angeles, CA	8921
Dallas, TX	Oklahoma City, OK	8242
Wichita Falls, TX	Dallas, TX	8150
Seattle, WA	Portland, OR	8094
Eau Claire, WI	Madison, WI	7476
Salt Lake City, UT	Cheyenne, WY	7380
Bakersfield, CA	Los Angeles, CA	6874
Seattle, WA	Hillsboro, OR	6854
Santa Barbara, CA	Los Angeles, CA	6641

East-origin to west- bound

Location	Location	# Probes
Trenton, NJ	Edison, NJ	78402
Kalamazoo, MI	Battle Creek, MI	78384
Dallas, TX	Fort Worth, TX	56233
Baltimore, MD	Towson, MD	46336
Baton Rouge, LA	New Orleans, LA	46328
Livonia, MI	Southfield, MI	46287
Topeka, KS	Lincoln, NE	46275
Spokane, WA	Boise, ID	44461
Dallas, TX	Atlanta, GA	41008
Dallas, TX	Bryan, TX	39232
Shreveport, LA	Dallas, TX	39210
Wichita Falls, TX	Dallas, TX	39180
San Luis Obispo, CA	Lompoc, CA	32381
San Francisco, CA	Las Vegas, NV	22986
Wichita, KS	Las Vegas, NV	22169
Las Vegas, NV	Salt Lake City, UT	22094
Battle Creek, MI	Lansing, MI	15027
South Bend, IN	Battle Creek, MI	14795
Philadelphia, PA	Allentown, PA	12905
Philadelphia, PA	Edison, NJ	12901

West-origin to east-bound

Top 10 ISPs in terms of number of conduits carrying probe traffic

Findings:

- Level3 is most widely used infrastructure
- XO also considered tier-1 ISP carries only 25% of the volume

ISP	# conduits
Level 3	62
Comcast	48
AT&T	41
Cogent	37
SoftLayer	30
MFN	21
Verizon	21
Cox	18
CenturyLink	16
XO	15

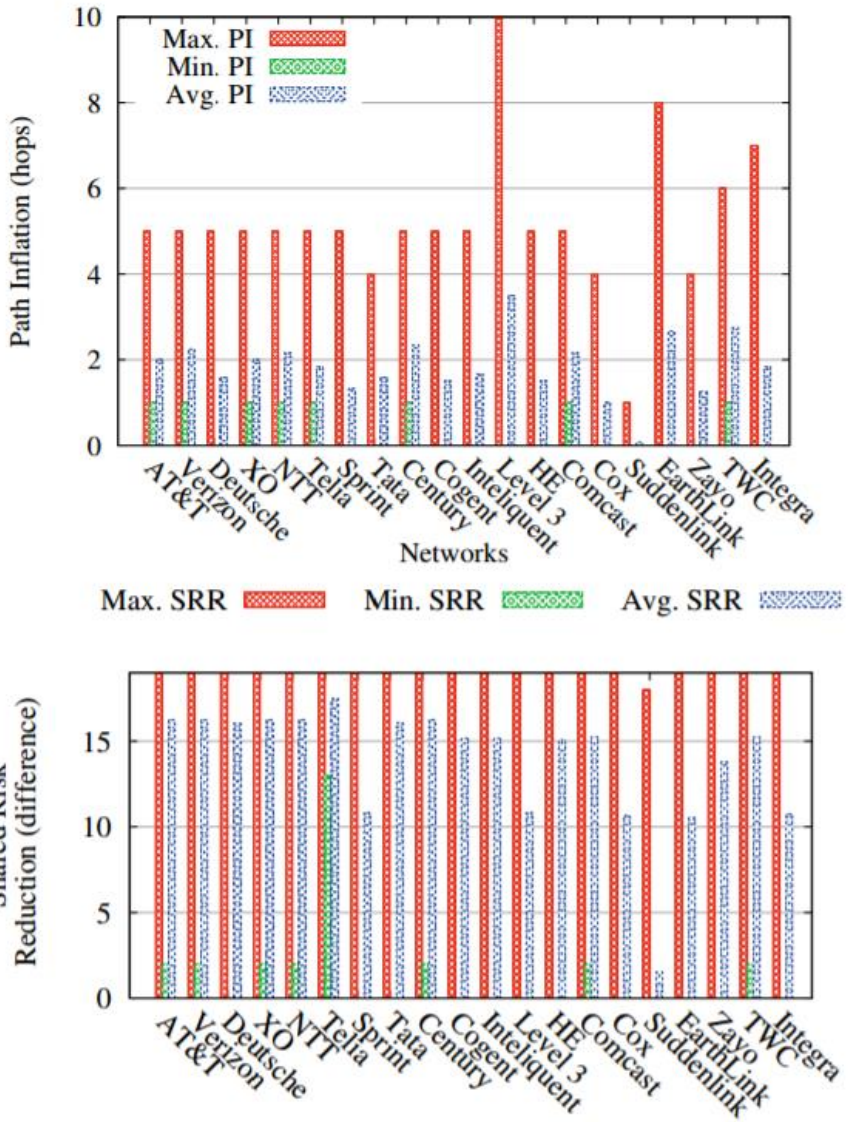
Mitigating Risks

Robustness suggestion infrastructure for 12 heavylinks

- Utilizing existing conduits
- Carefully choose ISPs to peer

Metrics:

- Path Inflation
- Shared Risk Reduction



Mitigating Risks

Increasing Network Robustness (I) – peering suggestions

Table 5: Top 3 best peering suggested by the optimization framework for optimizing the twelve shared links.

ISP	Suggested Peering
AT&T	Level 3 | Century | Verizon
Verizon	Level 3 | Century | AT&T
Deutsche	Level 3 | AT&T | Century
XO	Level 3 | AT&T | Century
NTT	Level 3 | AT&T | Century
Telia	Level 3 | Century | AT&T
Sprint	Level 3 | AT&T | Century
Tata	Level 3 | AT&T | Century
Century	Level 3 | AT&T | Verizon
Cogent	Level 3 | AT&T | CenturyLink
Inteliquent	Level 3 | Century | AT&T
Level 3	Century | Integra | EarthLink
HE	Level 3 | AT&T | Century
Comcast	Level 3 | AT&T | Verizon
Cox	AT&T | Level 3 | Century
Suddenlink	Level 3 | AT&T | Sprint
EarthLink	Tata | Integra | AT&T
Zayo	Level 3 | AT&T | Century
TWC	Level 3 | AT&T | Verizon
Integra	Level 3 | Sprint | Century

Mitigating Risks

Increasing Network Robustness (II) – adding links to lower shared risk

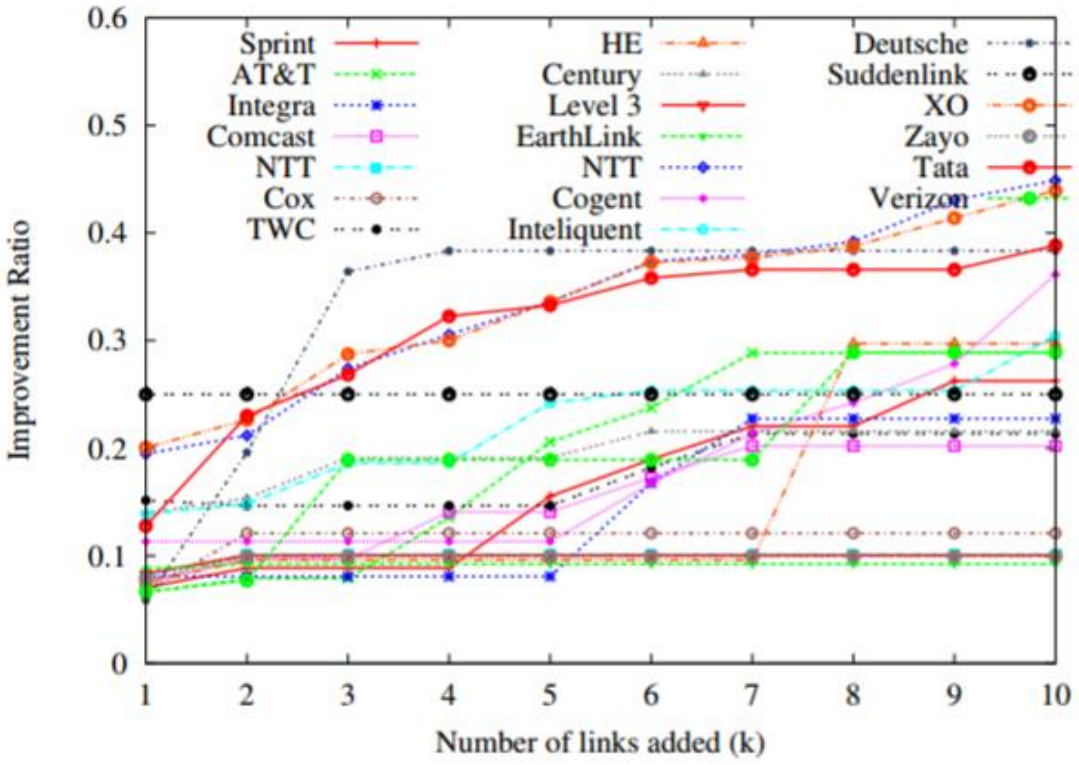


Figure 11: Potential improvements to ISP

Mitigating Risks

Reducing Propagation Delay between individual city pairs

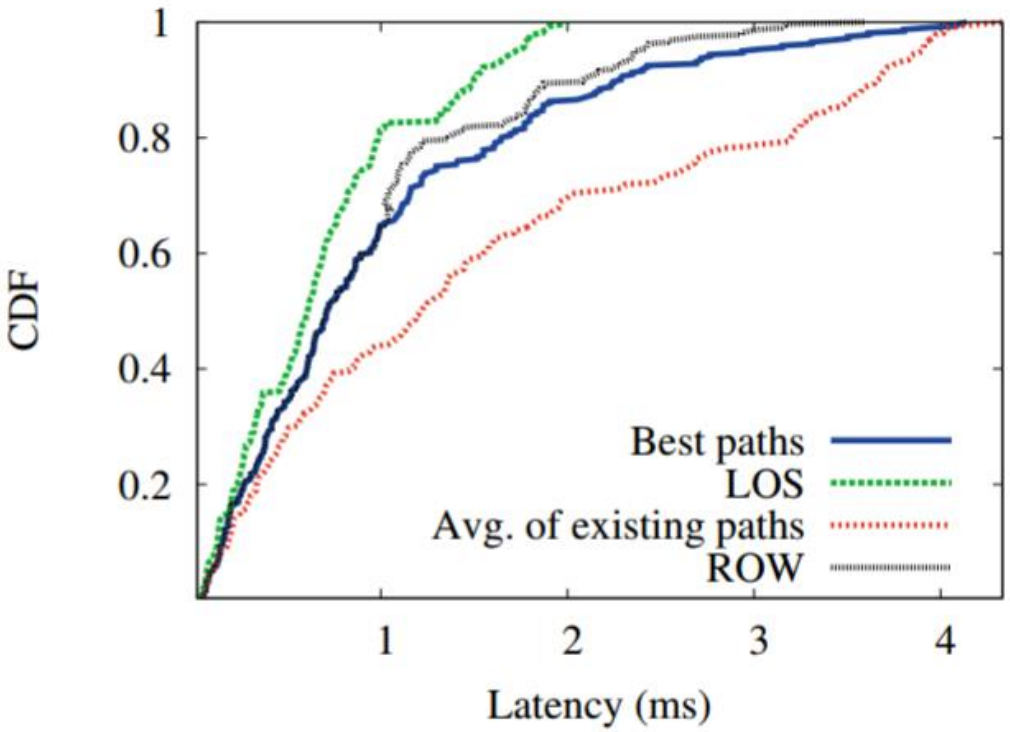


Figure 12: Comparison of best links against avg. latencies of links, ROW links and LOS links.

Discussion

- Map gives very quick and easy to understand overview
- Concern for FCCs Title II classification
- Based on the map future improvements to the network are easy to see

Future work

- Further improve coverage of the long-haul map
- Add Data from Metro networks
- Continue link validation process
- Focus on traffic an propagation delay

Thank you for listening

Question?