On the Prevalence and Characteristics of MPLS Deployments in the Open Internet

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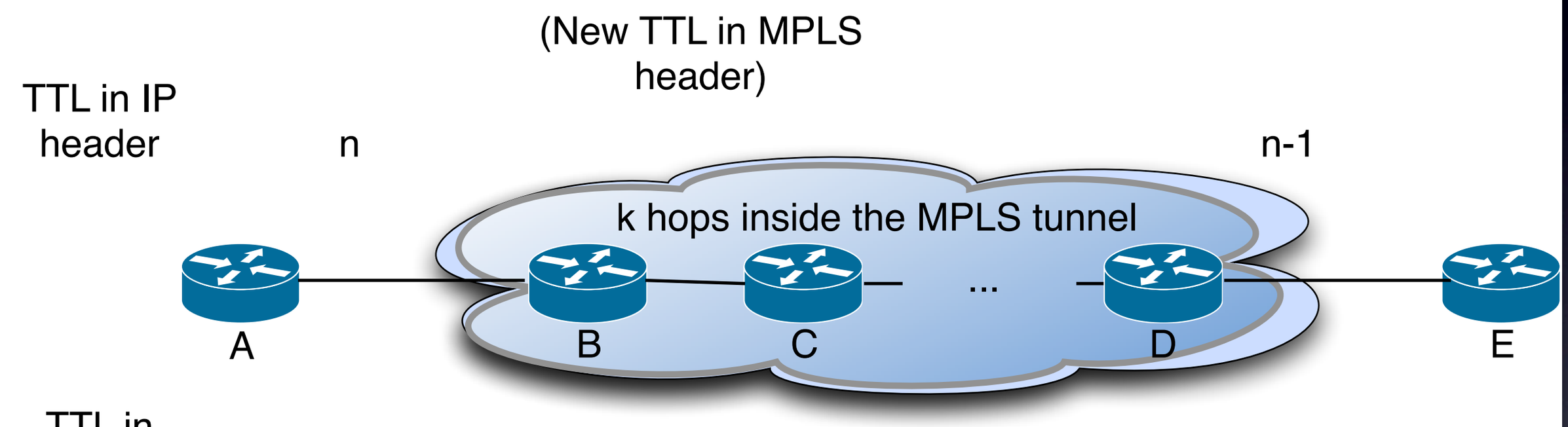
The elephant in the room

- ISPs spend considerable effort managing traffic
- MPLS: one (big?) tool in the TE toolbox
- How widely deployed? What are the characteristics of deployed tunnels?
- Implications for Internet measurement?
- RFC 4950 enables observation of *some* tunnels

Detecting MPLS

Pipe Mode (hidden to traceroute)



Uniform Mode (visible to traceroute)

Example traceroute with MPLS

```
1 129.186.6.251 0.341
2 129.186.254.131 0.416
3 192.245.179.52 3.214
4 4.53.34.13 4.699
5 4.69.135.238 17.945
6 4.69.132.53 53.546
7 4.68.105.44 44.481
8 192.205.36.153 44.856
9 12.122.146.174 74.801
   MPLS Label 16424 TTL=1 CoS=0x0
10 12.122.31.129 74.451
   MPLS Label 16354 TTL=1 CoS=0x0 | MPLS Label 22767 TTL=1 CoS=0x0
11 12.122.2.22 74.352
   MPLS Label 16354 TTL=1 CoS=0x0 | MPLS Label 23741 TTL=1 CoS=0x0
12 12.122.2.217 74.745
   MPLS Label 16761 TTL=1 CoS=0x0 | MPLS Label 11345 TTL=1 CoS=0x0
13 12.122.4.69 73.864
14 12.122.248.49 73.934
15 199.37.170.202 73.775
```

Full MPLS stack included in ICMP time exceeded response (scamper and paris-traceroute show MPLS response)

Round-trip times are similar for each LSR in the tunnel: suggests basis for inferring the presence of tunnels

Objectives

- Understand extent and characteristics of (visible) MPLS deployments
    - How many ASes employ MPLS? Which ones? What are the characteristics of deployed tunnels?
    - How have MPLS deployments changed over time?
    - Can we infer the presence of uniform-mode MPLS tunnels even if we can't positively identify them using ICMP?
- Little existing empirical work that examines MPLS deployments across the internet

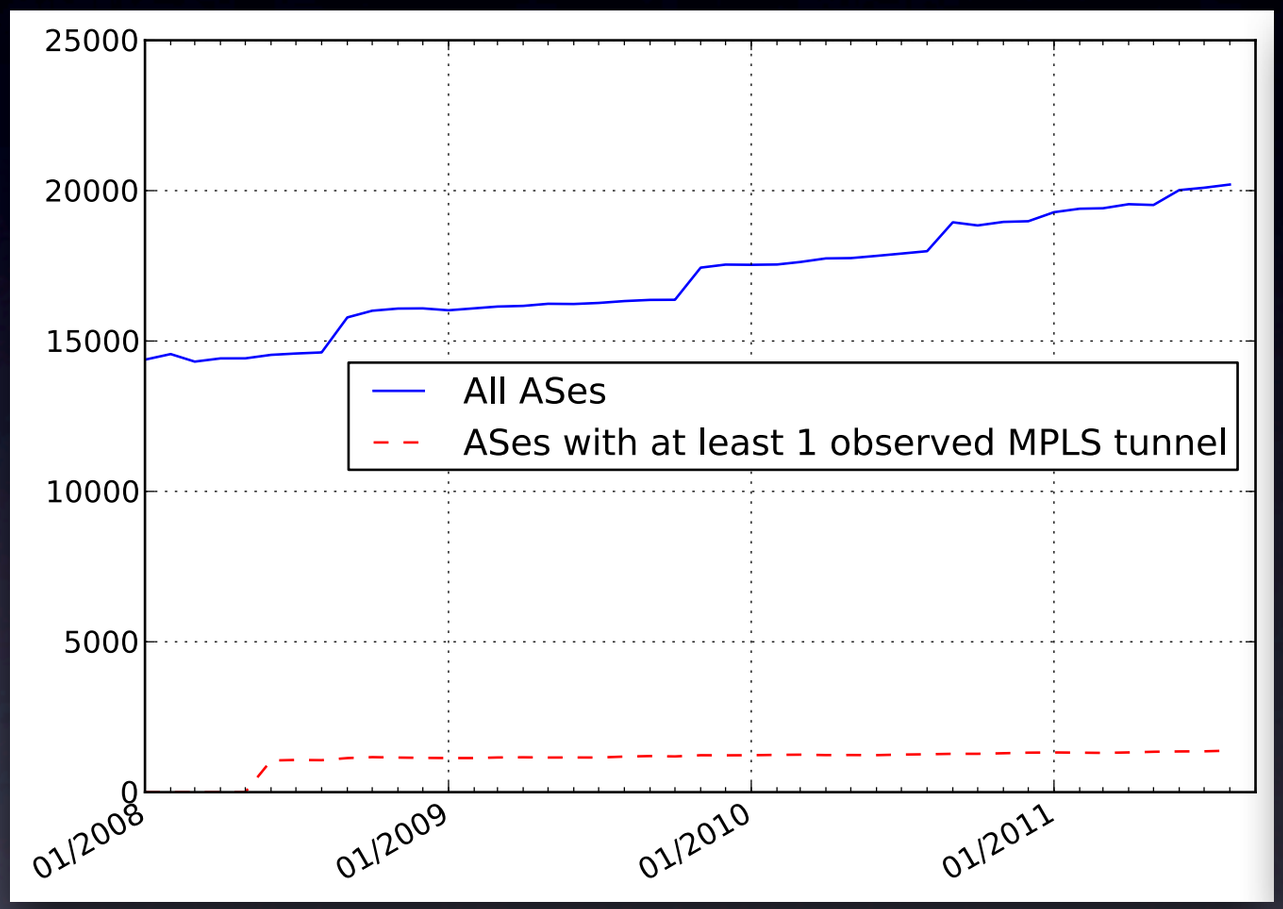
Data analyzed

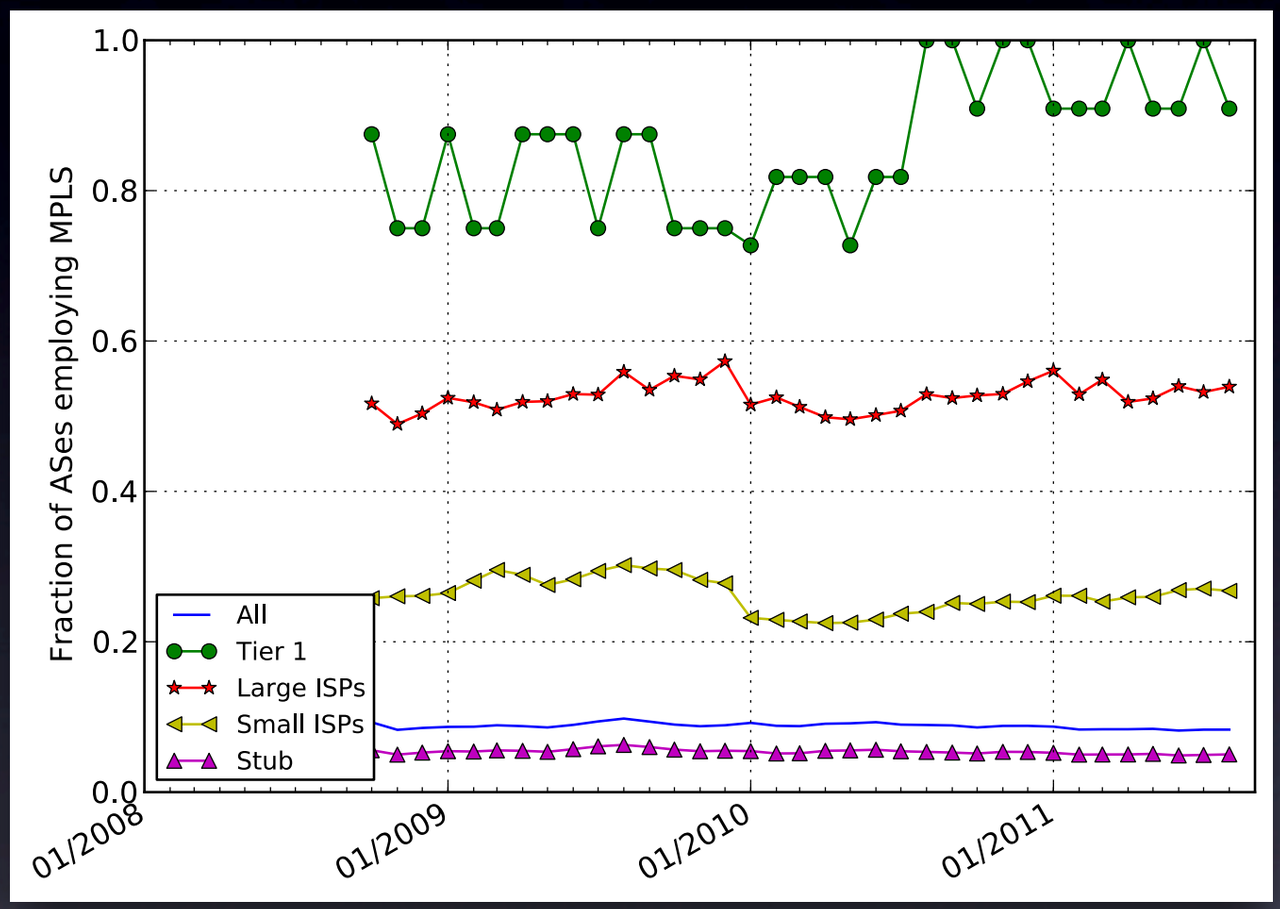
- 3 years of CAIDA Archipelago data: June 2008-August 2011
  - Ark “team” collaborates to probe all routable /24’s
  - Starting in May, 2008, measurements include ICMP extension data
    - Used first full set of data for each month => more than 250M traceroute measurements analyzed
  - Additionally used CAIDA IPv4 prefix to AS mapping data and UCLA Cyclops data to classify AS by ISP type

Results summary

- About 7% of ISPs are observed to employ MPLS
  - Basically all tier-1 providers and half of large ISPs
  - About 25% of end-to-end paths in Ark cross at least 1 tunnel
    - Number of tunnels over time has varied widely
- Tunnel length distribution is skewed; most are short, but some are very long
- Stacking and CoS field usage suggests a variety of TE practices

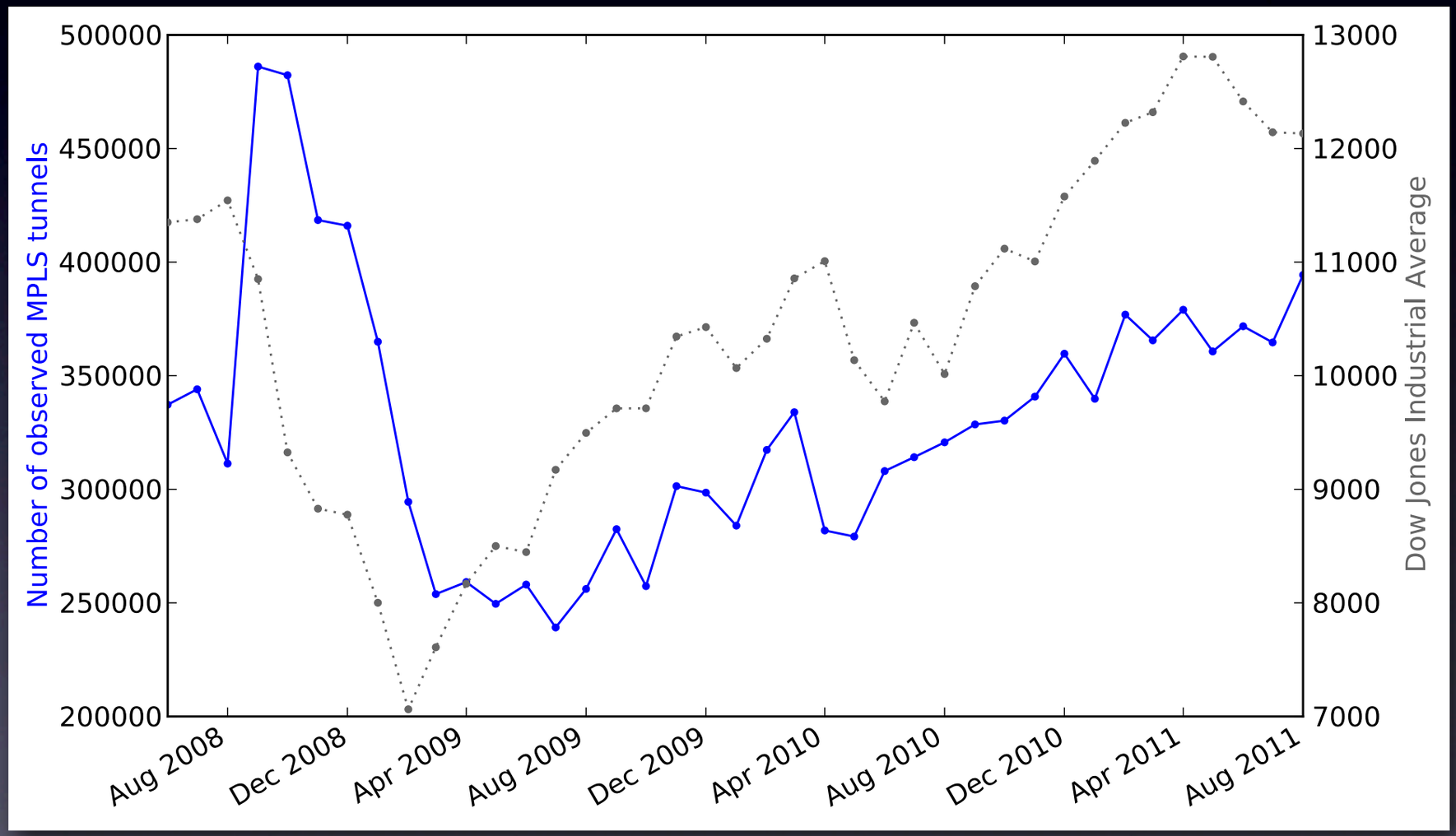
MPLS prevalence





About 7% of all ISPs use (uniform mode) MPLS

Number of observed tunnels over time

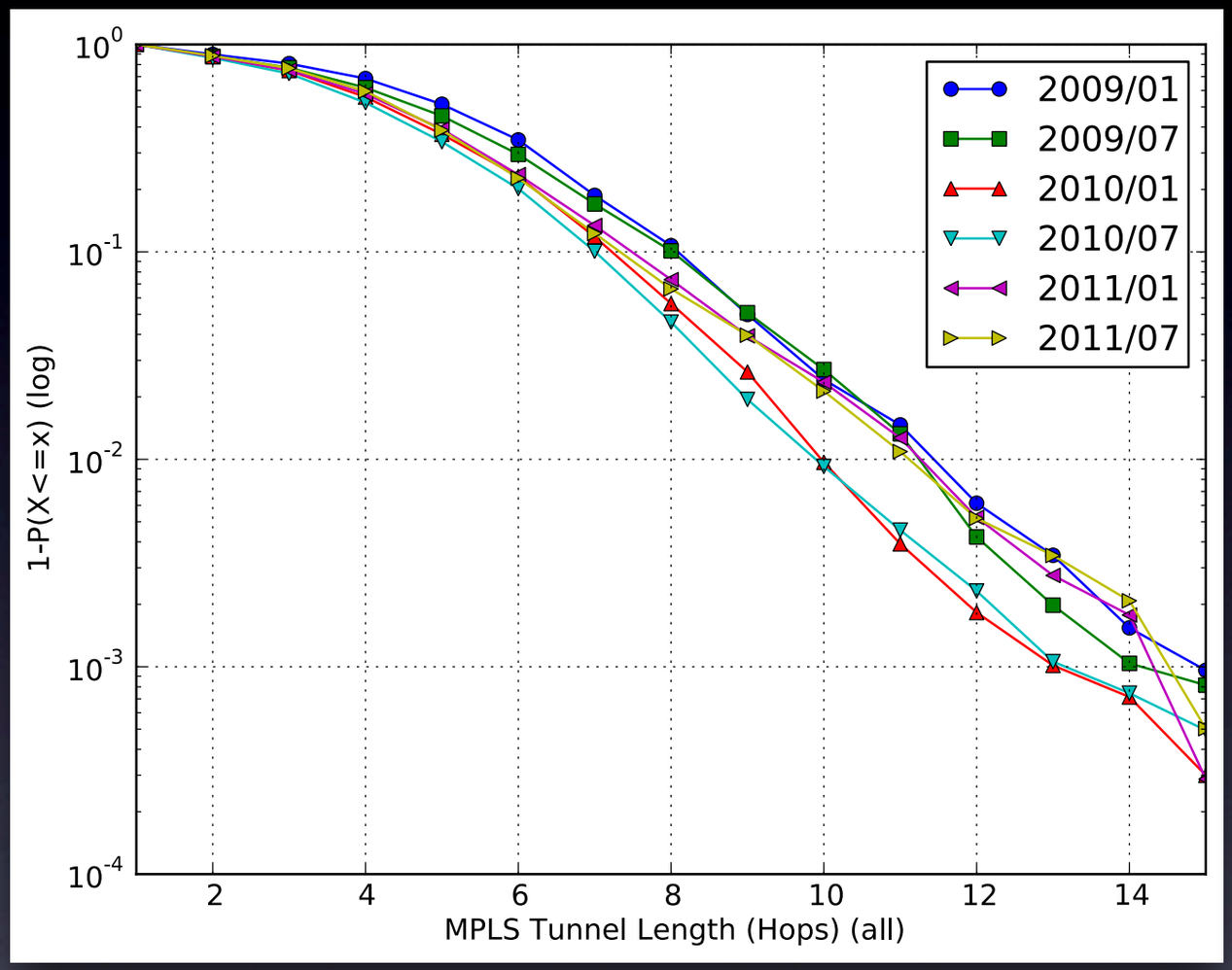


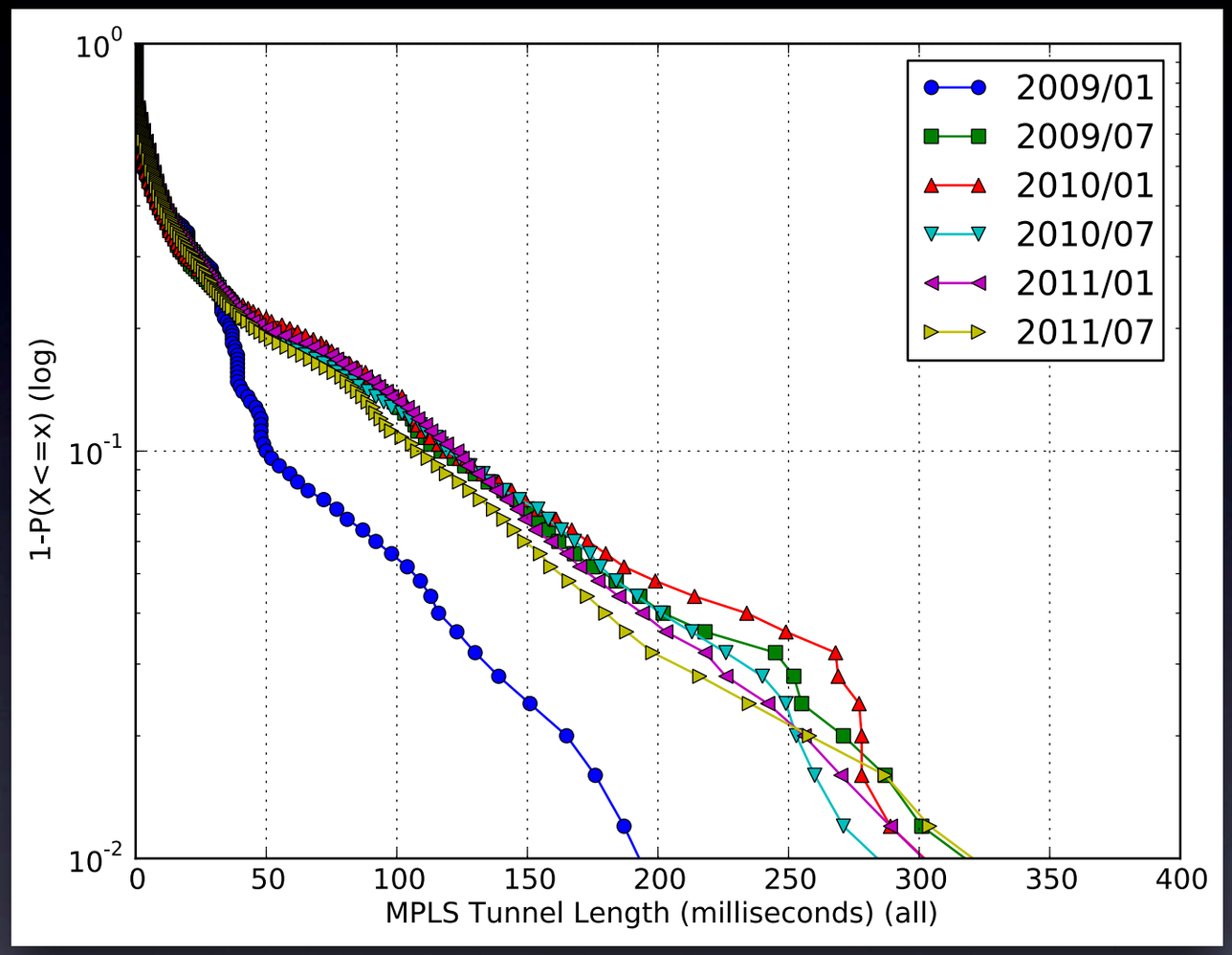
Number of tunnels rebounding from low in mid 2009

Top ASes using MPLS

Rank	7-12/2008	1-6/2009	7-12/2009	1-6/2010	7-12/2010	1-6/2011
1	7018 AT&T	7018 AT&T	7018 AT&T	7018 AT&T	7018 AT&T	7018 AT&T
2	6389 Bellsouth	6389 Bellsouth	6461 Abovenet	6461 Abovenet	6461 Abovenet	6461 Abovenet
3	6461 Abovenet	6461 Abovenet	6389 Bellsouth	19262 Verizon	4837 China-169	6830 UPC
4	6453 Tata	3269 Telecom Italia	3269 Telecom Italia	6389 Bellsouth	6453 Tata	6453 Tata
5	3292 TDC	6453 Tata	19262 Verizon	6453 Tata	1273 CW	174 Cogent
6	4134 Chinanet	19262 Verizon	6453 Tata	4837 China-169	6830 UPC	1273 CW
7	4230 Embratel	4230 Embratel	4230 Embratel	4230 Embratel	4134 Chinanet	4837 China-169
8	19262 Verizon	4134 Chinanet	4837 China-169	4134 Chinanet	19262 Verizon	4134 Chinanet
9	5462 Virgin	4837 China-169	4134 Chinanet	6774 Belgacom	6774 Belgacom	4230 Embratel
10	4837 China-169	2914 NTT	2914 NTT	1273 CW	4230 Embratel	10318 Cablevision SA

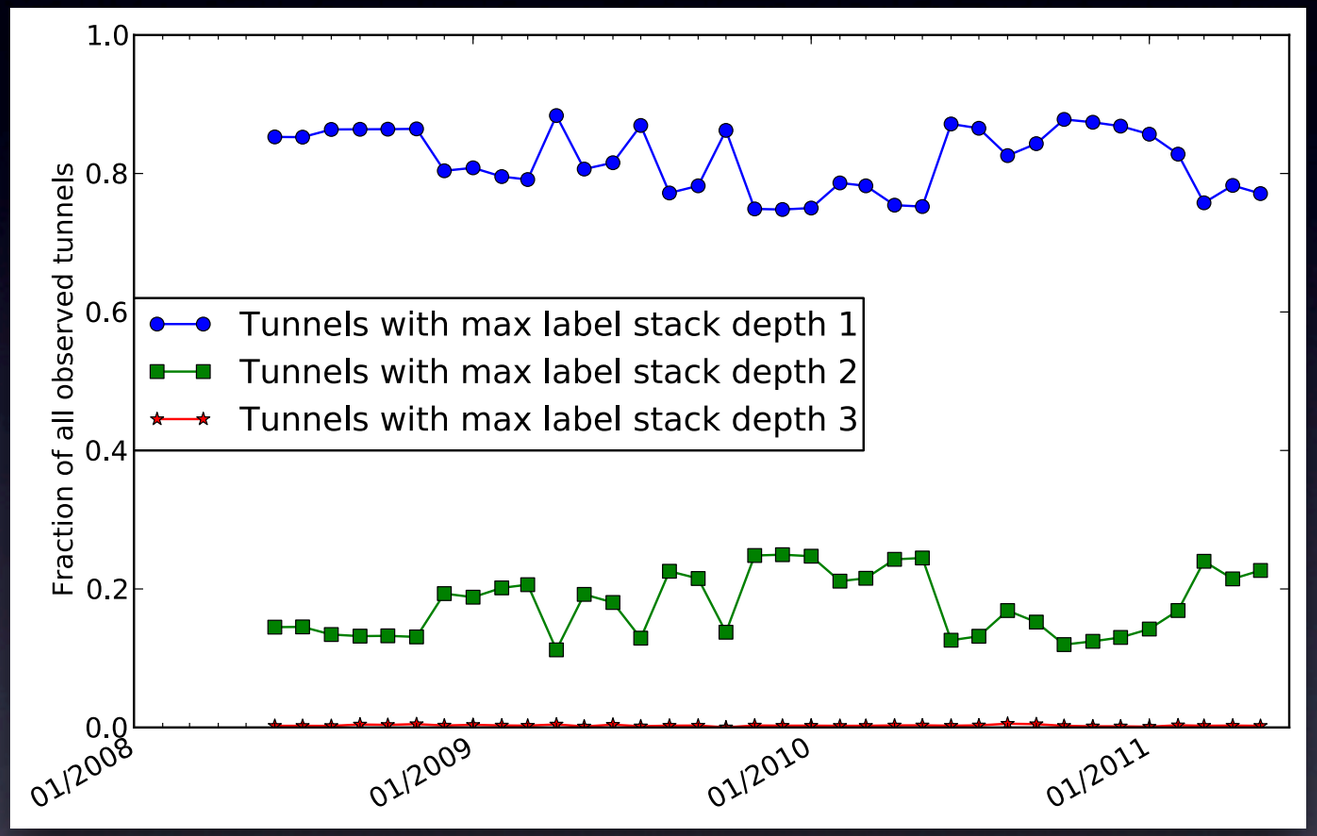
Tunnel lengths



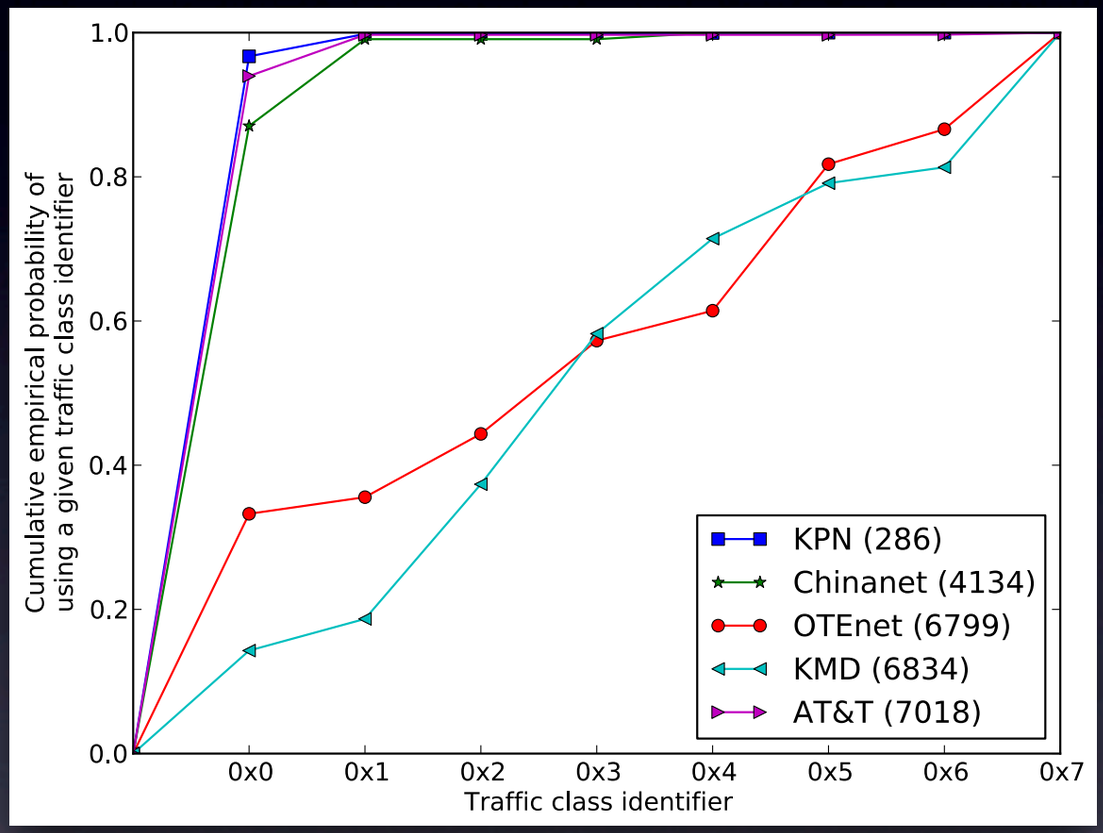


Tunnels have grown slightly longer over the past three years

Stacking and classes of service

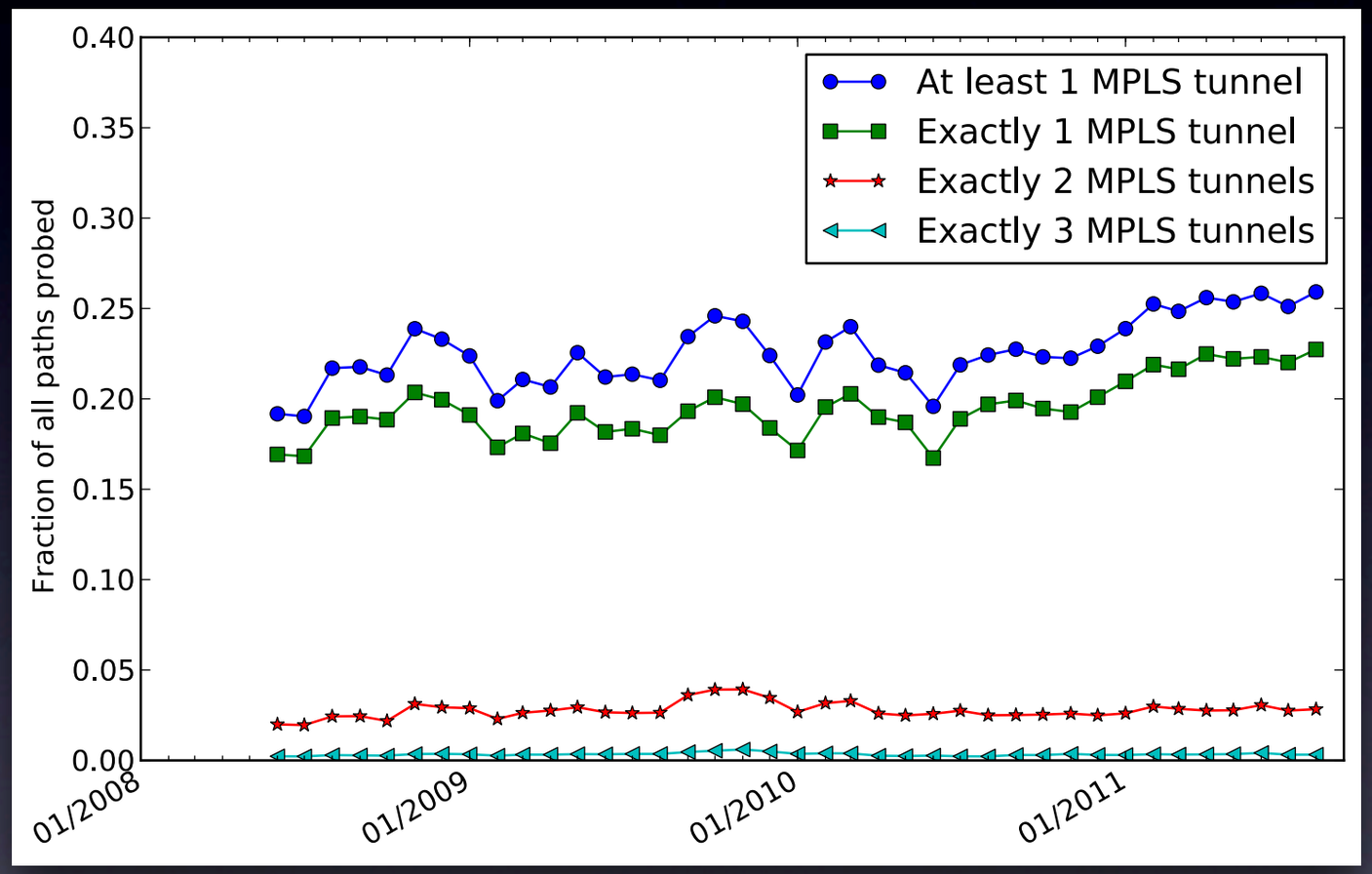


Stacking suggests fast failover engineering, among other possibilities



Use of CoS field varies widely across ISPs

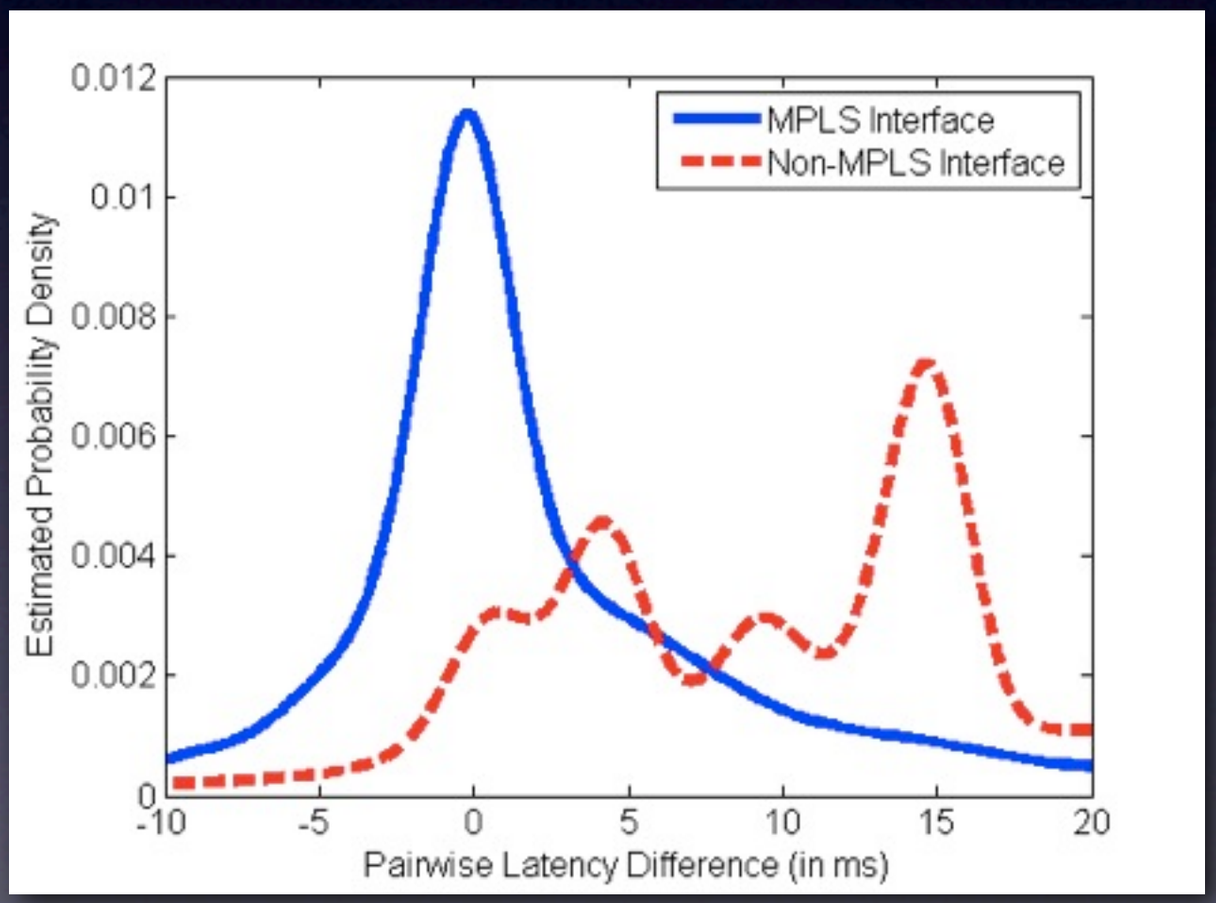
Likelihood of encountering MPLS on a path

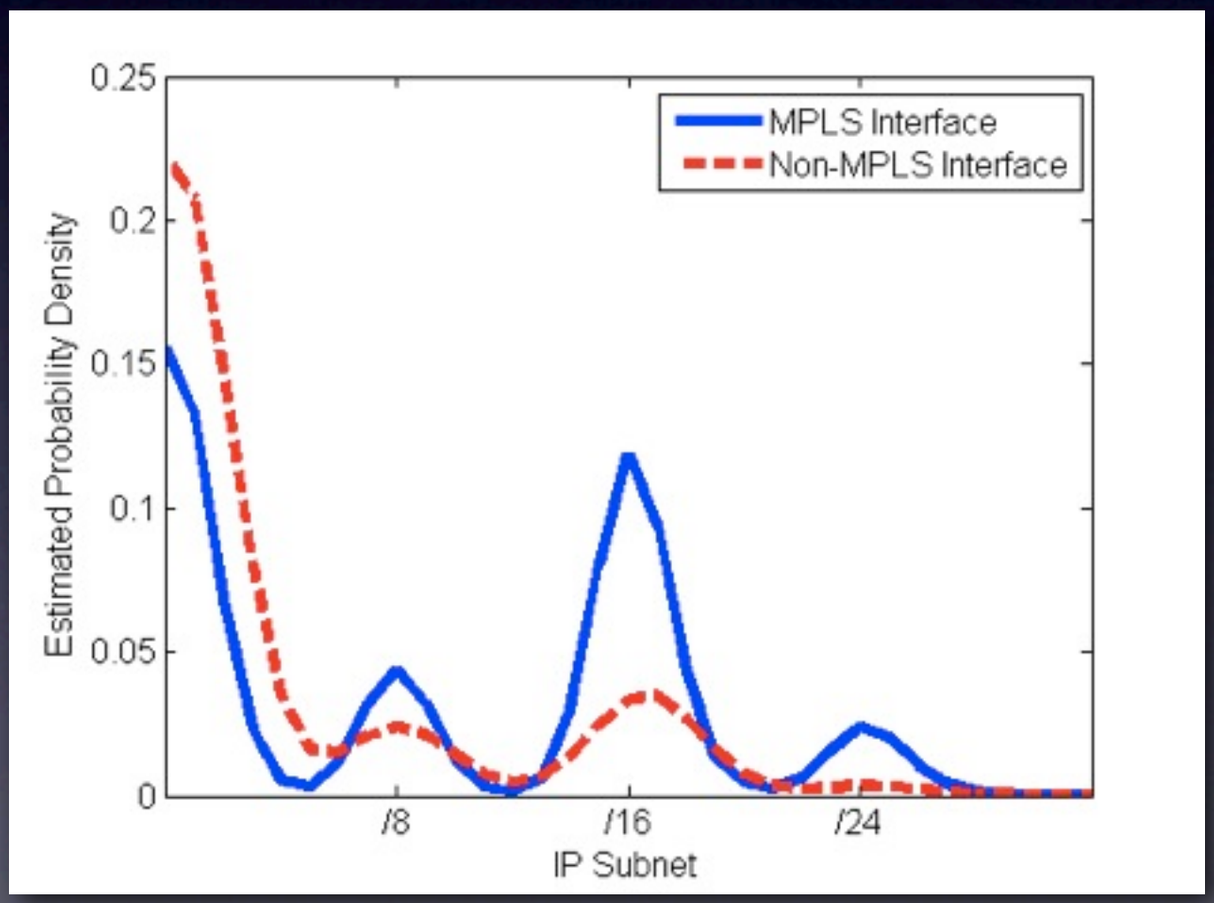


About 25% of paths between Ark hosts cross at least 1 tunnel

Inference intuition

Given distributions of pair-wise latency and IP subnet, we may be able to discriminate between MPLS and non-MPLS pairs of interfaces





Distributions produced using 5% of April 2011 data

Inference formulation

Combining both observed characteristics of latency and IP subnet, we devised a Naïve Bayesian classifier to determine the probability of an interface existing in an MPLS tunnel.

Log-probability interface *i* is in an MPLS tunnel

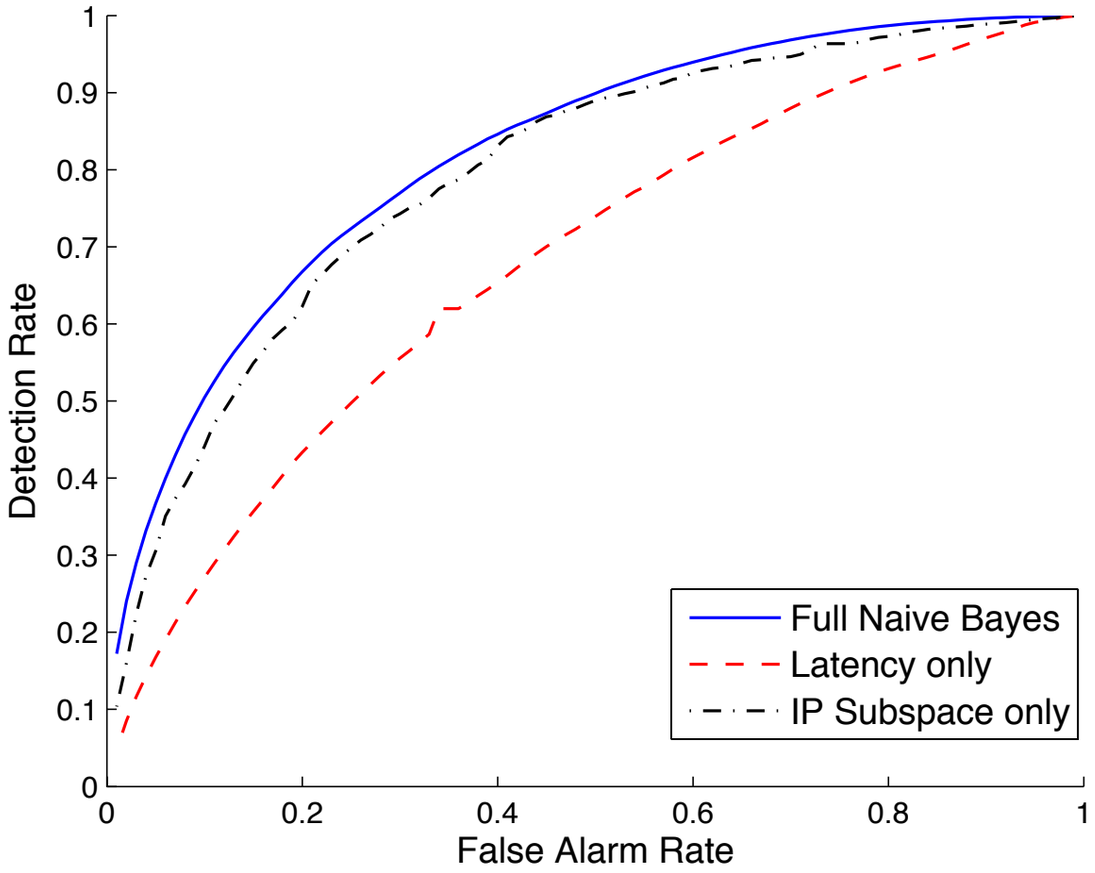
Probability of MPLS given observed latency

$$\log \hat{P}\left(\mathrm{MPLS}_i\right) = \sum_{k=-K}^{K} \log \hat{P}_{lat}^{(k)}\left(\ell_{i,i+k} \mid \mathrm{MPLS}\right) + \sum_{k=-K}^{K} \log \hat{P}_{IP}^{(k)}\left(s_{i,i+k} \mid \mathrm{MPLS}\right)$$

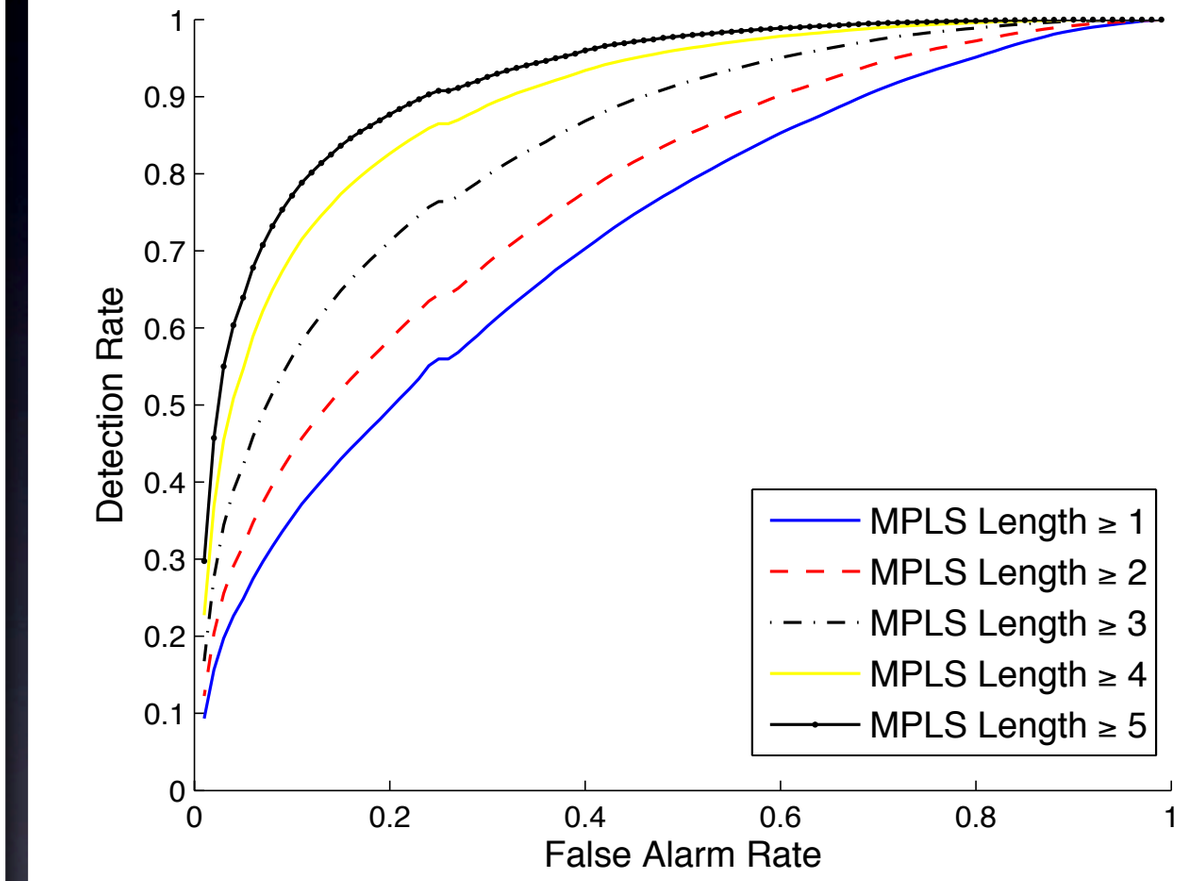
Iterate over K consecutive interfaces found in traces with i.

Probability of MPLS given observed IP subnet

Inference results



Interface classification



Path classification

Data from April 2011; training on 5%, testing on 95%

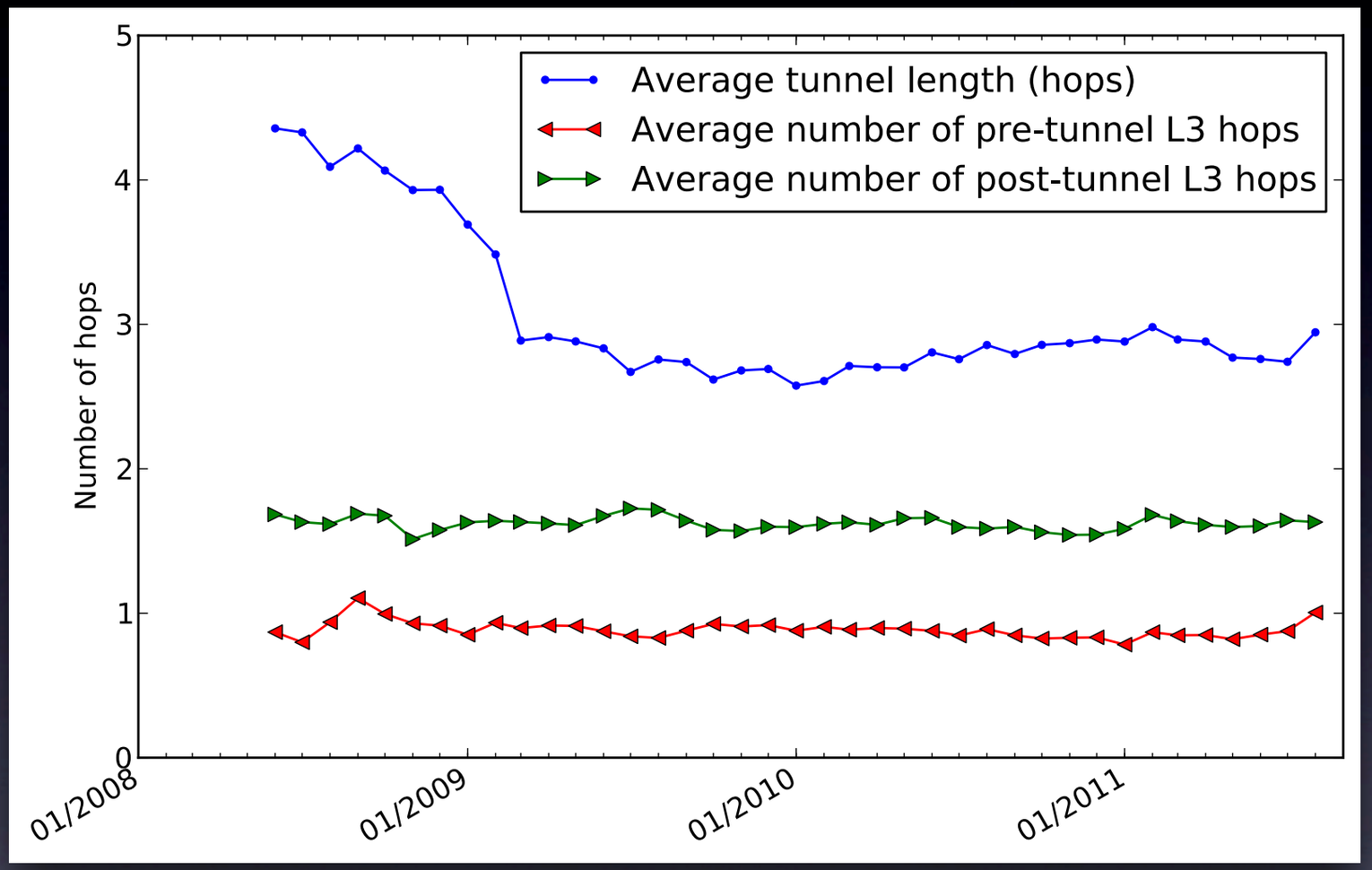
Summary & ongoing work

- Uniform-mode MPLS tunnels are widely deployed
- Clear impact on traceroute delay measurements

- Unclear by how much we underestimate deployments; can we do better?
- Probe based study of traffic engineering: how do CoS bits relate to observable performance characteristics?
- Can inference method be applied to larger corpus of historical data (e.g., Skitter)?

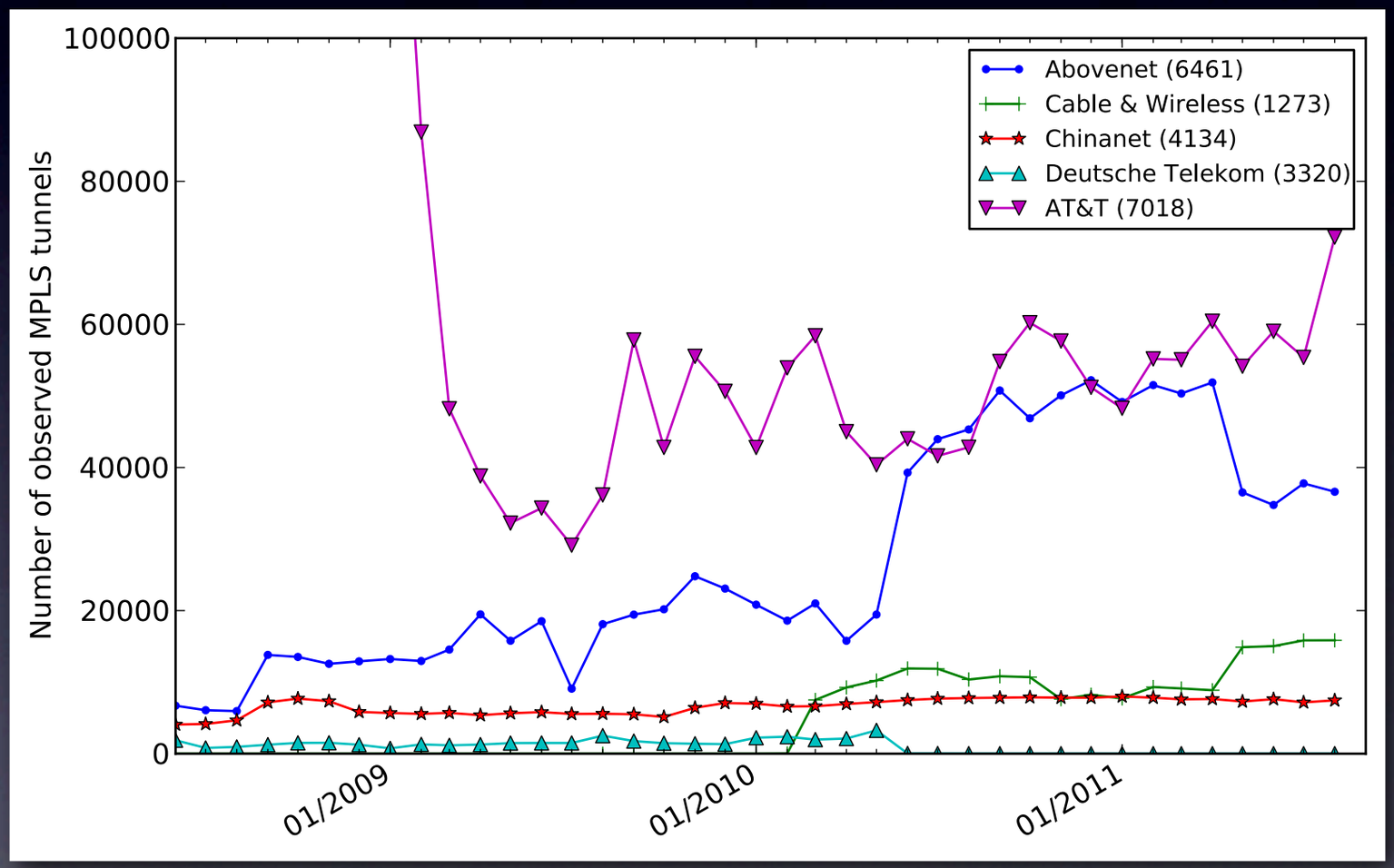
Additional slides

More on tunnel lengths

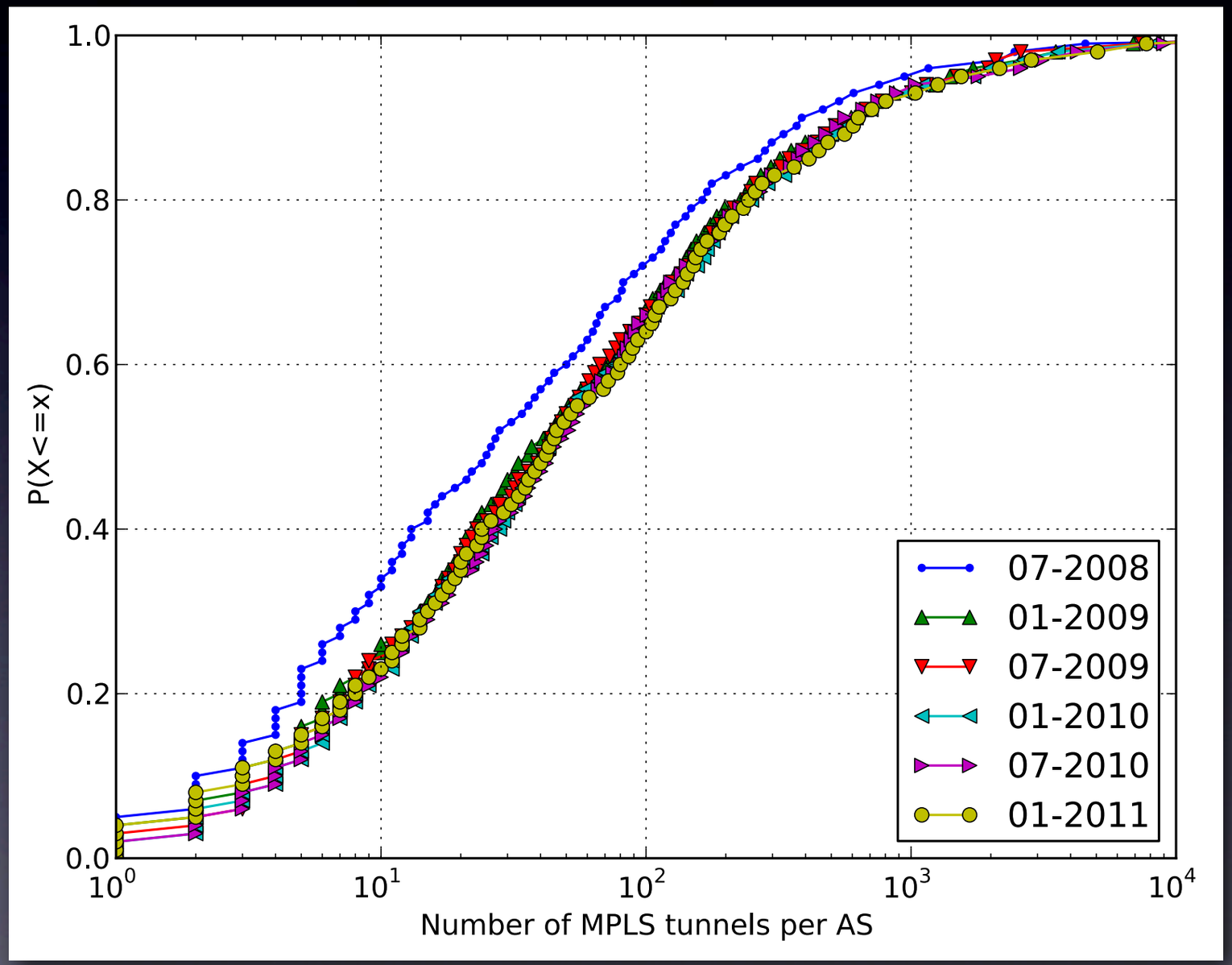


After shrinkage in 08, tunnel lengths have remained stable

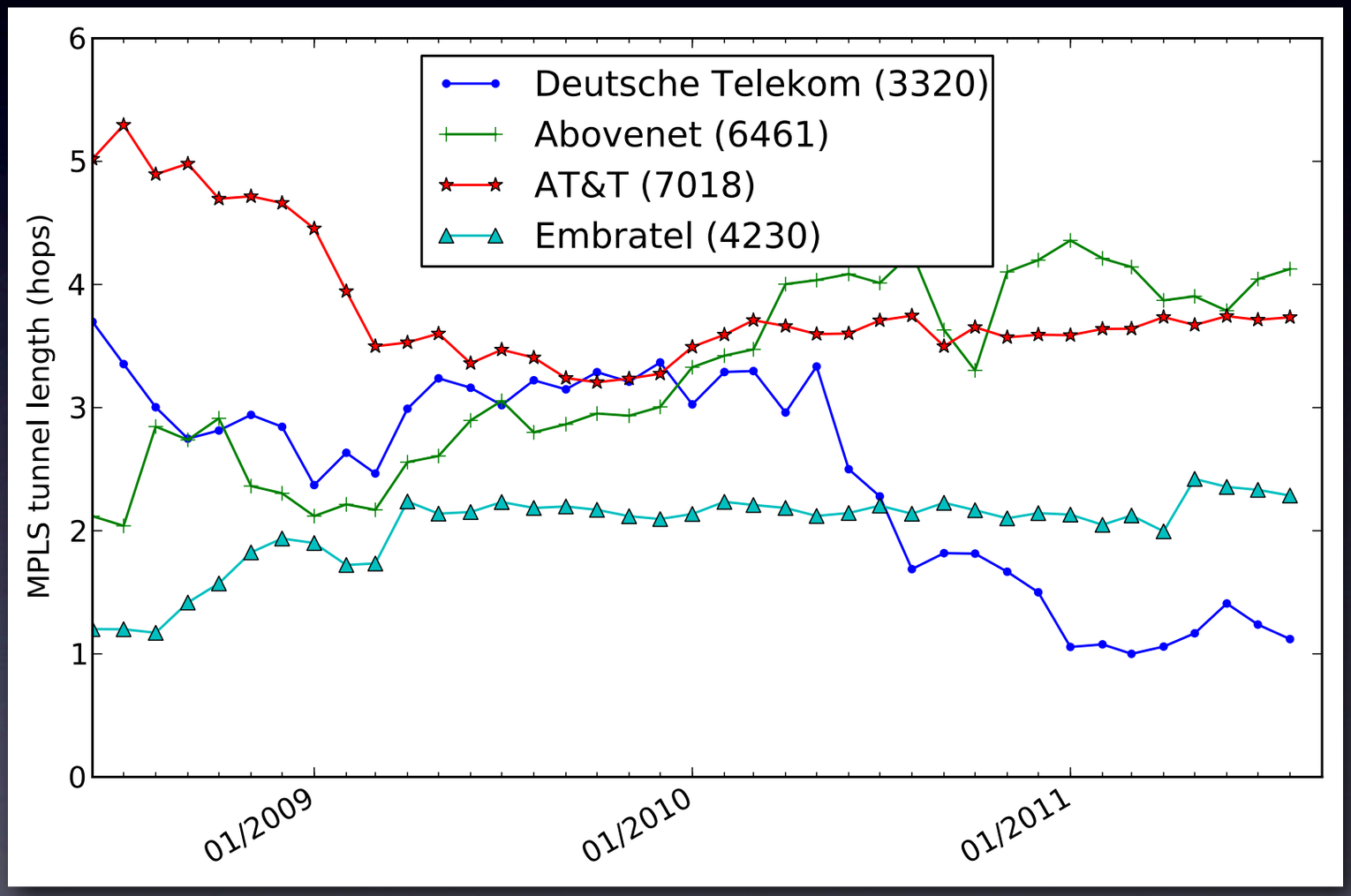
Number of tunnels over time, specific ASes



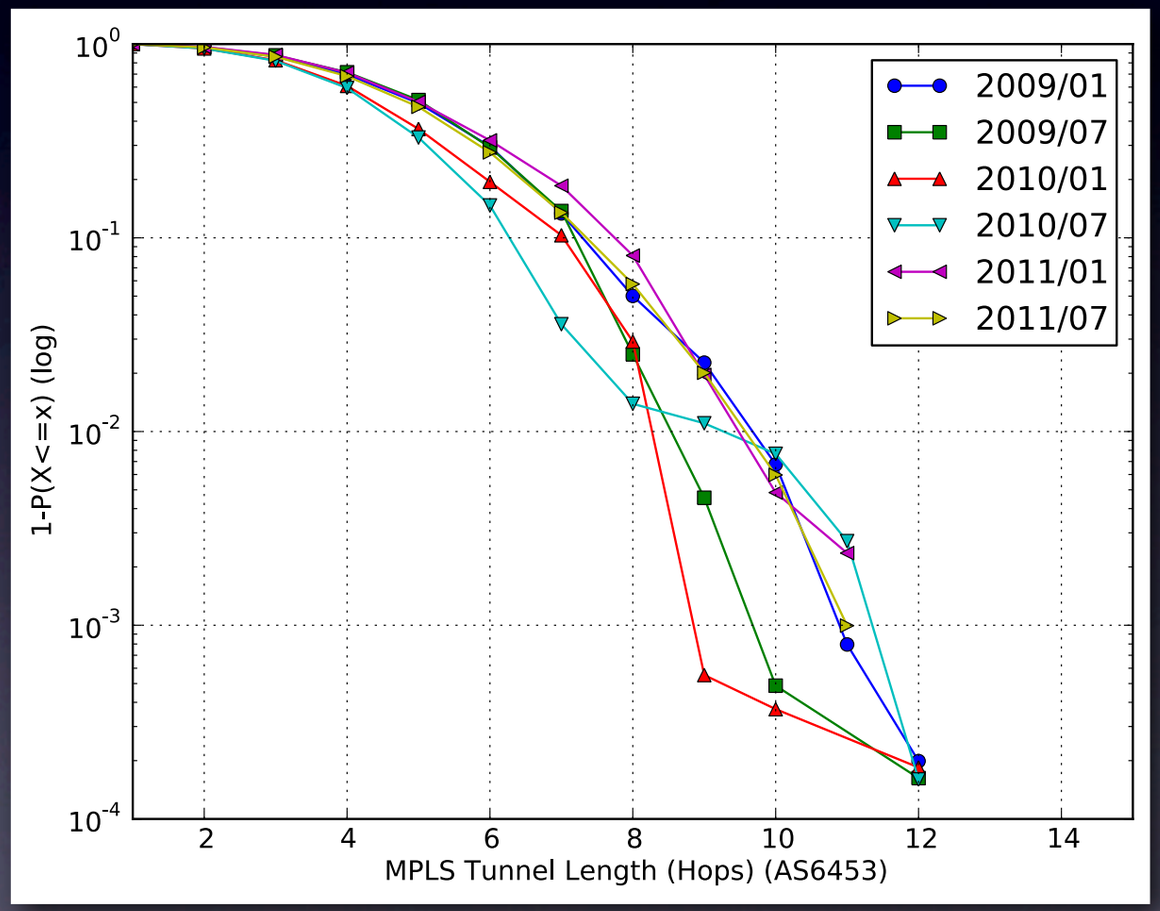
Number of tunnels per AS

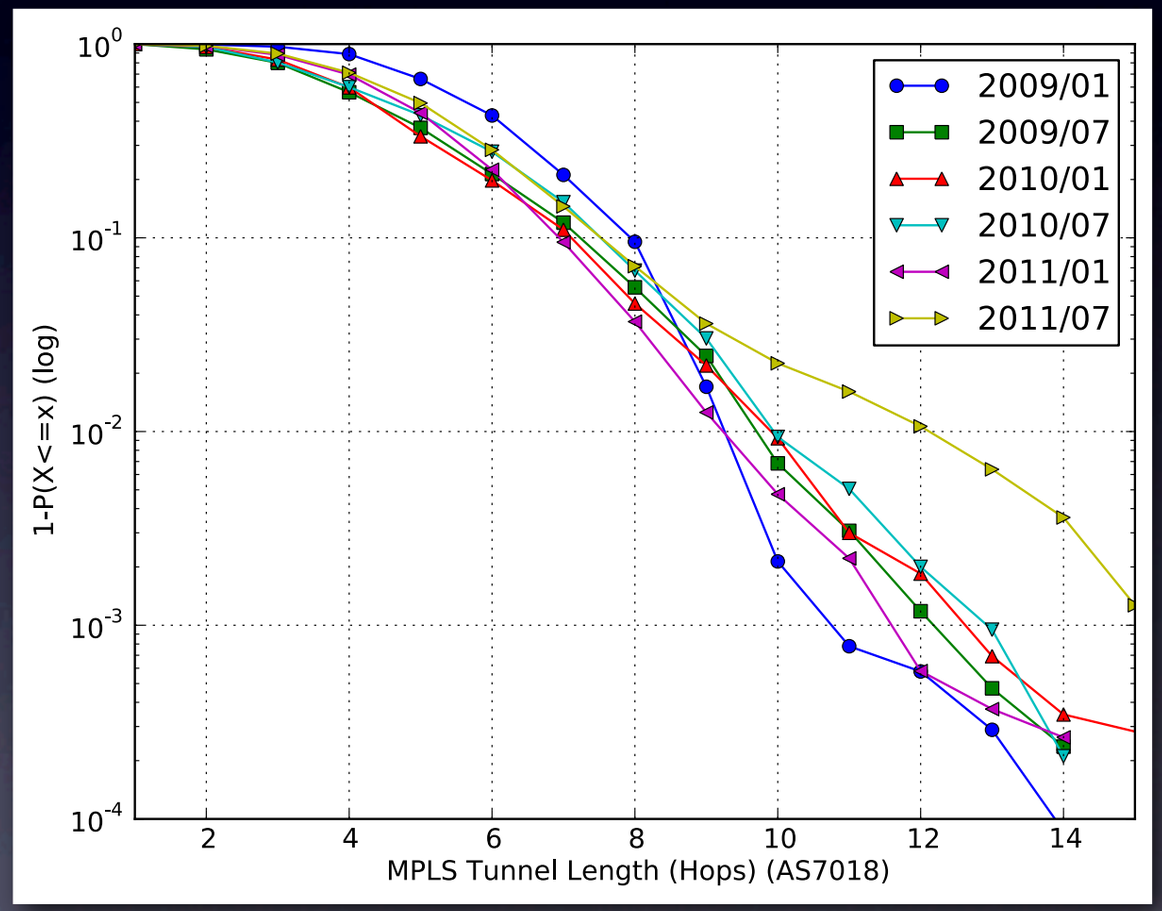


Average tunnel lengths, specific ASes

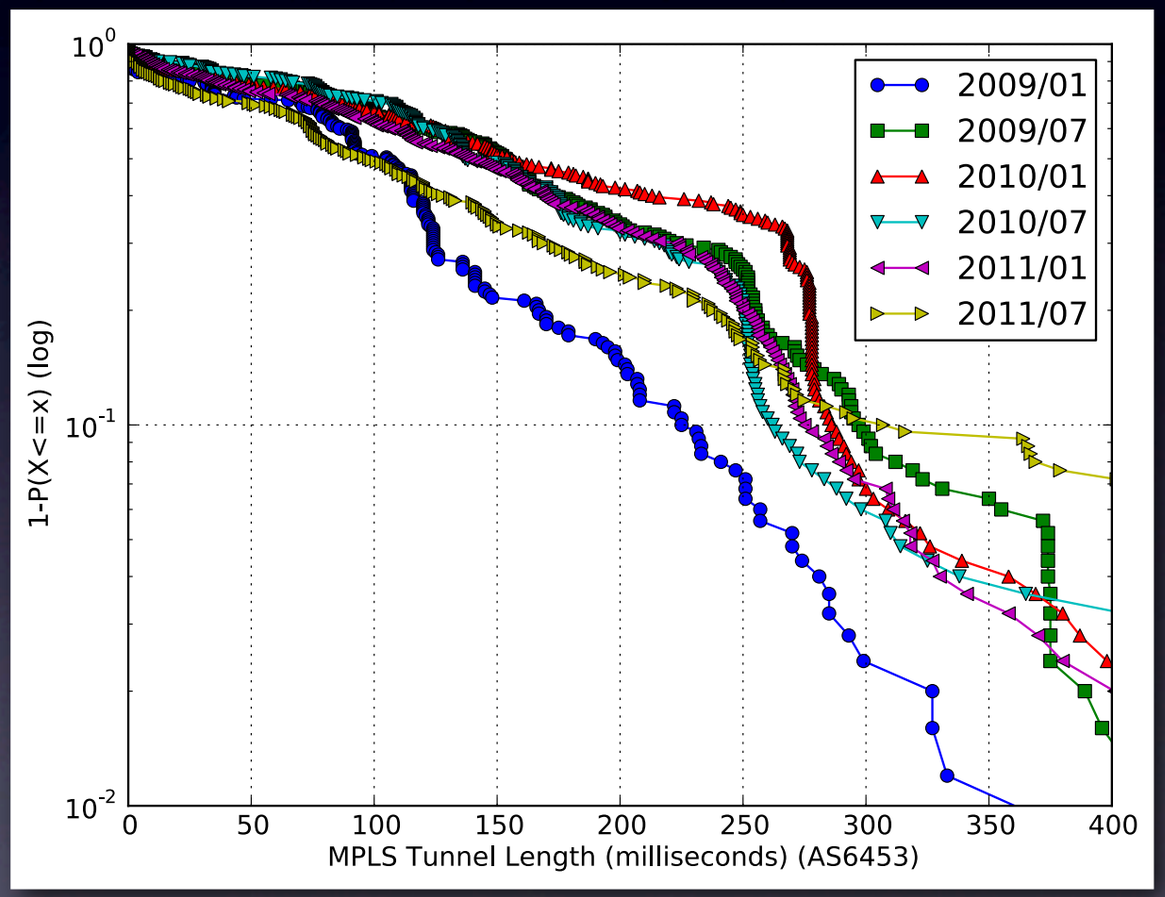


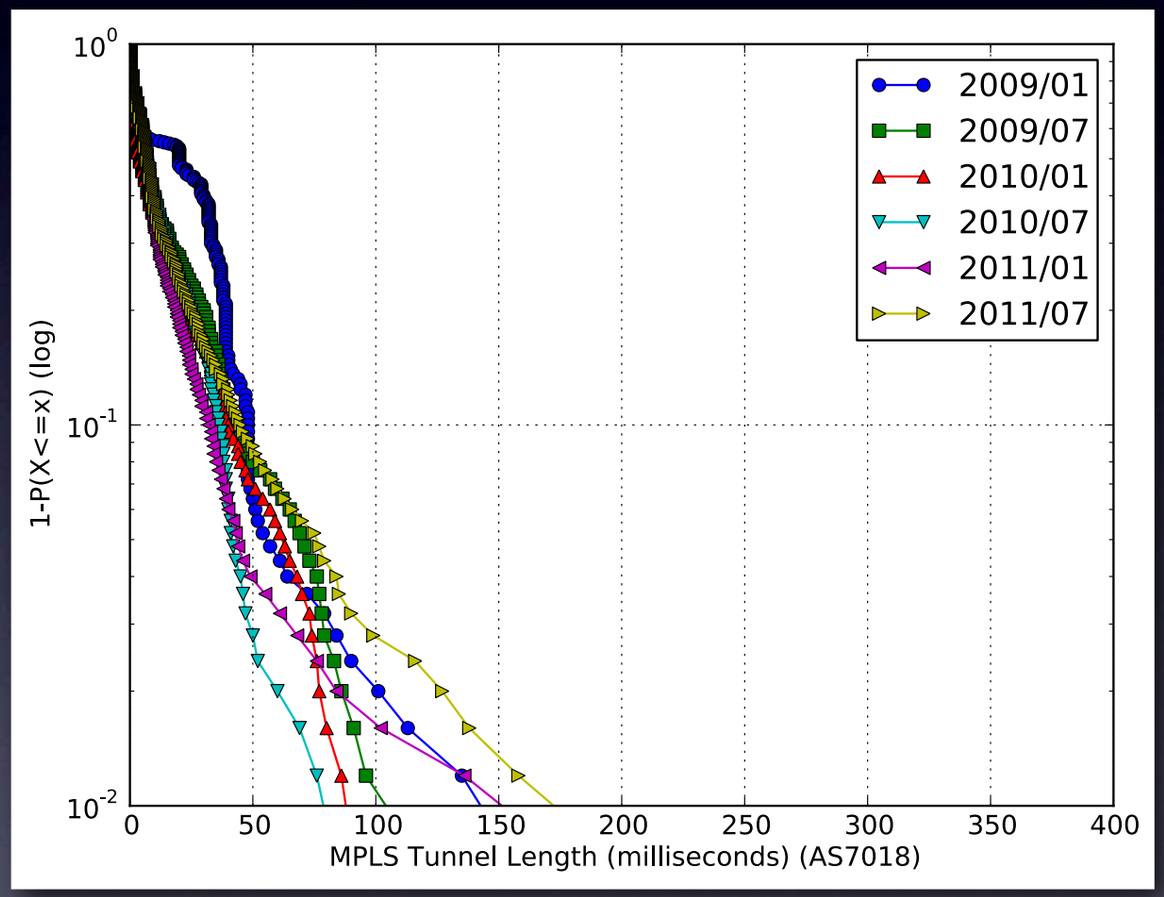
Tunnel length distributions (hops)



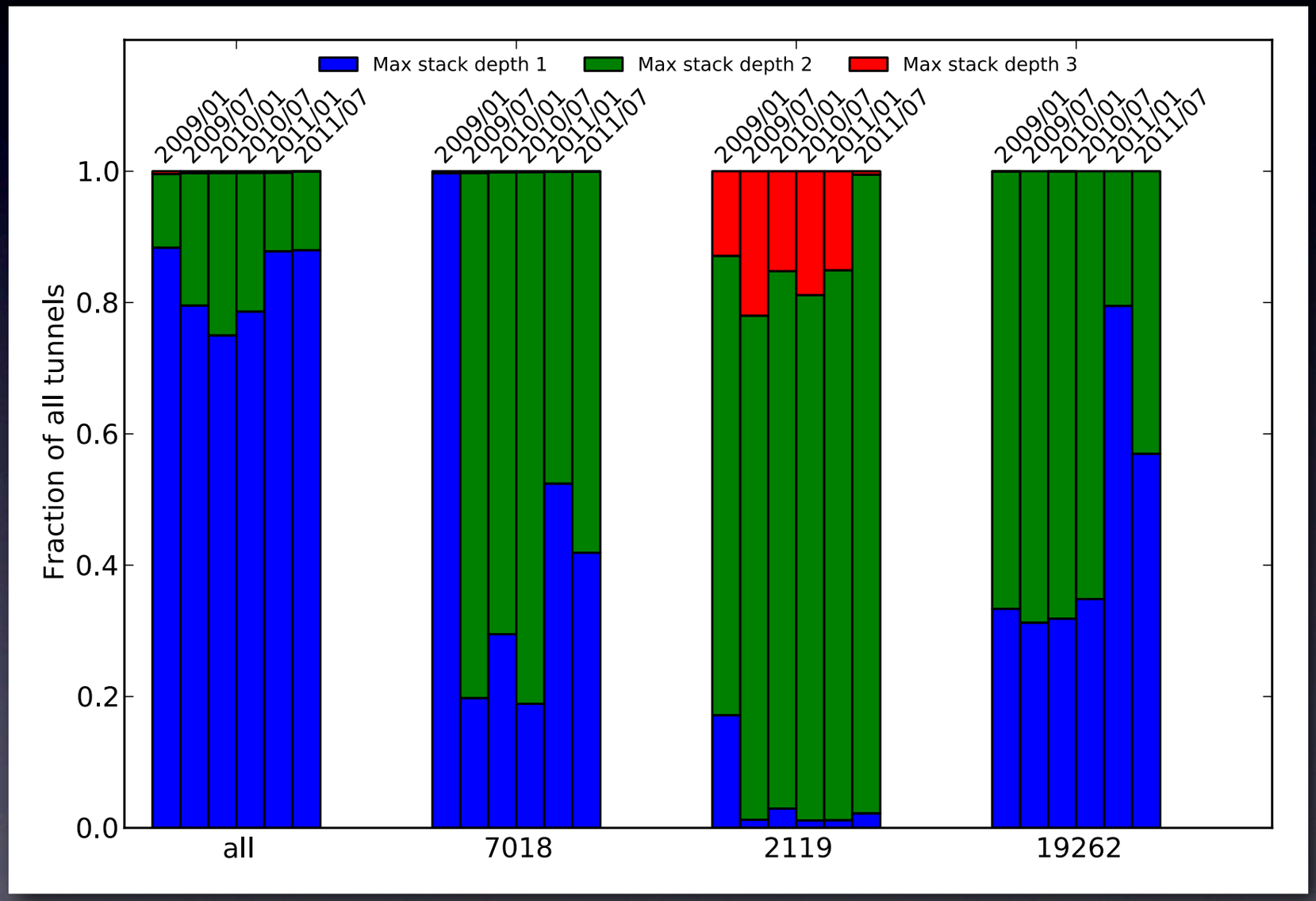


Tunnel length distributions (milliseconds)





Fraction of tunnels employing different stack depths



Additional tunnel inference results

- Good accuracy, especially if trained on temporally close data

AS	3/08	4/08	5/08	6/08	6/08
7018	60.7%	59.2%	76.7%	62.5%	69.2%%
6389	54.2%	67.5%	66.4%	69.5%	71.0%
4134	7.1%	8.1%	8.5%	3.1%	0.4%
4230	35.5%	27.0%	29.8%	29.4%	25.8%

estimate

observed