The Flattening Internet Topology:
Natural Evolution, Unsightly Barnacles or Contrived Collapse?

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Overview

Part I

- Objectives, Motivation, Background Information

Part II

- Measurement Methodology & Results

Part III

- Implications, Conclusions, Future Work

Objectives

- Determine if content providers are deploying private WANs
- Examine the extent of deployment
- Identify effects on Internet topology

Our Motivation

Original Problem

- Identify and quantify compute utility operational costs

What We Learned

- There are some significant trends developing in infrastructure to support emerging “Cloud services”

Trends

Reduce costs by owning and operating infrastructure

- Companies like Google and Microsoft are betting big
- This is evidenced by the roll-out of massive, distributed data centers
- Need new data centers for scale, power density (also, little available data center space on the market)

Provide end-to-end service delivery

- Cloud service providers are deploying private WANs
- Offers numerous potential benefits

Evidence: Google's Massive Data Centers

Construction started on 10 data centers since mid-2006

- Two ~100,000 ft^2 data centers at each of these locations[1]:
  - The Dalles, OR
  - Lenoir, NC
  - Goose Creek, SC
  - Pryor, OK
  - Council Bluffs, IA
- Cost of each site estimated at $600M ($3,000/ft^2, with equip.)
- Google's CEO hinted larger data centers are planned:
  - "…in a year or two the very large ones will be the small ones, because the growth rate is such that we keep building even larger ones, and that's where a lot of the capital spending in the company is going." – *Wired* interview

[1] http://www.datacenterknowledge.com

Summary of Internet Architecture

- The Internet evolved to a 3-tiered architecture
- Tier-1 ISPs
  - Interconnected backbone providers
- Tier-2 ISPs
  - Regional networks
- Tier-3 ISPs
  - Access networks
- Content providers typically connect via Tier-3
- Tier-1 transit customer (Tier-2) traffic for a fee, exchange traffic with (Tier-1) peers for free

Motivations for Change

Why would content providers build their own WAN?

1. Business reasons
   - Risk mitigation; e.g., reduce dependencies
   - Cost control; reduce/eliminate existing costs
2. Overcome technical challenges
   - e.g., more control over quality of service
3. Exploit opportunities
   - Purchase dark fiber below cost of new fiber installation

Methodology

- Selected one server from each of the 20 most popular content providers (identified by Alexa.com)
- Queried these servers from 50 public, globally distributed `traceroute` servers
- For each discovered path, we:
  - Determined the organization ID for each discovered IP address
  - mapped the distinct router IP addresses to Autonomous System (AS) numbers to identify hops on Tier-1 ISPs
- FQDNs and `traceroute` latency estimates used to determine geographic location of routers

Example Measurement

traceroute from Othello server (UK) to Google server (US):

Hop	Hostname	IP address	AS #	Latency Measurements		
1	*.uk.othellotech.net	80.82.140.227	29527	0.239 ms	0.201 ms	0.187ms
2	transit2.as29527.net	80.82.140.42	29527	0.412 ms	0.401 ms	0.389 ms
3	peering1.as29527.net	80.82.140.43	29527	0.484 ms	0.476 ms	0.463 ms
4	unknown-LIPEX NA	193.109.219.50	N/A	0.941 ms	1.048 ms	1.163 ms
5	unknown-LINX-PEER-1	195.66.224.125	702	0.890 ms	1.102 ms	1.089 ms
6	unknown-GOOGLE	209.85.252.40	15169	1.323 ms	1.238 ms	1.224 ms
7	unknown-GOOGLE	72.14.236.216	15169	71.532 ms	71.396 ms	68.750 ms
8	unknown-GOOGLE	216.239.46.227	15169	90.721 ms	90.755 ms	90.744 ms
9	unknown-GOOGLE	72.14.233.115	15169	82.481 ms	136.491 ms	136.489 ms
10	unknown-GOOGLE	72.14.233.56	15169	136.401 ms	136.359 ms	136.349 ms
11	unknown-GOOGLE	72.14.233.119	15169	139.580 ms	140.230 ms	140.225 ms
12	unknown-GOOGLE	72.14.233.54	15169	186.172 ms	143.874 ms	146.345 ms
13	unknown-GOOGLE	72.14.233.27	15169	141.707 ms	144.377 ms	147.607 ms
14	unknown-GOOGLE	216.239.47.34	15169	145.104 ms	157.081 ms	147.812 ms
15	po-in-f104.google.com	72.14.253.104	15169	145.284 ms	145.394 ms	145.386 ms

Metrics

In total, we collected 20x50=1,000 “paths”

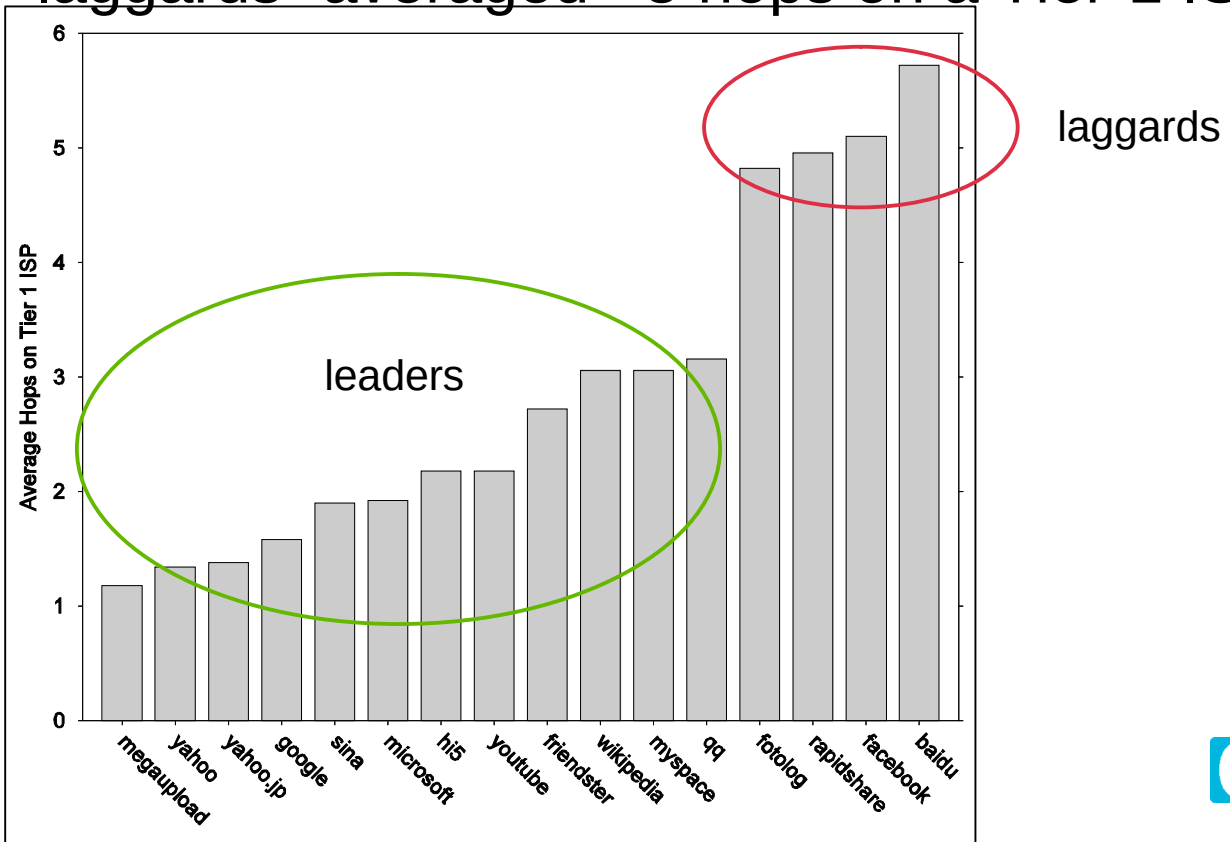
We compared the paths using four different metrics:

- Average number of hops on Tier-1 networks
- Number of paths that involved no Tier-1 ISPs
- Degree: number of different ISPs a content provider connects to
- Number of geographic locations a content provider’s routers were found

Measurement Results: Avg. Tier-1 Hops

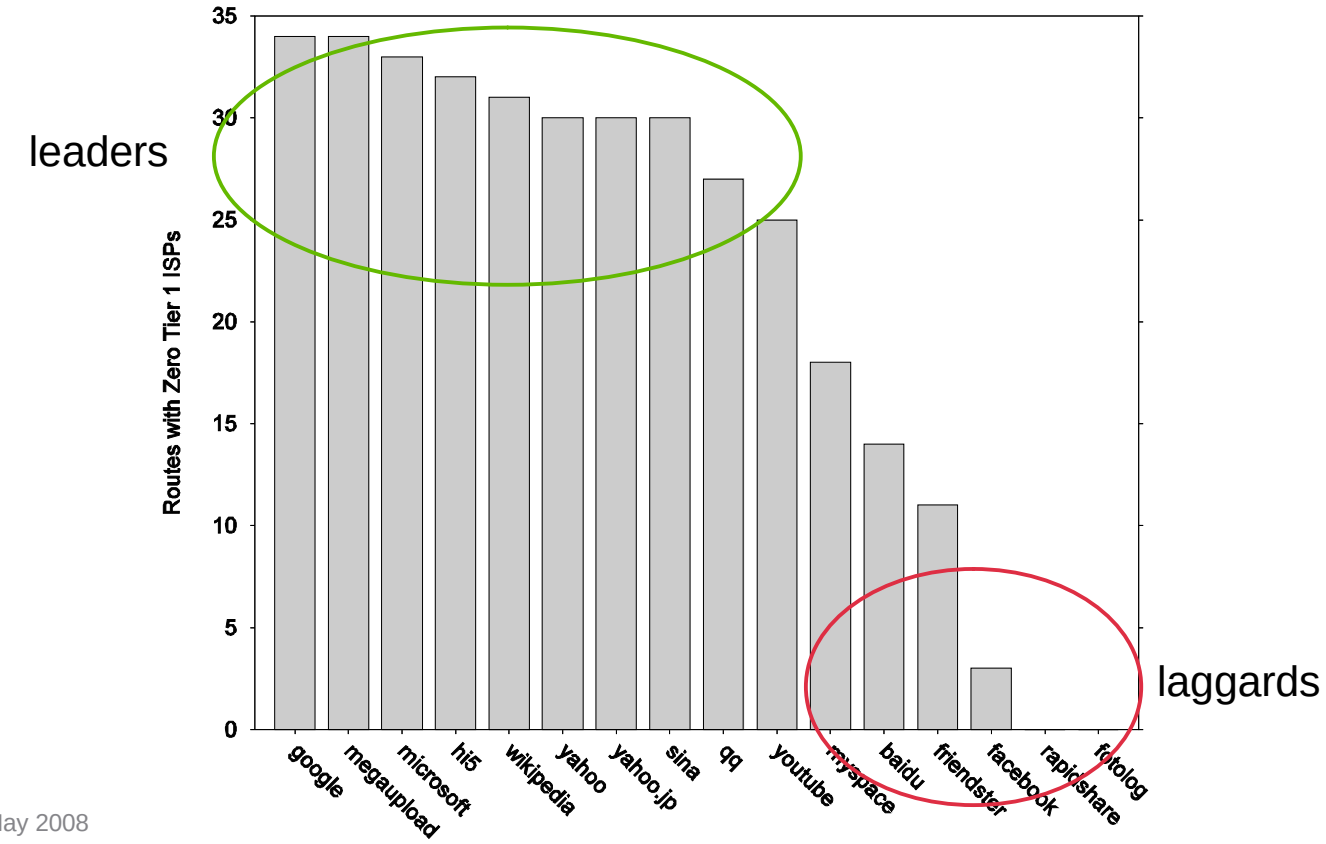
A dichotomy appears to be forming:

- Paths to the “leaders” (such as the “Big 3” - Google, Yahoo!, Microsoft) averaged 1-3 hops on a Tier-1 ISP network
- Paths to the “laggards” averaged ~5 hops on a Tier-1 ISP



Measurement Results: No Tier-1 Hops

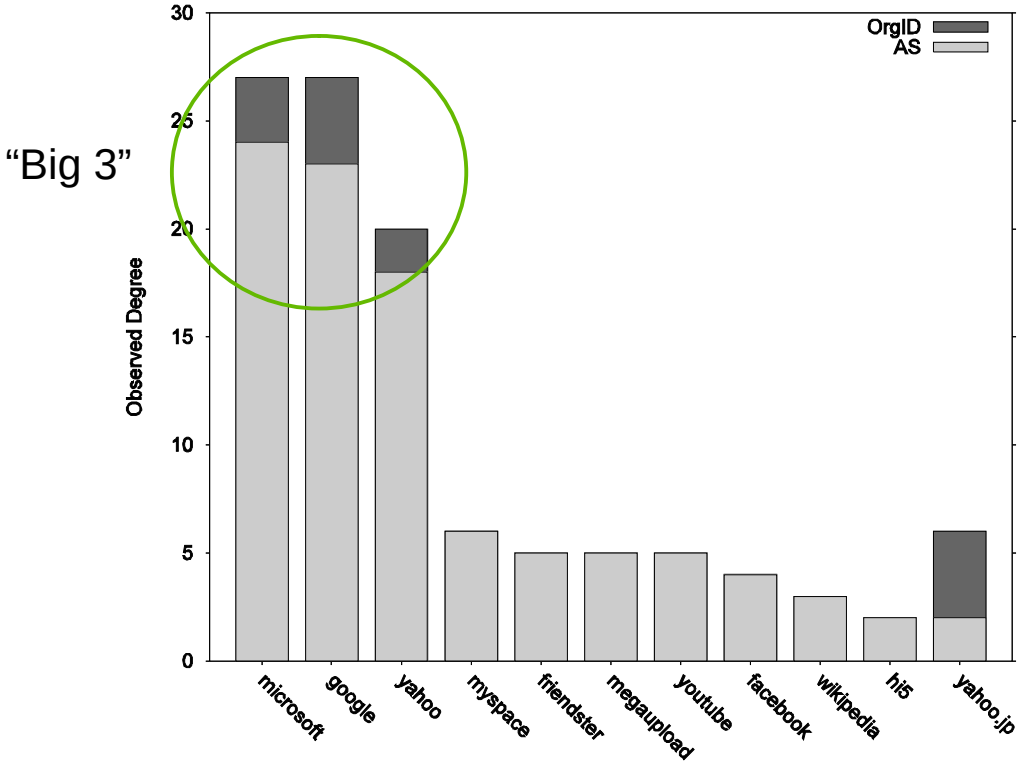
- Paths to the “leaders” had 25-34 (out of 50) paths with no hops on Tier-1 networks
- “laggards” are still utilizing Tier-1 ISPs in most/all paths



Measurement Results: Connectedness

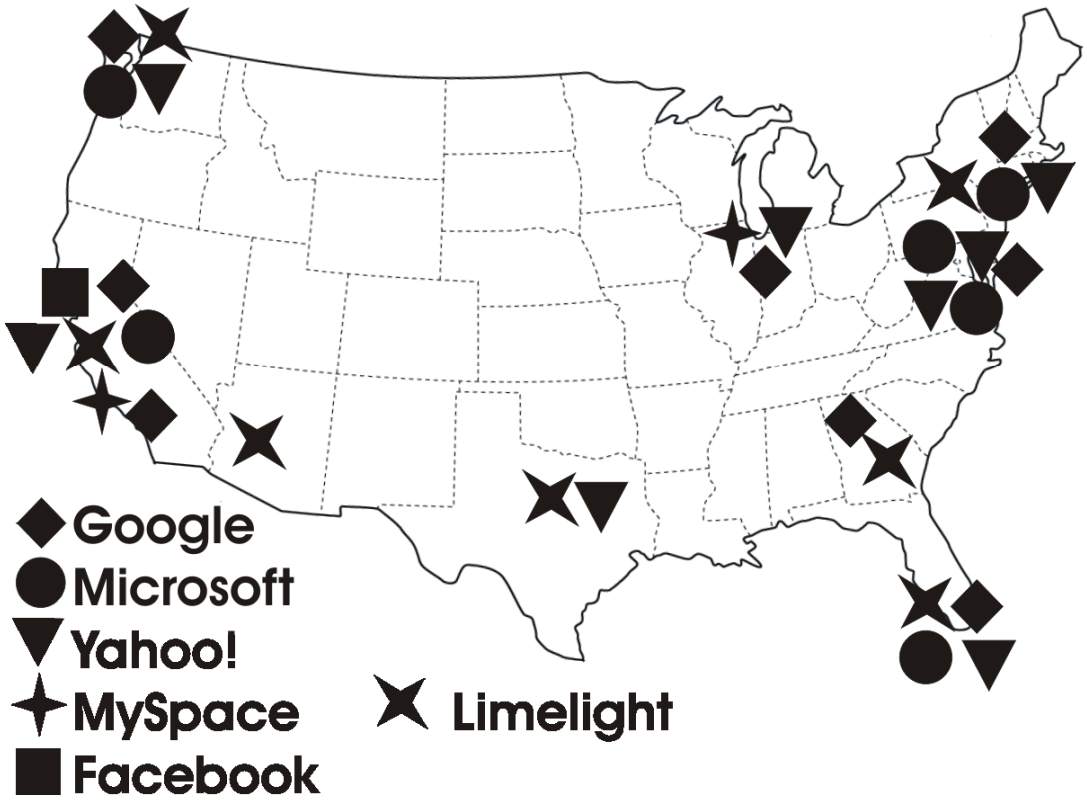
The “Big 3” clearly more connected than other sites:

- Microsoft and Google connected to at least 27 distinct ISPs (ASs); Yahoo! to 20 (when both AS and OrgID used to identify connectedness)
- Next highest is MySpace, at only 6



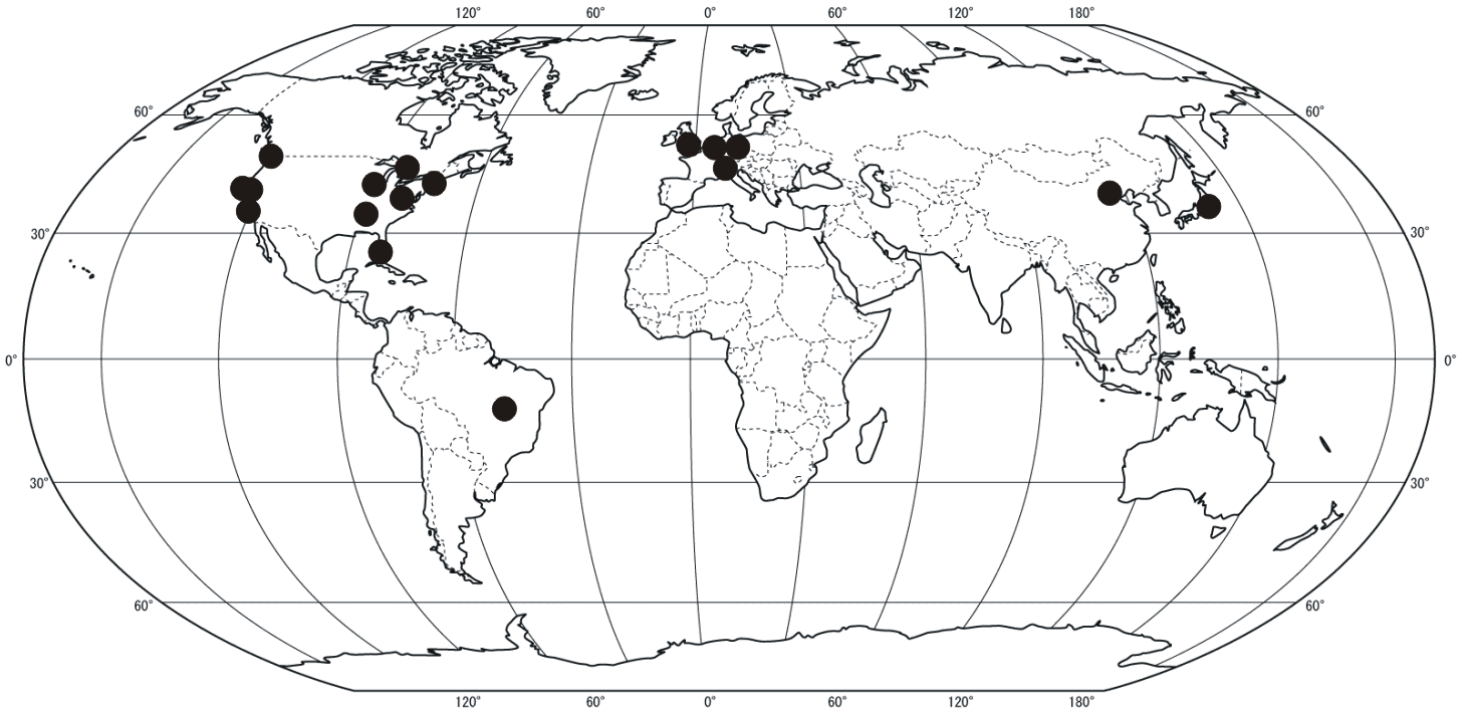
Network End-points: USA (Oct. 2007)

- "Big 3" have WANs that span the United States
  - Entry-points located in large centers where carrier hotels exist
- Other popular sites are also following suit, but perhaps via partnerships
  - E.g., MySpace partnering with Limelight, a Content Delivery Network



Google's Global WAN (Oct. 2007)

- Google had the most extensive WAN of any content provider we examined
- Our probes entered Google's network in:
  - 10 North American cities
  - 4 European cities
  - 2 Asian cities
  - 1 South American city



Observations, Implications & Speculations

"Big" content providers are deploying private WANs

- Google by far the most aggressive

As inexpensive dark fiber sells, it will be more costly (in terms of time & money) for others to follow, thus raising the barriers for "laggards"

- "leaders" can differentiate themselves; e.g.,
  - Speculation: *Google will deploy hundreds of "portable" data centers at the edge of their WAN.*[1]
  - Consequence: this would enable scalable Video-On-Demand[1], and allow Google to directly compete with Cable and TV companies.
  - Speculation: *this infrastructure could be used for voice services* (if Google provides last-mile services)
  - Consequence: they could compete with telcos & wireless providers[2].
- Tier-1 ISPs (and others) may need to adapt as a result of these trends

[1] Robert Cringely, Weekly Column, pbs.org, Nov. 17, 2005.

[2] John Delaney, www.ovum.com, Nov. 30, 2007.

Conclusions

- We utilized active measurements to study the deployment of content provider WANs
- We showed that “cloud” service providers such as Google, Microsoft, Yahoo! have sizeable WANs
- We found that some smaller content providers are also following this trend
- There are obvious implications for ISPs
- There are also implications for network researchers
- Further study is needed

Future Work

- A longitudinal study
  - Determine if this is a long term trend or short term barnacle
- Increase the breadth of the study
- Consider alternative metrics
  - e.g., how do these networks affect user experience?
- Examine other tools or methodologies
  - e.g.,Tcptraceroute [22] or Paris Traceroute [2]
  - Rocketfuel [19] mapped ISP topologies
  - Compare results with measurements from PlanetLab

Acknowledgements

We would like to thank the following people:

- Providers of the public `traceroute` servers
- Anonymous reviewers
- Bala Krishnamurthy, AT&T Research
- Jeff Mogul, HP Labs
- Dejan Milojicic, HP Labs
- Carey Williamson, University of Calgary

Questions?

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Data: http://ita.ee.lbl.gov/html/contrib/gill-PAM08.html