Measuring the Deployment of IPv6: Topology, Routing, and Performance

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[simula . research laboratory]

IPv6 Will Be Deployed Any Day Now

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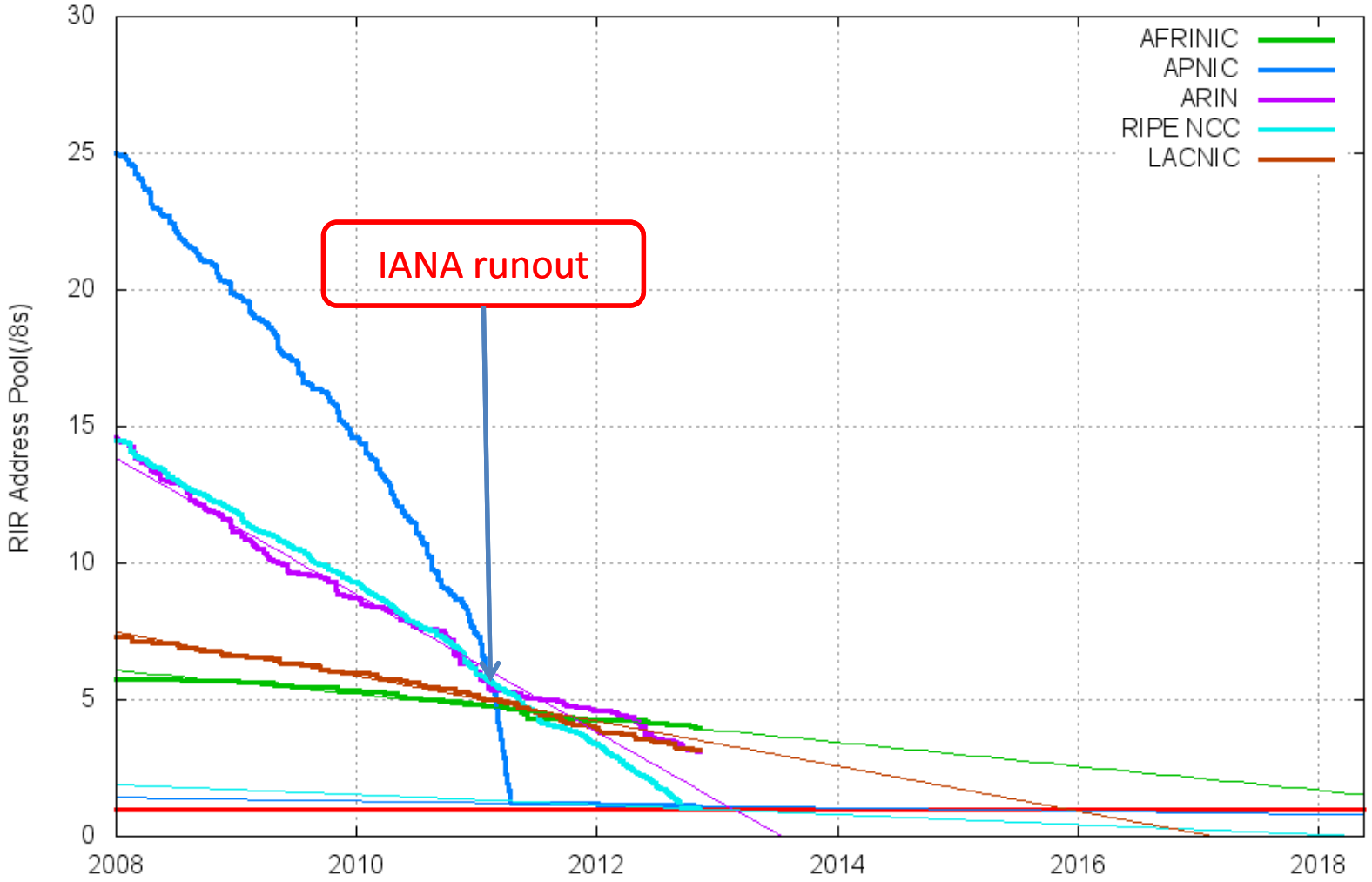
When will we run out of IPv4 addresses?



- IANA ran out of IPv4 addresses in 2011
- Regional Internet Registries (RIRs) are rationing but will soon run out too

Source: http://www.potaroo.net/tools/ipv4/index.html

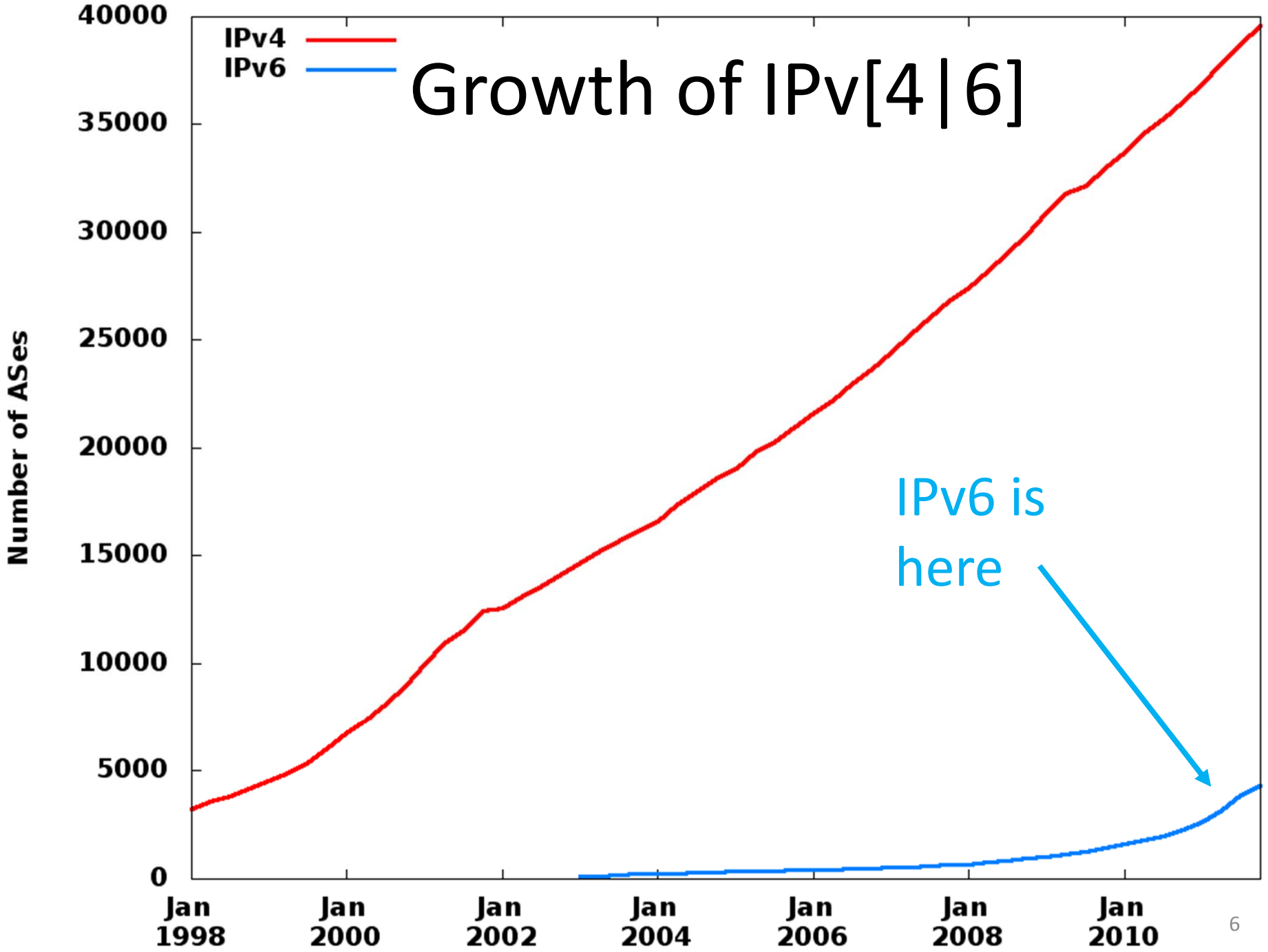
IPv6

- Address run-out was anticipated back in the 1990s
- IPv6 was standardized in the late 90s
- Operating systems and network hardware have supported IPv6 for many years now
- IPv6 provides much more address space than our foreseeable need

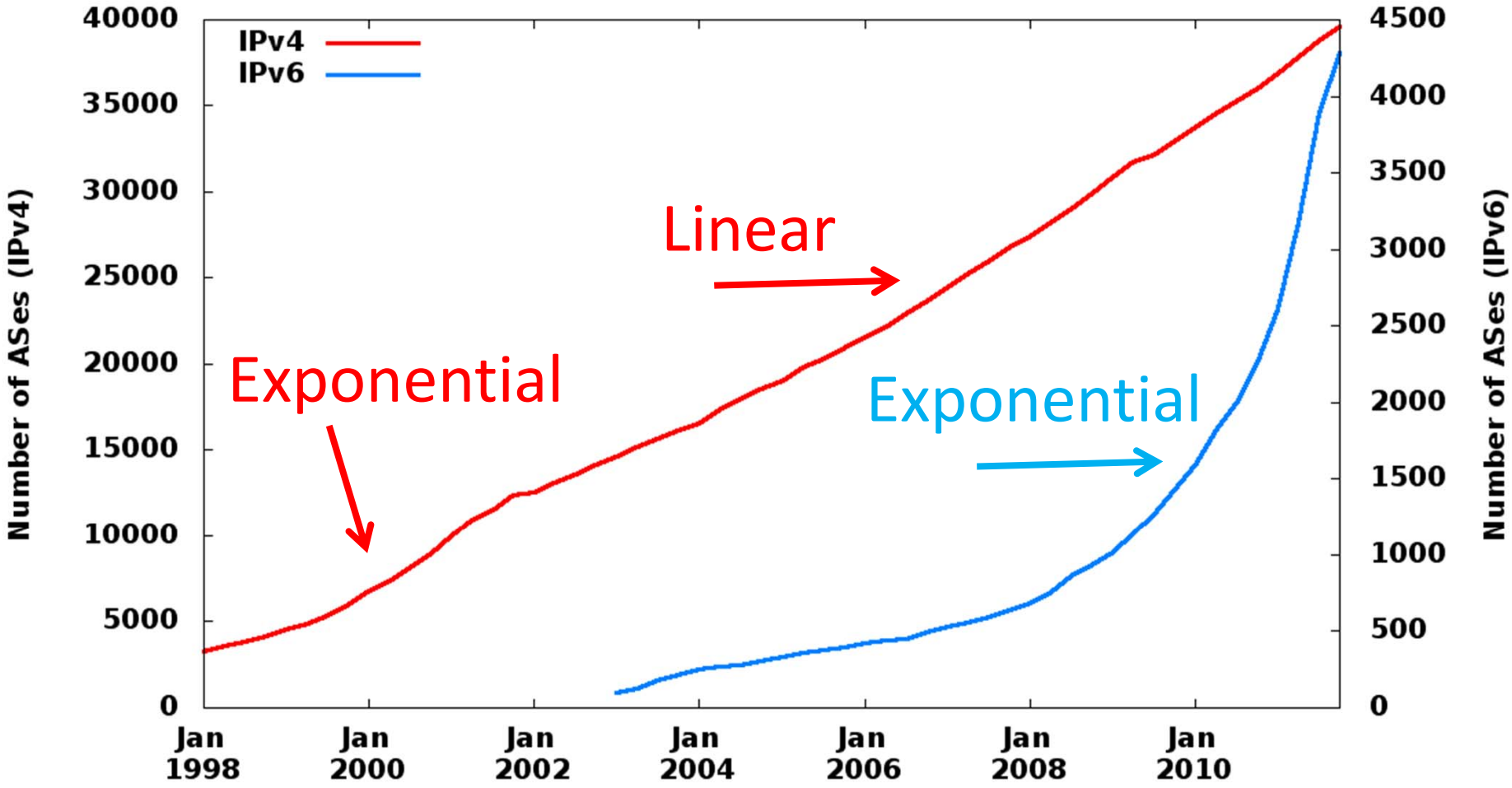
What's the Problem?

- Just use IPv6, right?
- The issue: IPv6 is not backwards compatible with IPv4
  - Hosts with an IPv4 address cannot directly communicate with hosts with IPv6 addresses
- IPv6 configuration, management and troubleshooting still not well understood

Growth of IPv[4|6]



IPv6 growth: we need to zoom in..



- The IPv6 topology grows exponentially while the IPv4 topology now grows linearly

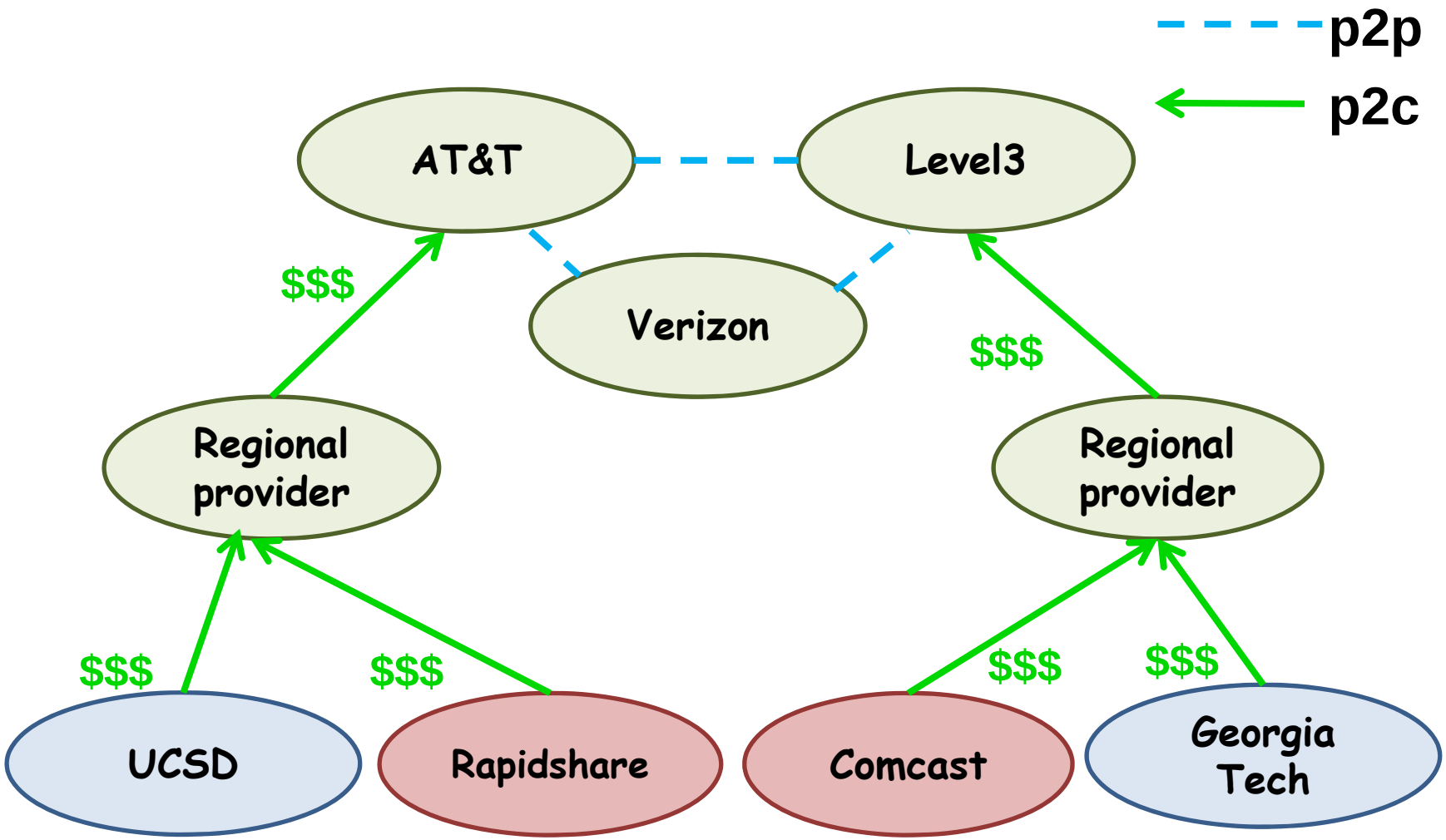
Digging deeper

- Exponential growth of IPv6 is encouraging
  - shift from a “toy” network to production?
- Which geographical regions and network types contribute most of the growth?
- Is the business mix in IPv6 converging to that in IPv4?
- Is IPv6 performance comparable to IPv4 performance?

Measurement Data

- Topology snapshots+updates from BGP routing datasets from 1998-present
  - Routeviews and RIPE
- Annotated AS topology with business relationships on each link (Gao)
  - TODO: Integrate CAIDA's algorithm (in process)
- Annotated ASes with
  - Business types
    - Transit, Content/Access, Enterprise, etc
  - Geographical regions
    - ARIN, RIPE, APNIC
- Web page downloads and AS paths to dual-stack webservers in Alexa 1M (performance)

AS Business Types



A. Dhamdhere, C. Dovrolis. *Twelve Years in the Evolution of the Internet Ecosystem*. IEEE/ACM Transactions on Networking, vol. 19, no. 5

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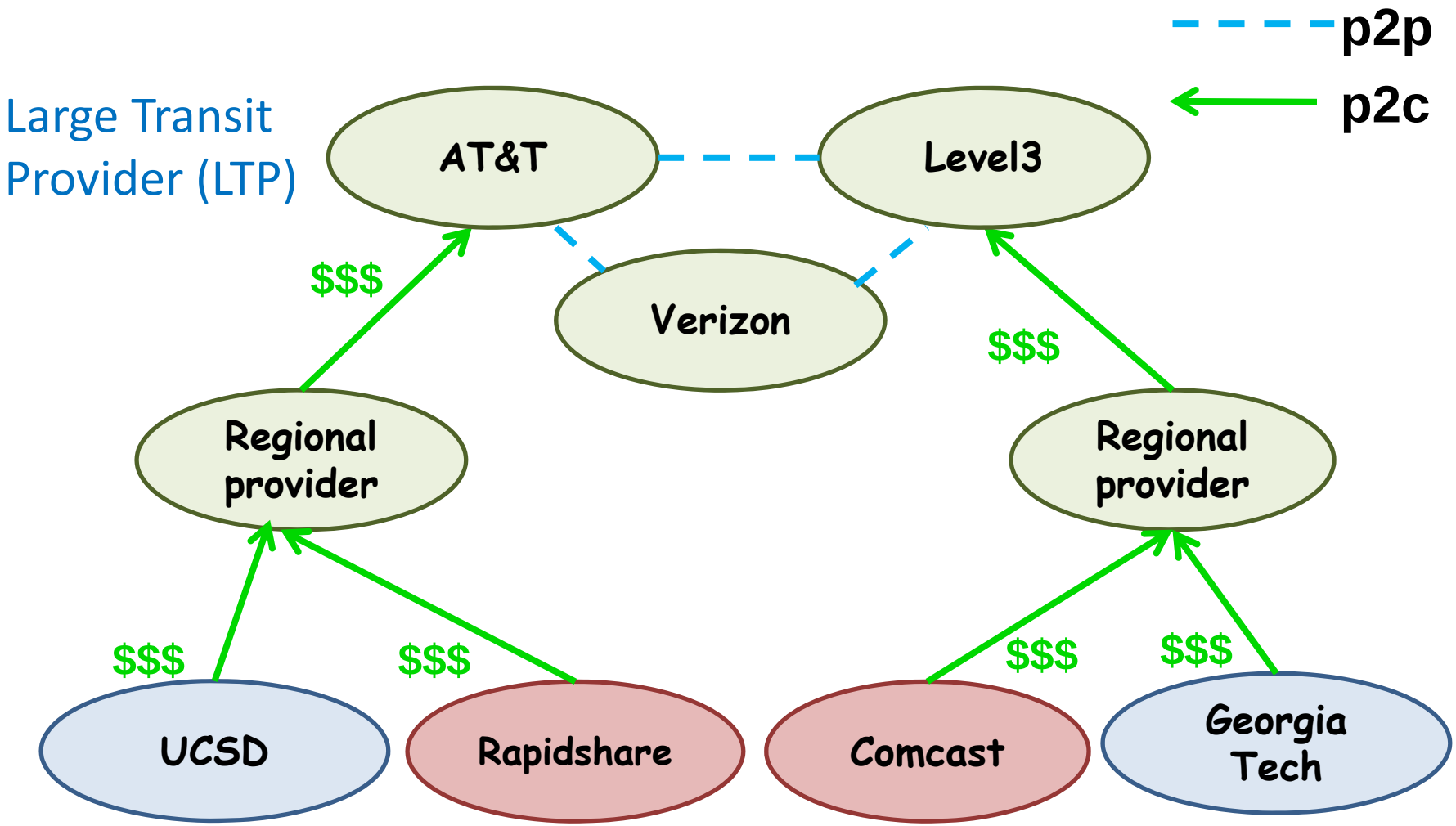

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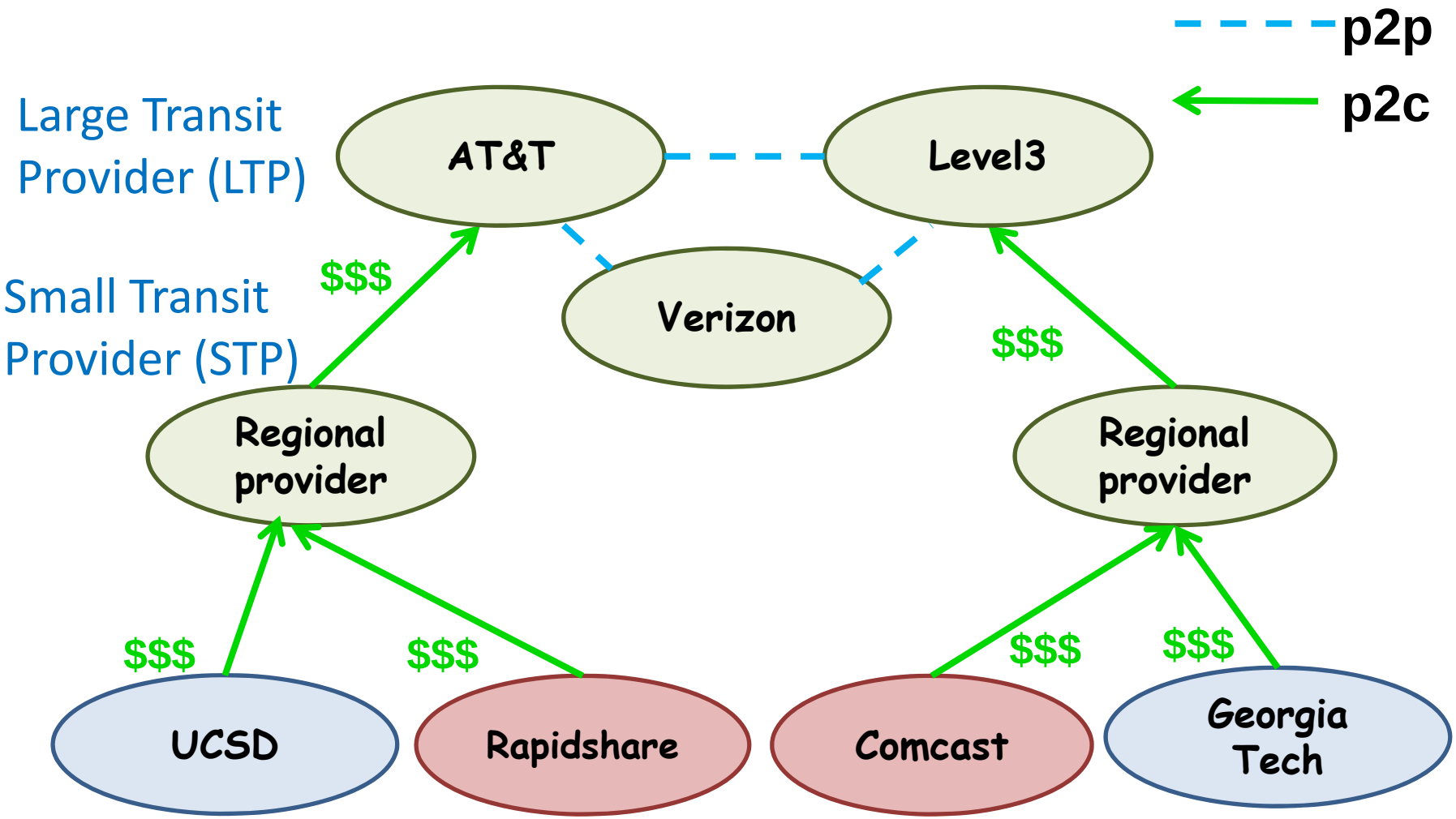

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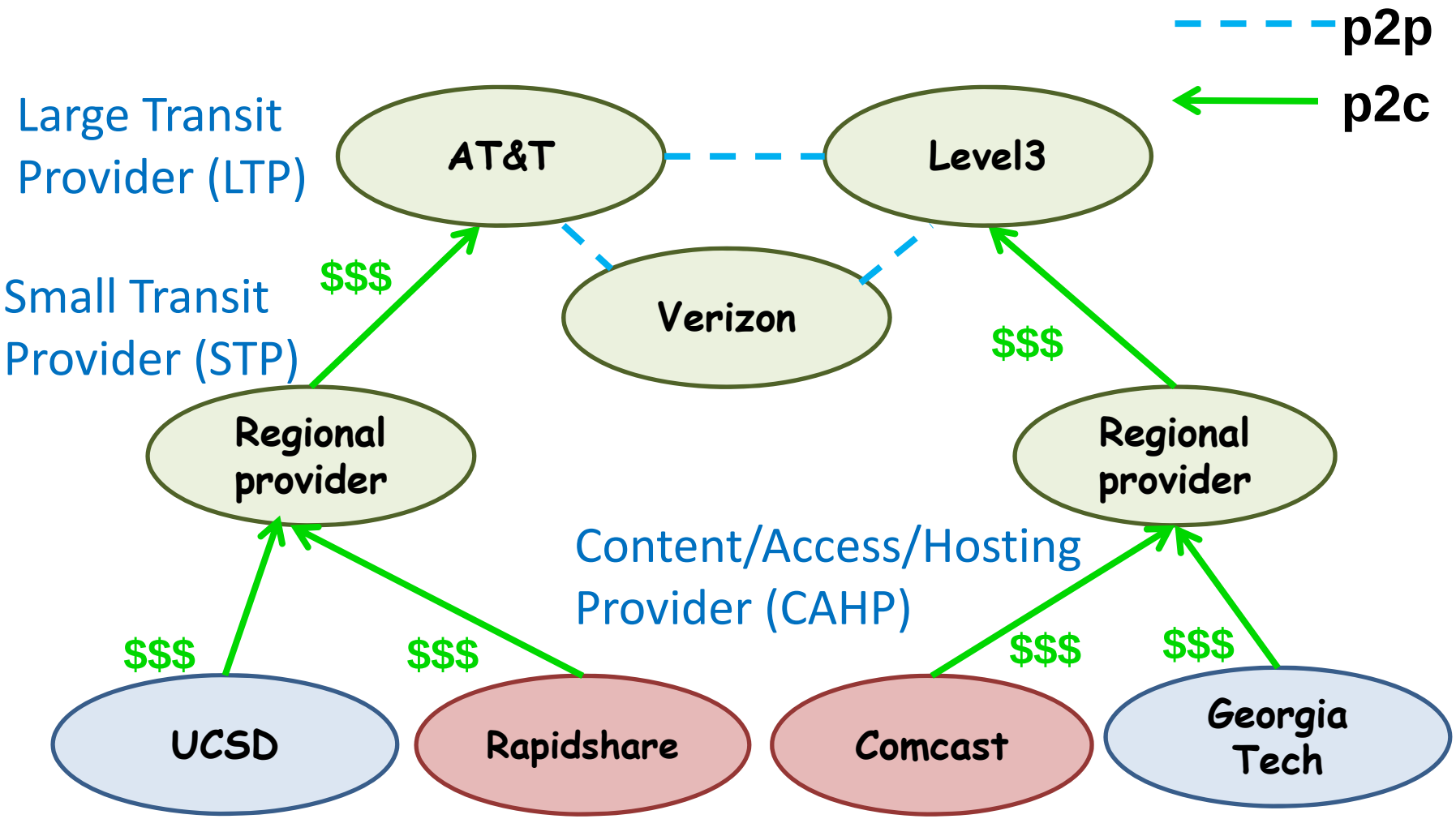

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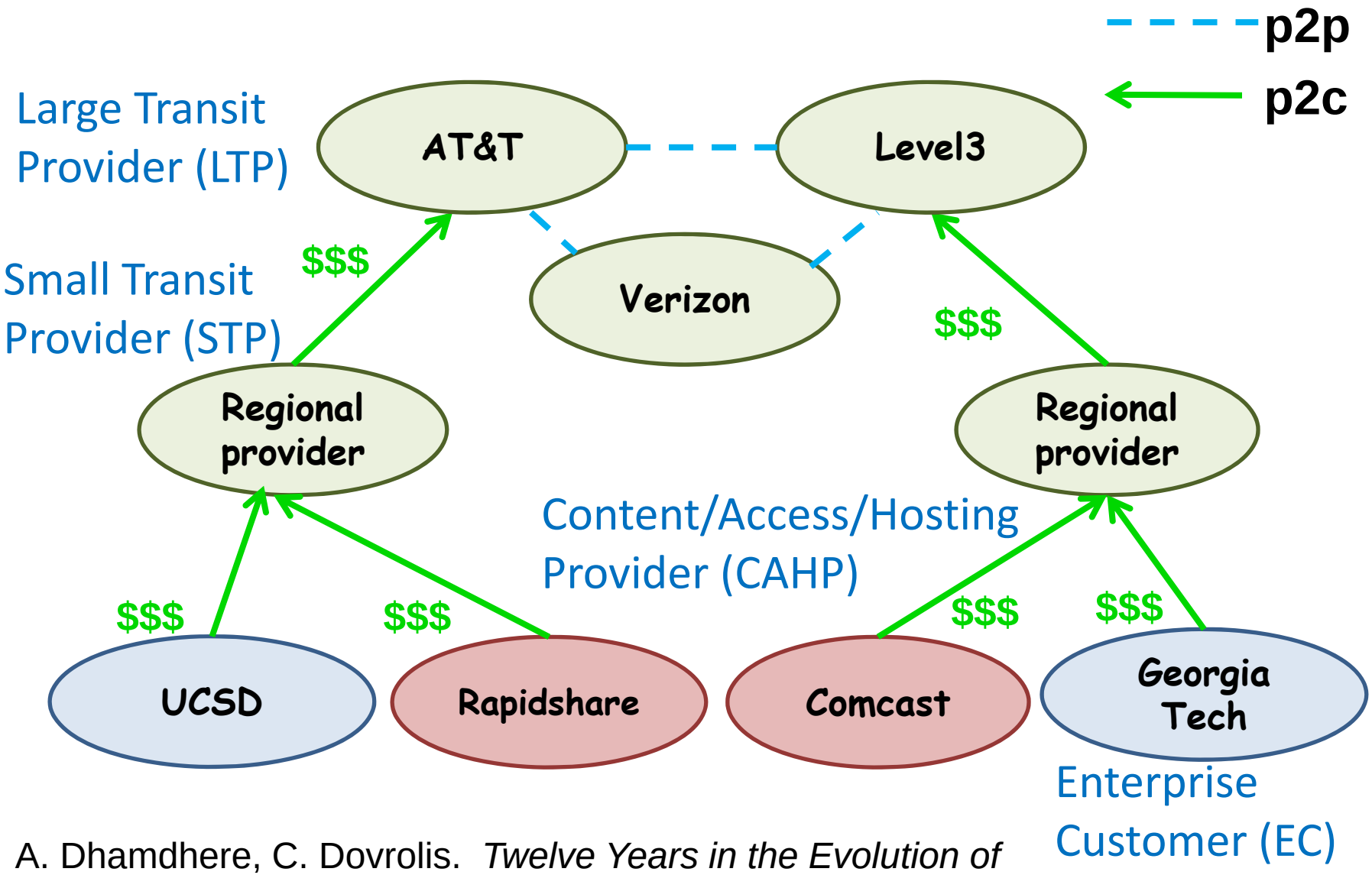

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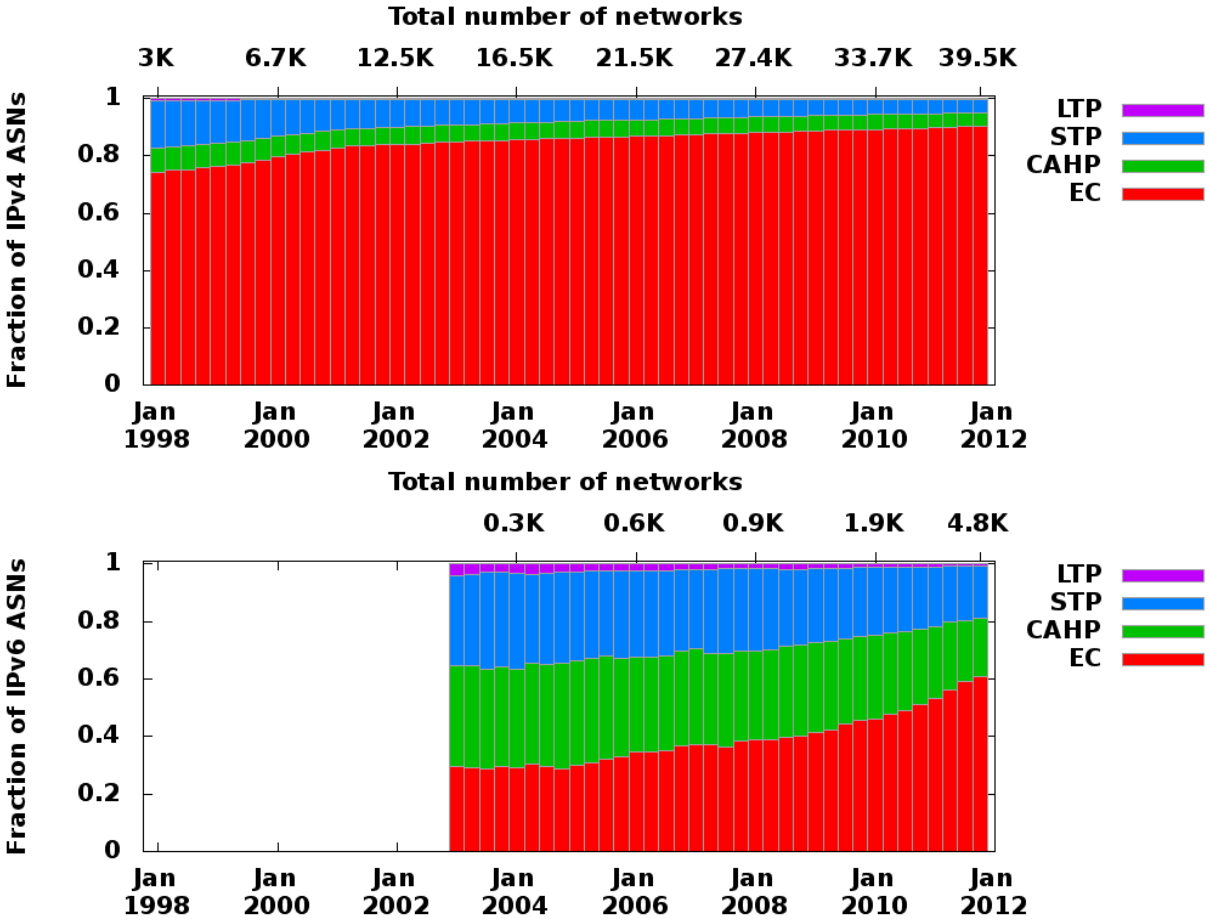
Key Results

- IPv6 deployment is strong in core, lagging at edge
- Performance is similar between IPv6 and IPv4
  - particularly with identical AS-level paths
- < 50% of AS-level paths are identical
  - But could be much larger without deploying any new infrastructure
  - 70% could be identical without establishing new peerings
  - >90% could be identical by establishing equivalent peerings amongst existing IPv6-deployed ASes
- Path exploration / convergence delay in IPv4 and IPv6 has been the same since 2008

Evolution of the business mix



Hypothesis: As IPv6 matures, the business mix should become similar to that in IPv4

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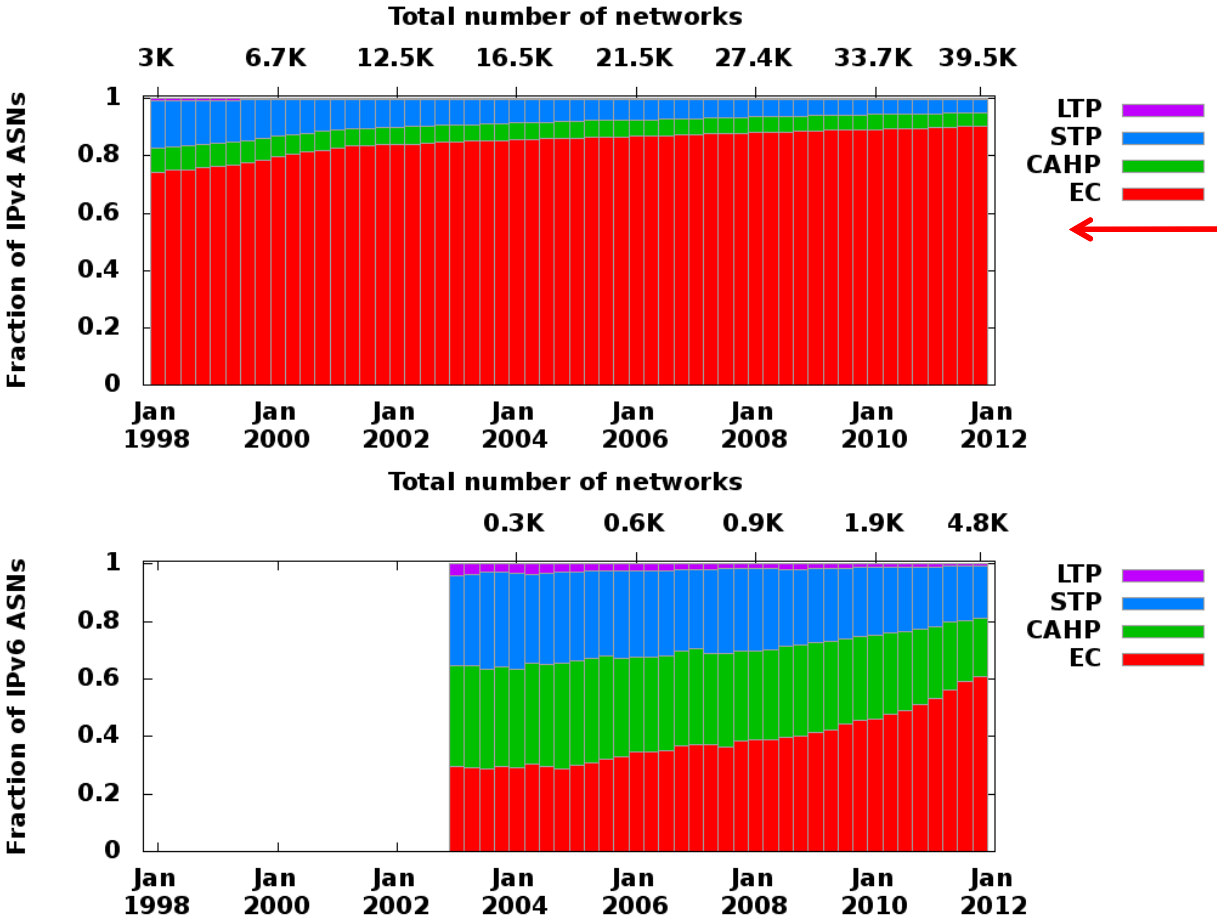

IPv4 network is dominated by ECs

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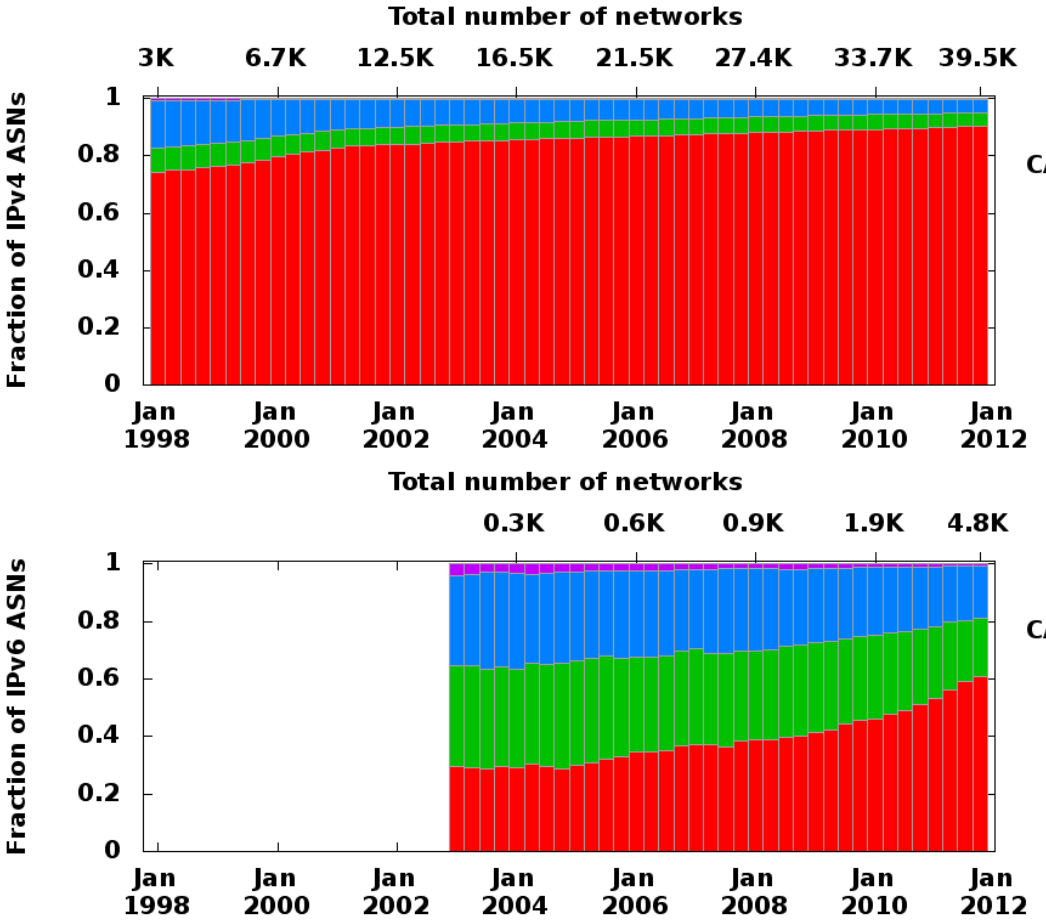


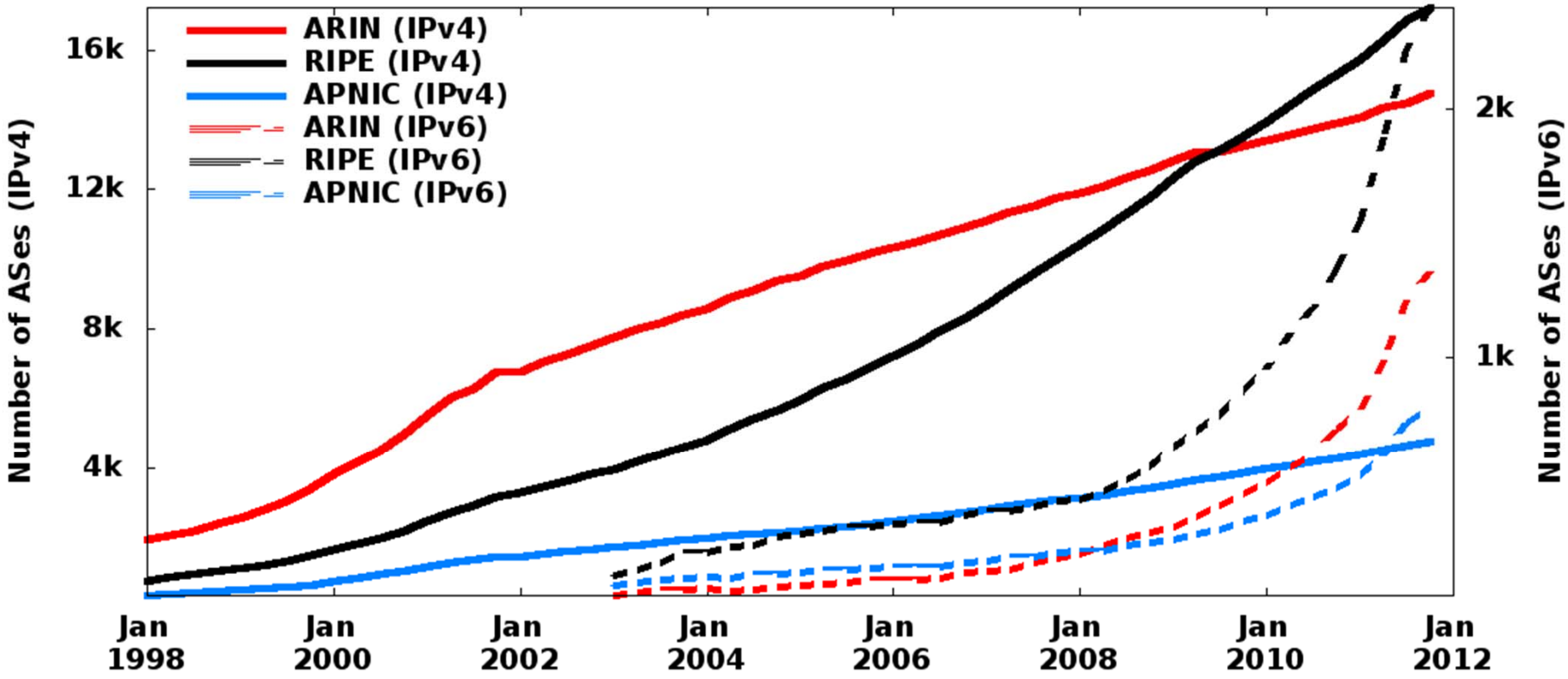
IPv4 network is dominated by ECs

Lower fraction of ECs in IPv6

Hypothesis: As IPv6 matures, the business mix should become similar to that in IPv4

IPv6 deployment at the edges is lagging

Growth trends by geographical region



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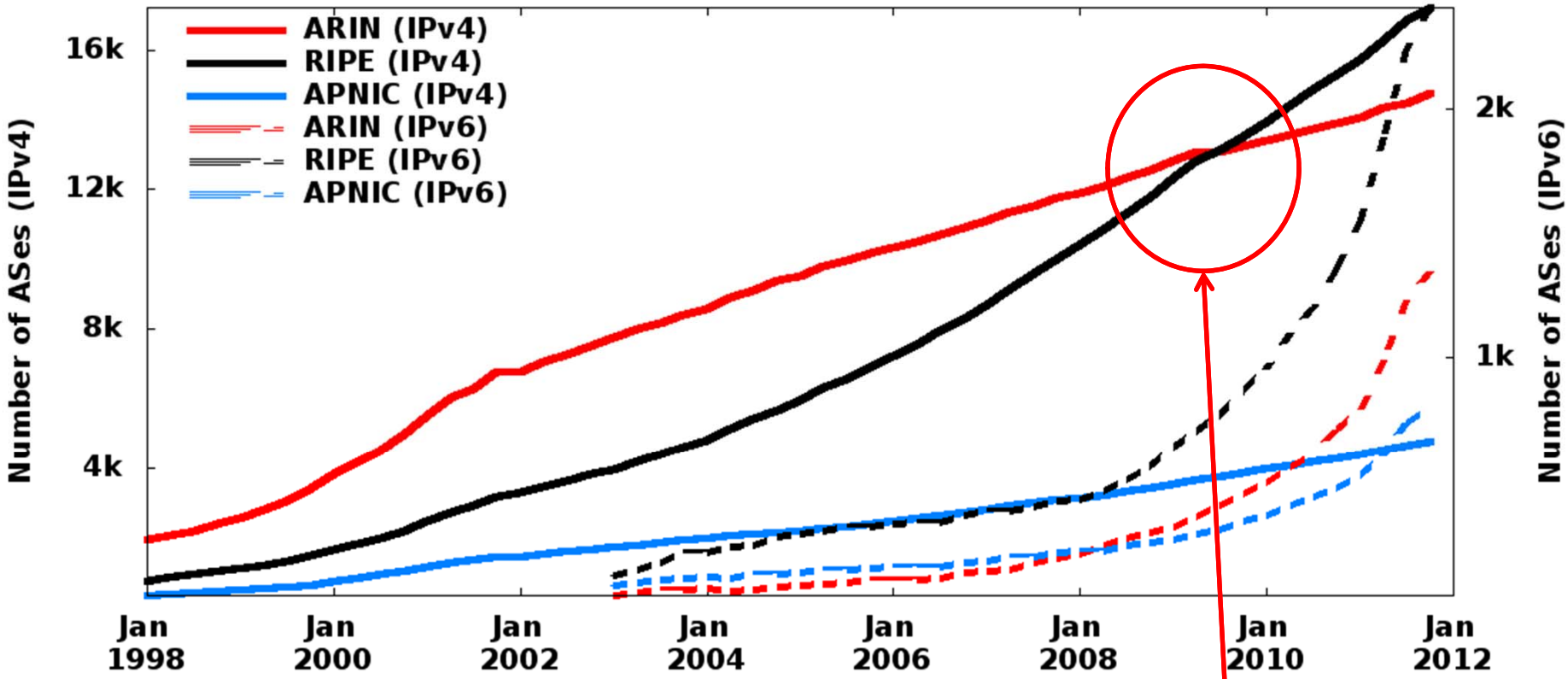

IPv4: More ASes in RIPE region than ARIN since 2009

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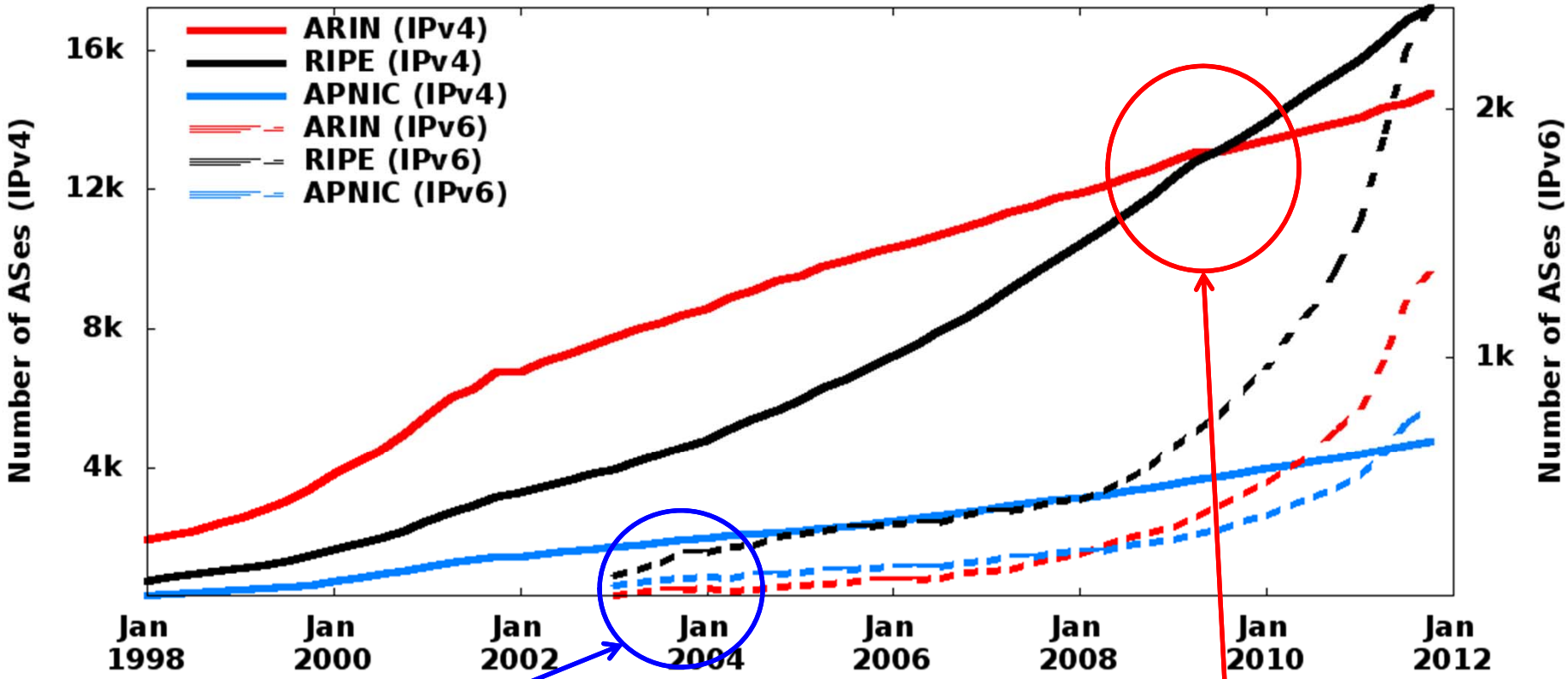

IPv6: RIPE region was always ahead of ARIN

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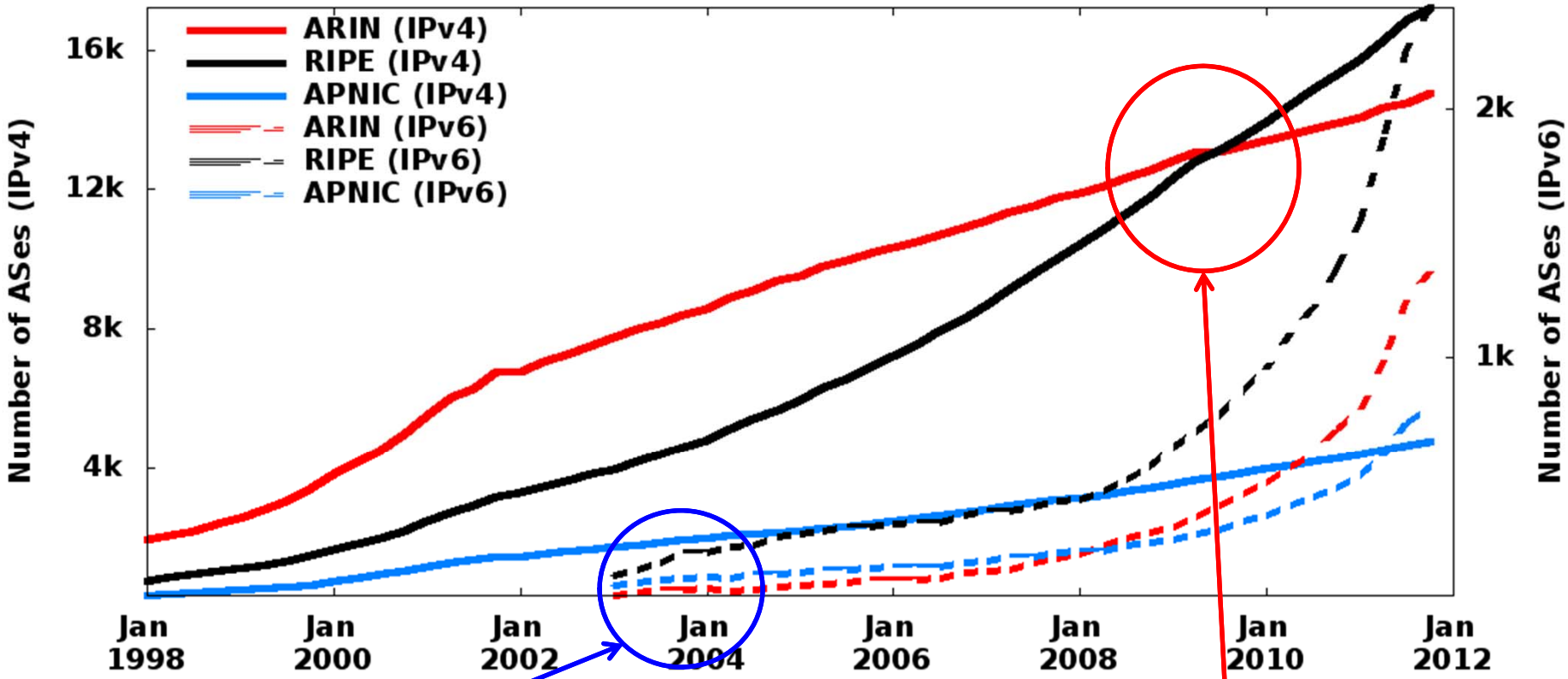


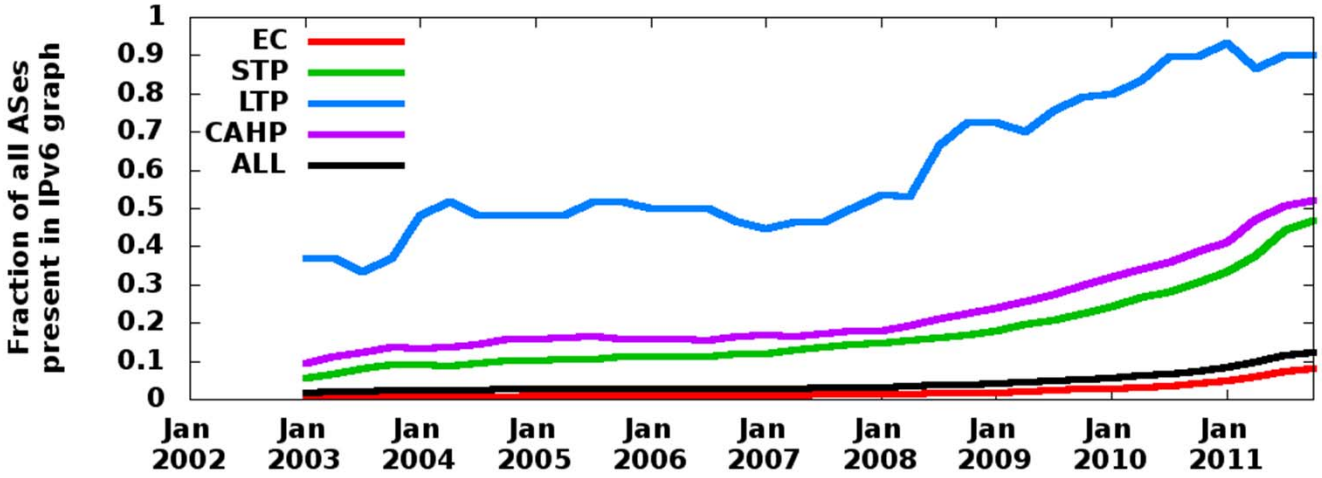
IPv6: RIPE region was always ahead of ARIN

IPv4: More ASes in RIPE region than ARIN since 2009

The ARIN region is lagging in IPv6 deployment

IPv4 and IPv6 topology convergence

Classification: business type



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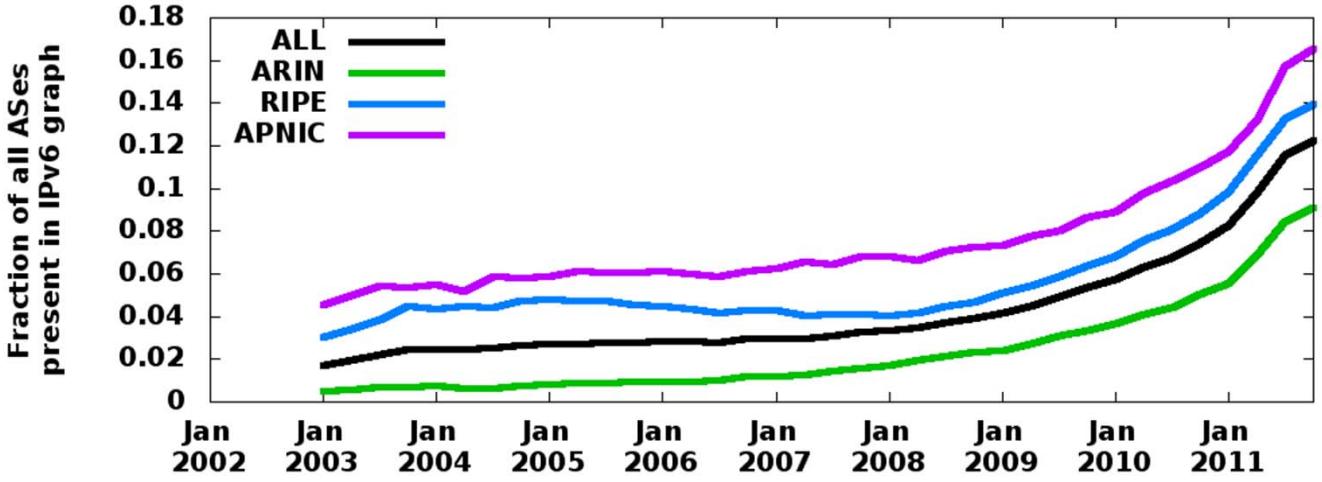

- Transit providers and content providers are mostly present in the IPv6 graph, ECs are lagging
- APNIC and RIPE lead ARIN in IPv6 presence

IPv4 and IPv6 topology convergence

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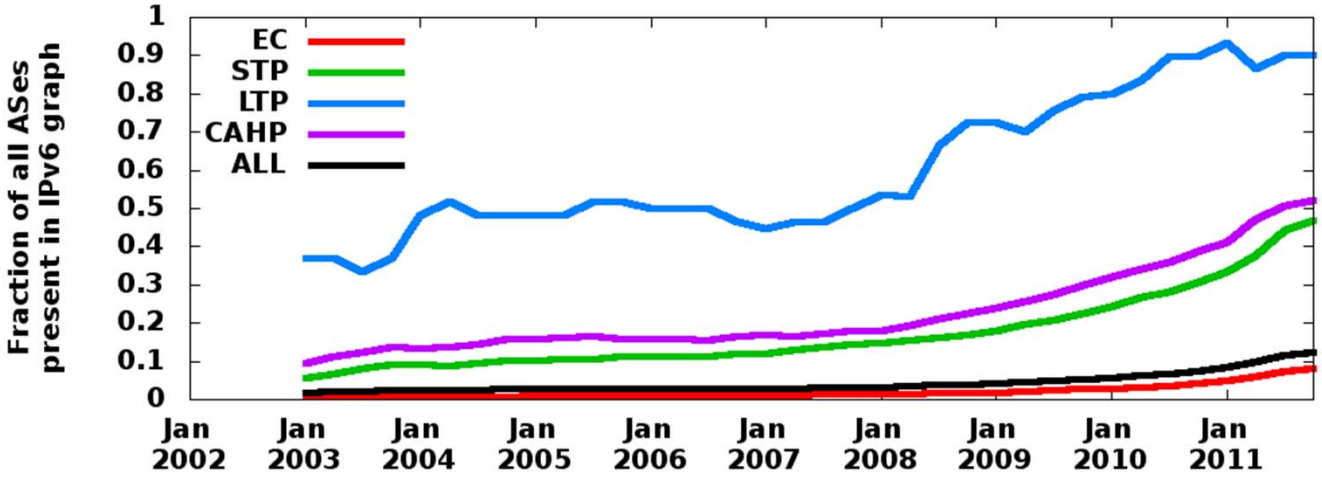

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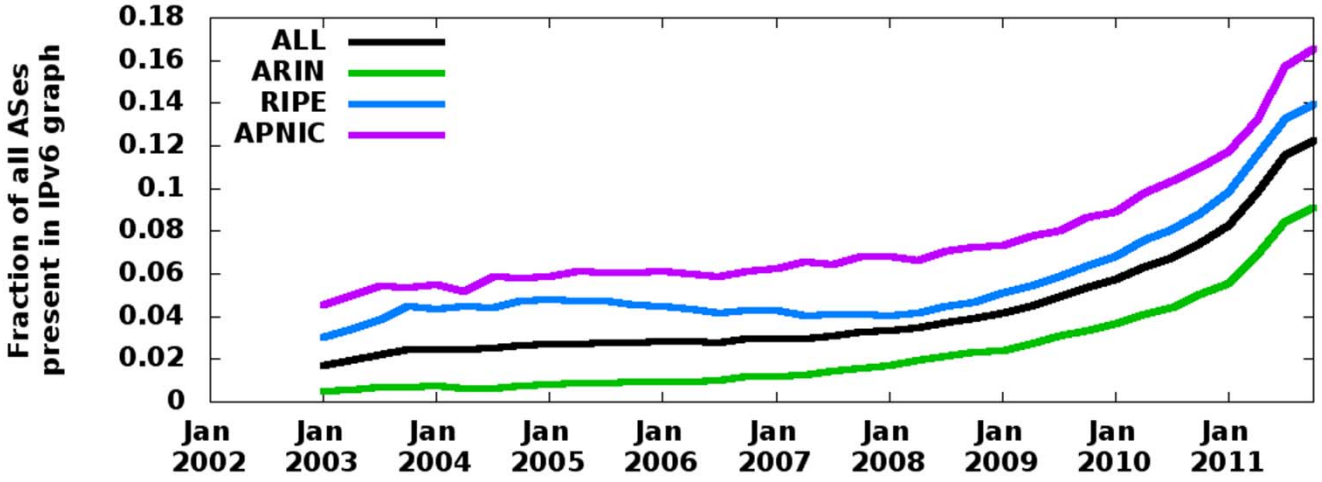


IPv6 convergence is not uniform across business types and geographical regions

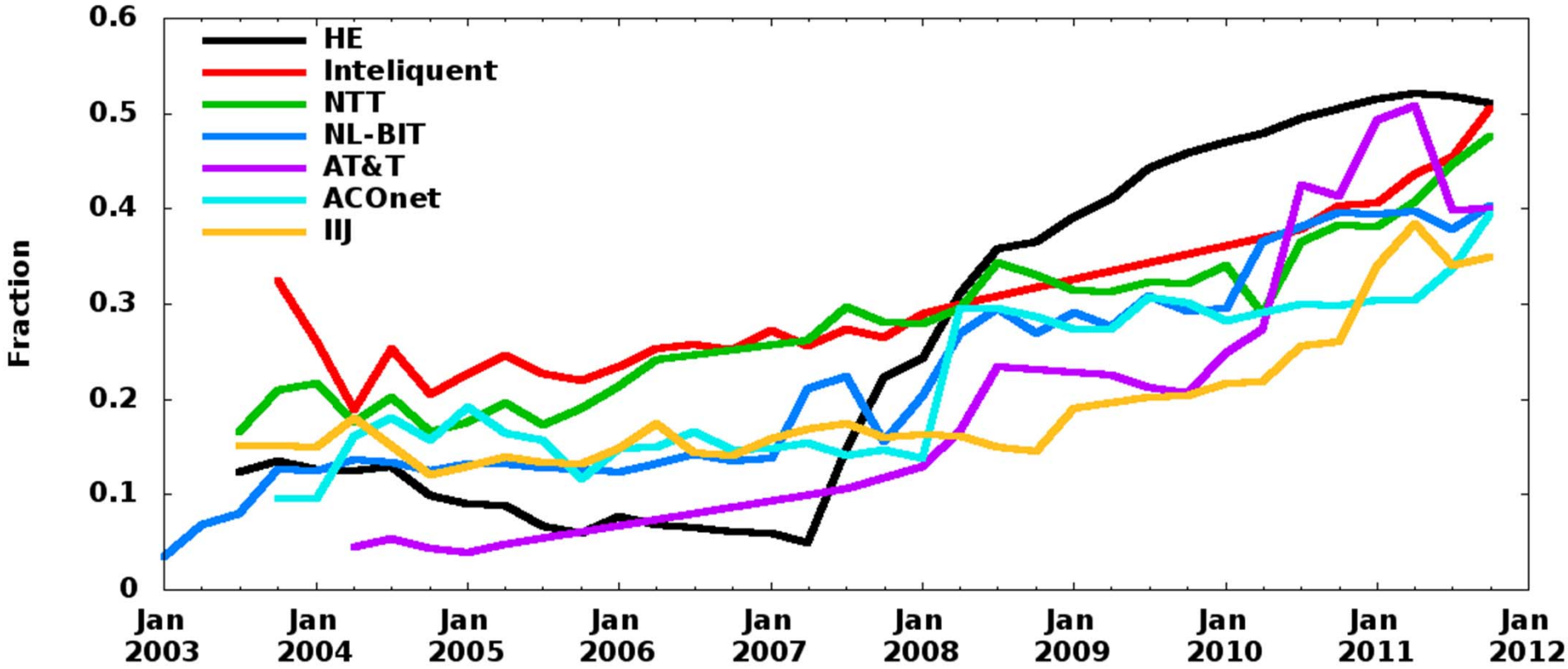
Structure of AS-level paths

- Hypothesis: As IPv6 matures, routing paths in IPv4 and IPv6 should become similar over time

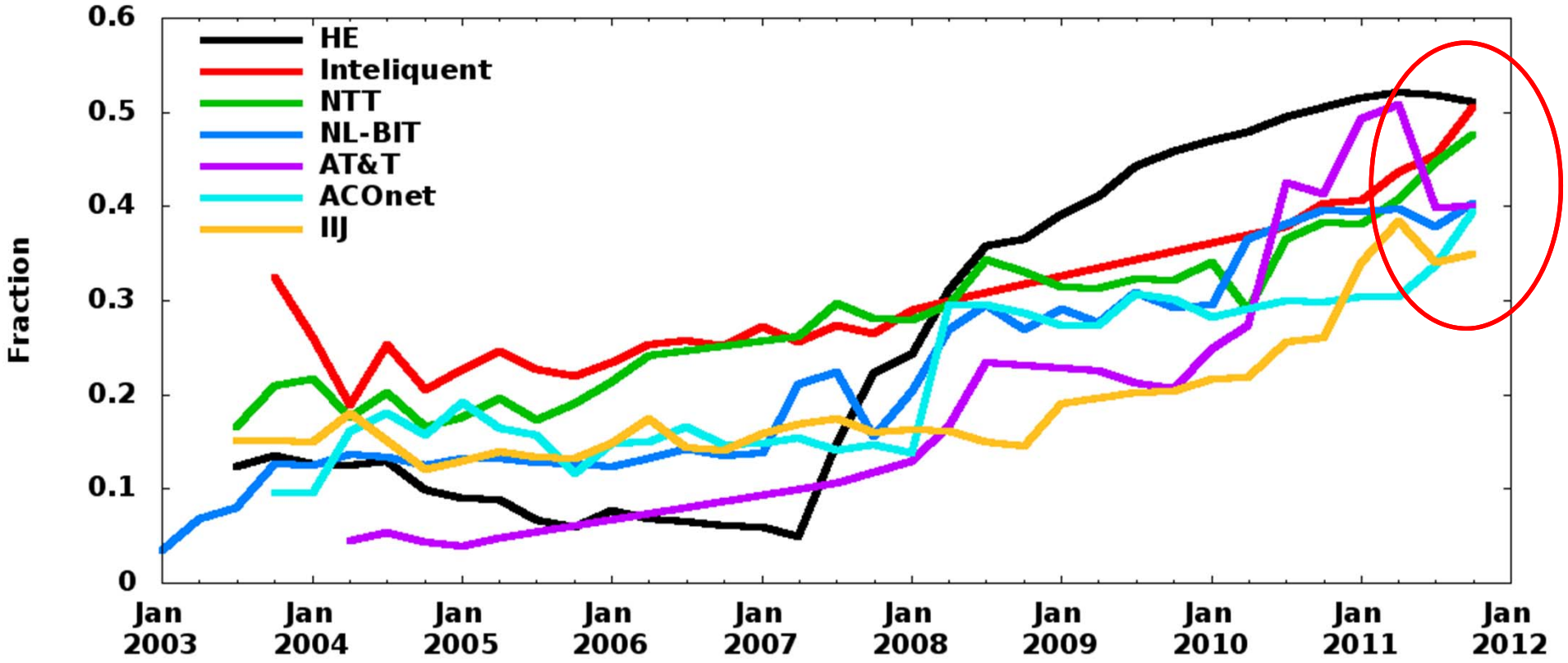
- Measured AS-level paths from 7 vantage points towards dual-stacked origin ASes

- Focused on the fraction of identical IPv4 and IPv6 paths from each VP

Identical AS-level paths



Identical AS-level paths



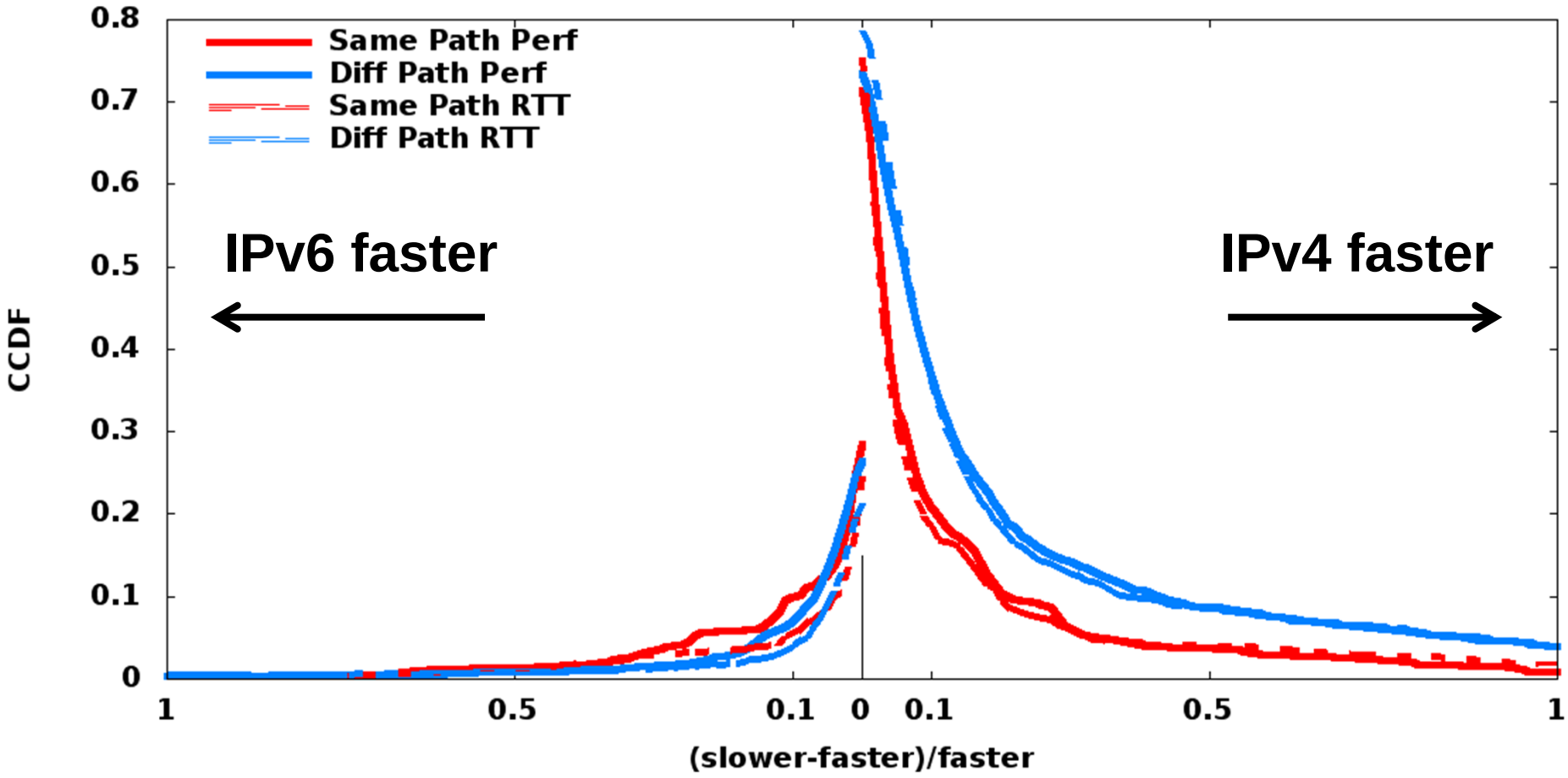
- The fraction of identical paths is increasing
- Currently less than 50% of IPv4 and IPv6 paths are identical

  The IPv6 network is maturing, but slowly

Comparing IPv4 and IPv6 performance

- Poor performance over IPv6 is likely to inhibit the adoption of IPv6
- How often is performance over IPv6 similar to that over IPv4?
- Measurements from 5 dual-stacked vantage points (CAIDA Ark) to dual-stacked websites
  - Webpage download times
  - AS paths to those websites (traceroute)

Performance: Webpage downloads



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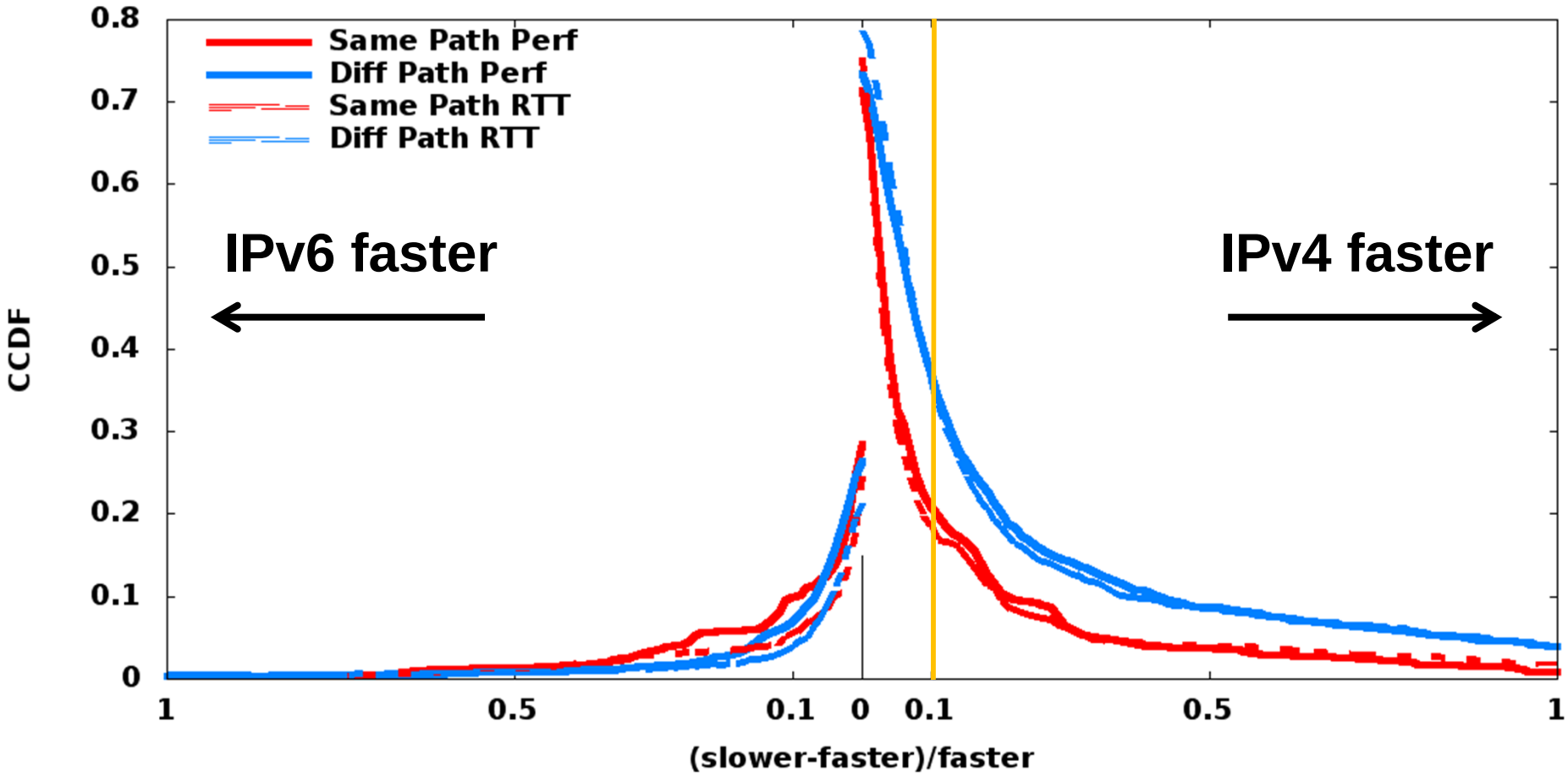

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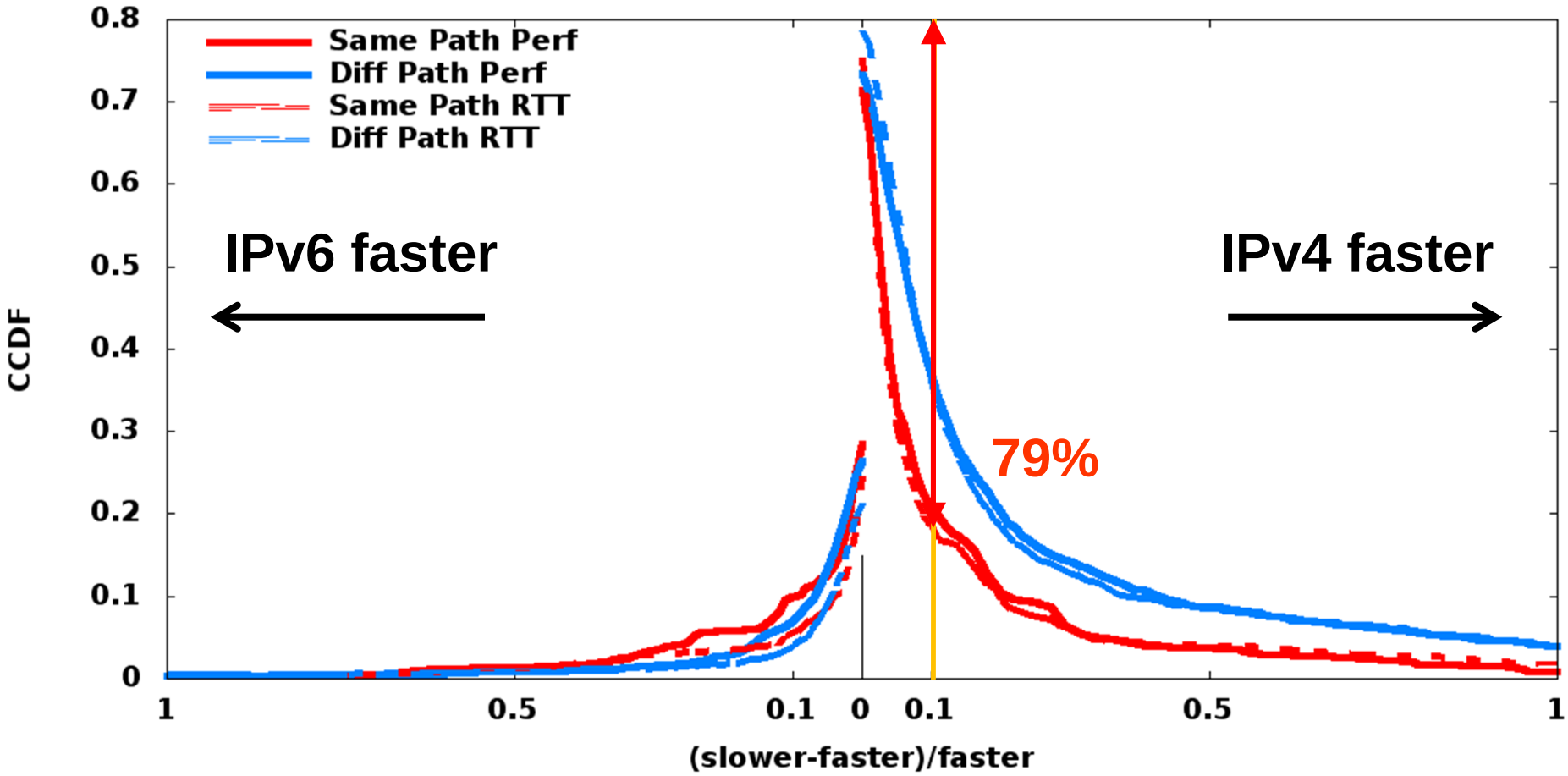
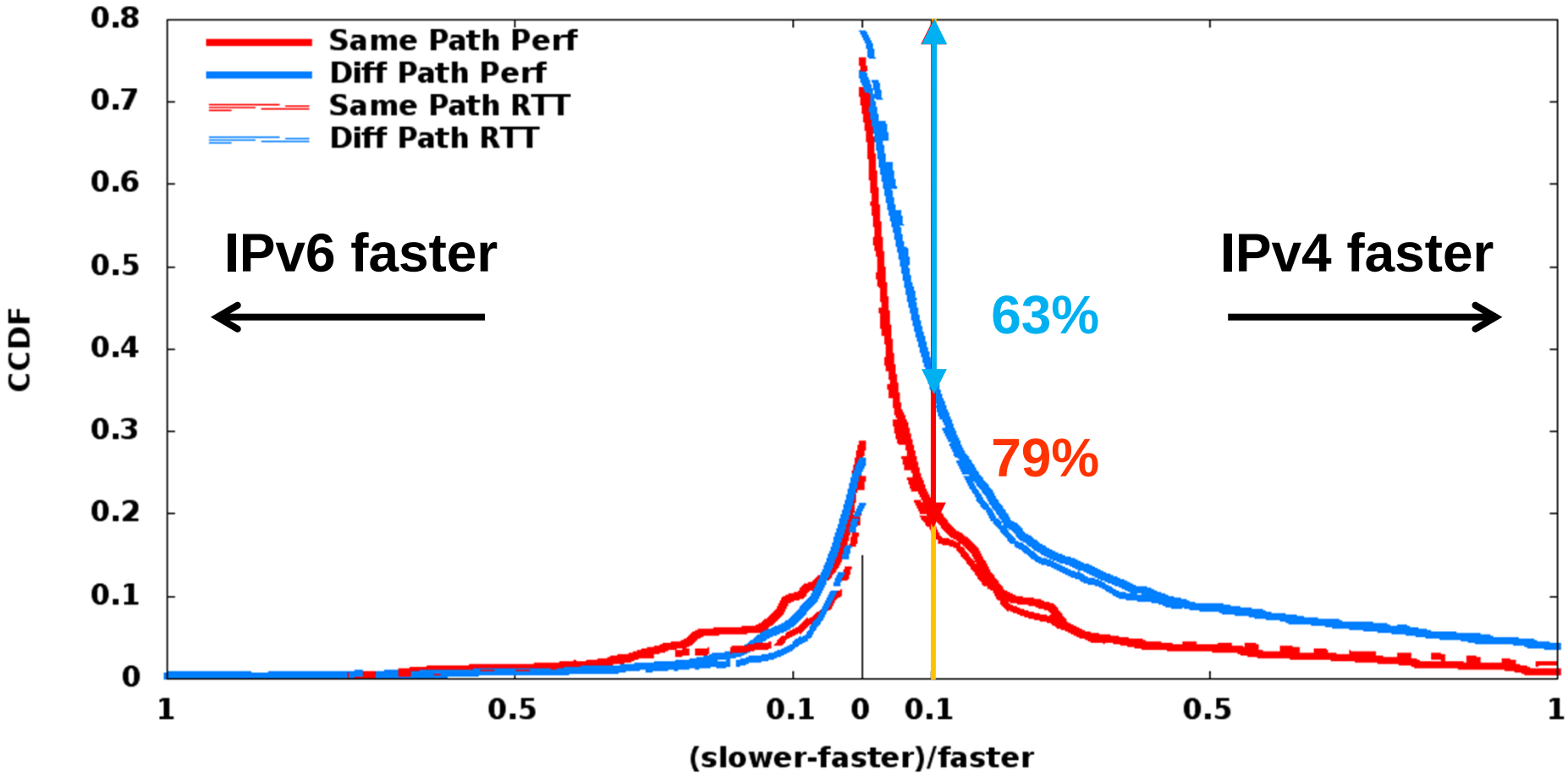


- **79% of paths had IPv6 performance within 10% of IPv4 when AS paths were the same**

Performance: Webpage downloads



- **79% of paths had IPv6 performance within 10% of IPv4 when AS paths were the same**
- **Only 63% of paths had similar performance when AS paths differed**

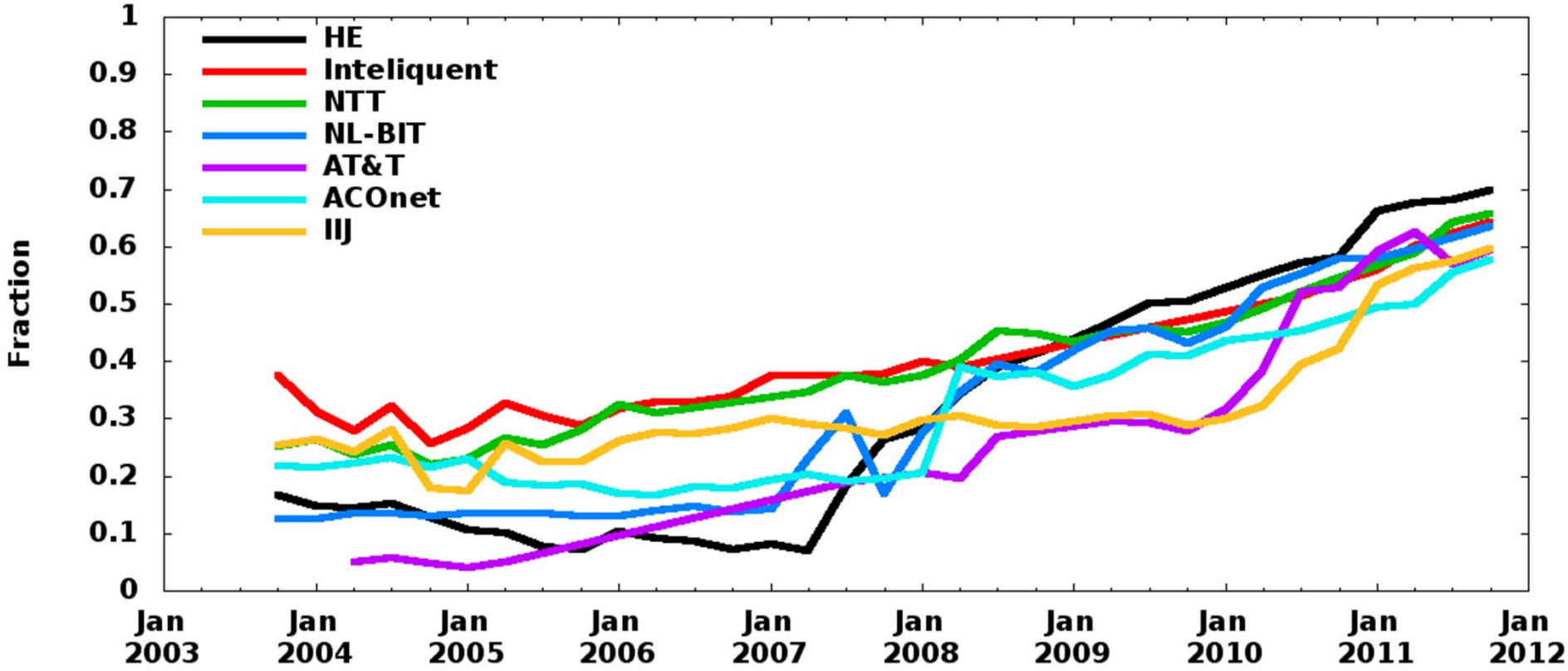
Relation between performance and AS-level paths

- IPv6 performance is similar to IPv4 performance, if AS-level paths are the same
  - Key finding of Nikkhah *et al.*
- < 50% of AS paths from dual-stacked vantage points are currently the same in IPv4 and IPv6

- Increasing congruence between IPv4 and IPv6 topology will improve performance and thus deployment incentives

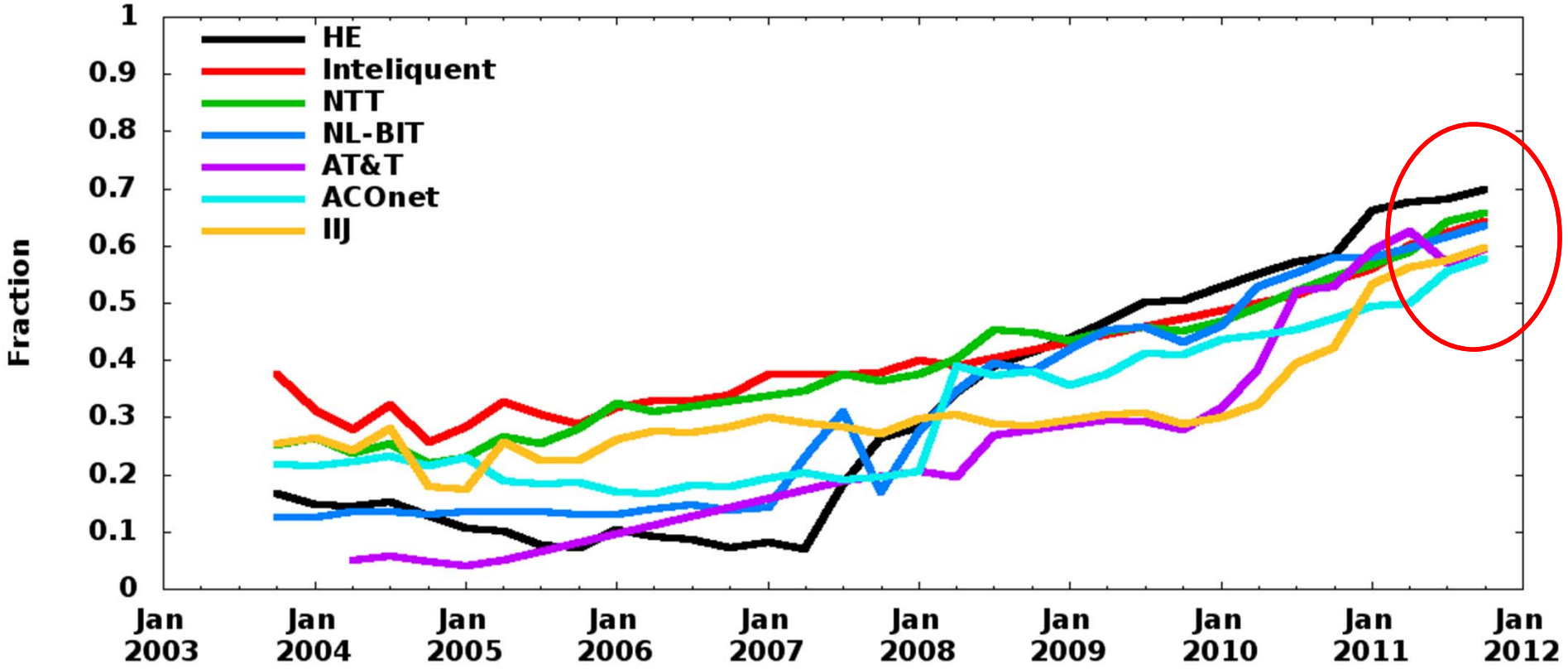
M. Nikkhah, R. Guerin, Y. Lee, R. Woundy. *Assessing IPv6 through web access: a measurement study and its findings*. CoNEXT 2011.

Potential AS-path congruence



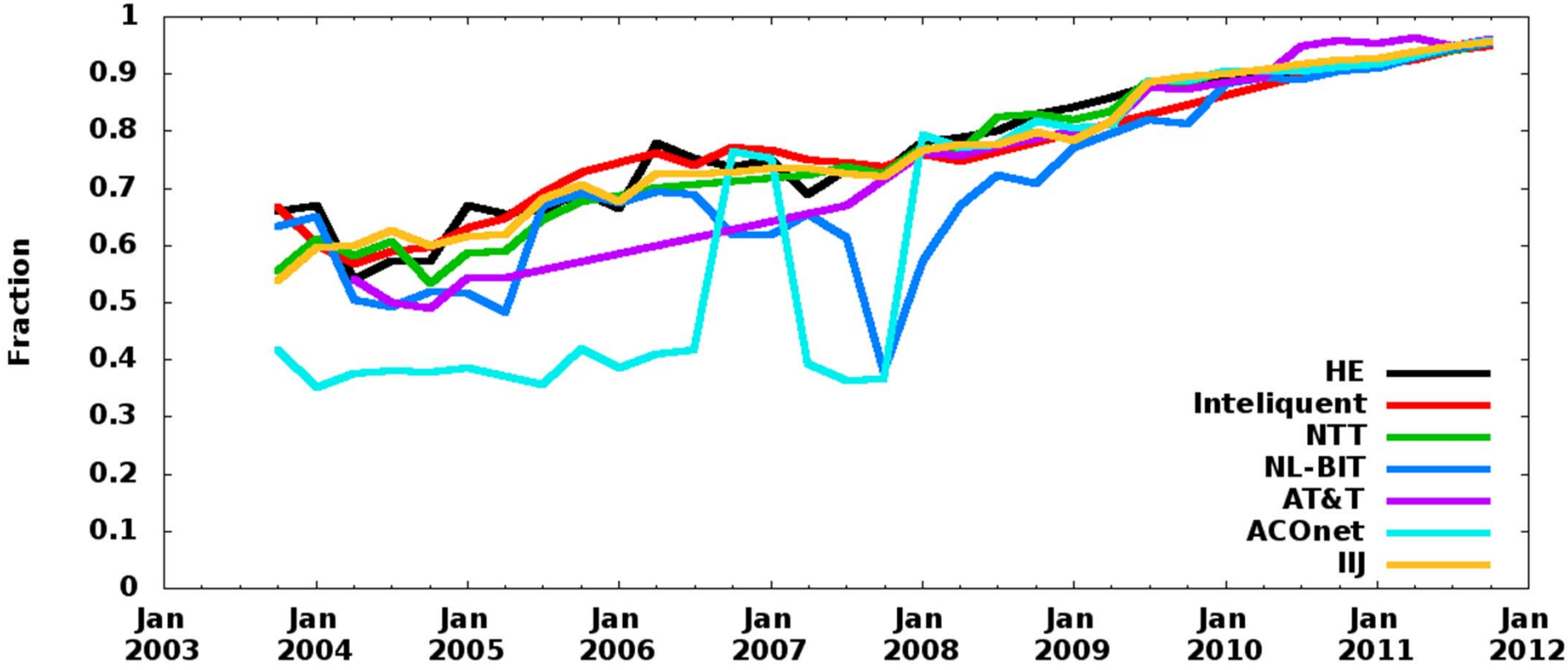
- For each link in an IPv4 AS path, is that link present in the IPv6 topology (anywhere)?

Potential AS-path congruence



- For each link in an IPv4 AS path, is that link present in the IPv6 topology (anywhere)?
- Based on links that already exist, up to 70% of paths could be identical (without building any new infrastructure)

Potential AS-path congruence



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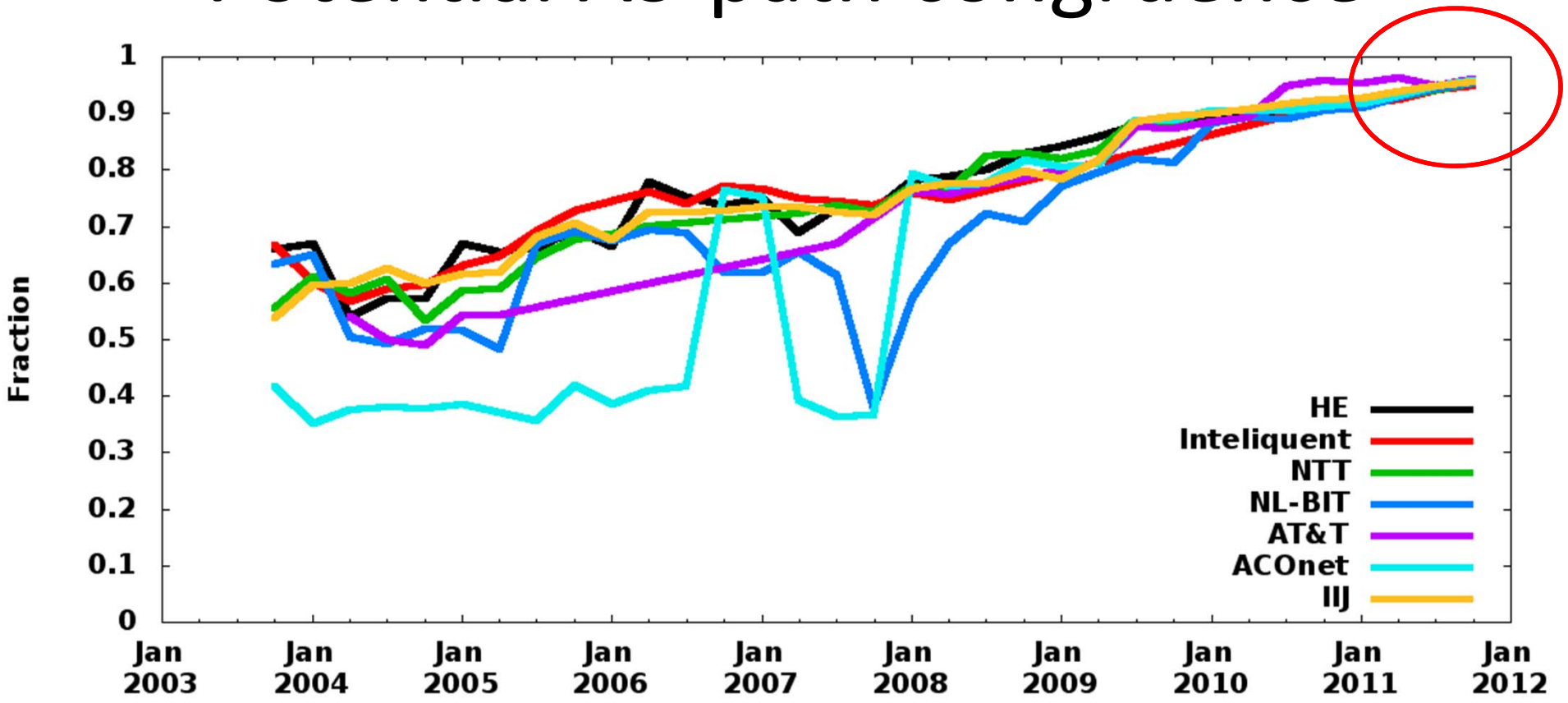
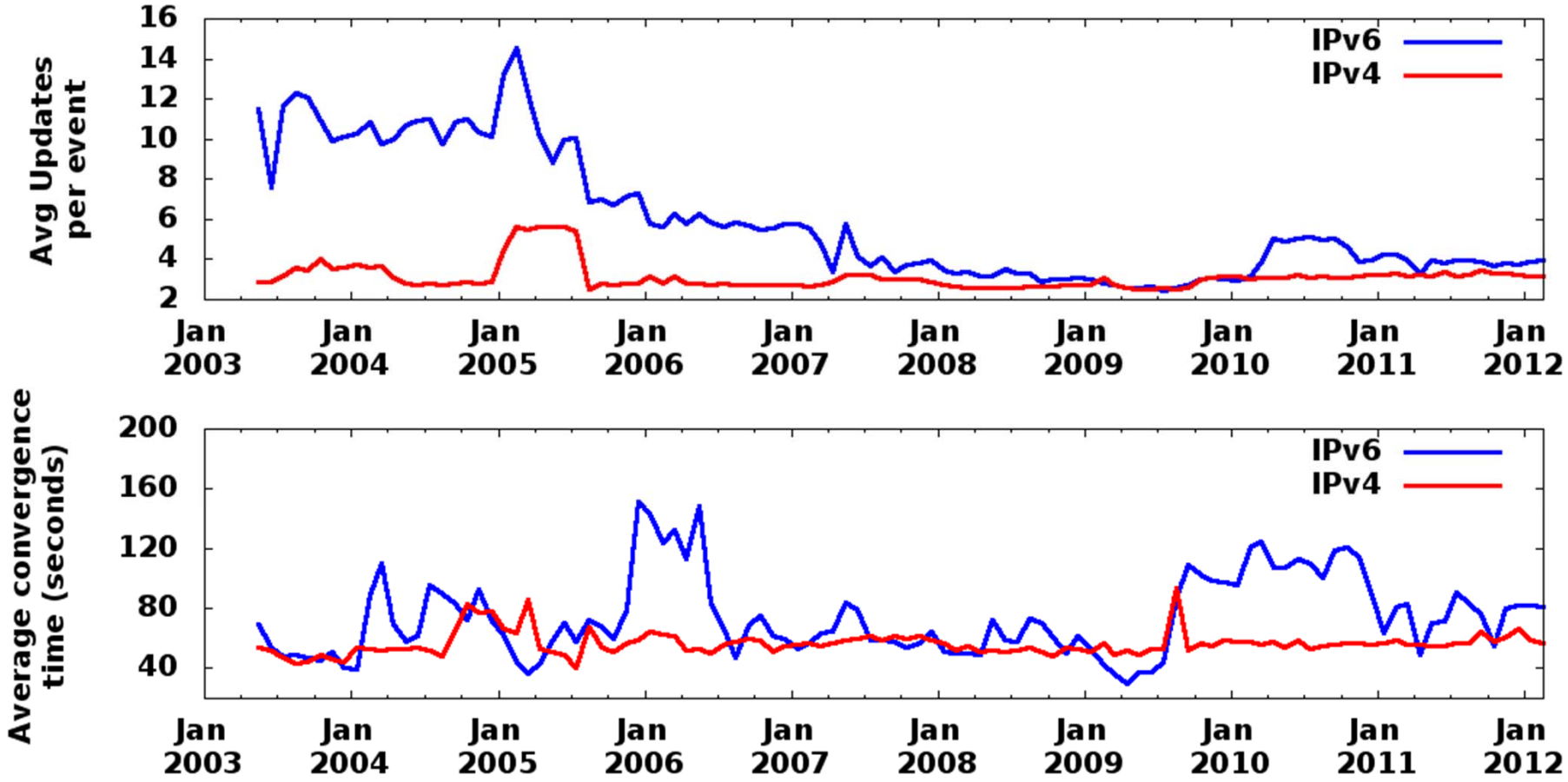


- For each AS in an IPv4 AS path, is that AS present in the IPv6 topology (anywhere)?
- Based on ASes that are already in the IPv6 graph, more than 90% of paths could be identical

Routing Stability -- IIJ



- **Path exploration is similar in IPv4 and IPv6 since 2008**
- **Time to convergence peaks in IPv6 are due to single prefix events -- convergence time is otherwise similar**

Summary of findings

- The IPv6 network is maturing…albeit slowly and non-uniformly
- The “core” of the network (transit providers) are mostly doing well with IPv6 deployment
- The edge (enterprises and access providers) is lagging
- IPv6 deployment is faster in Europe and Asia-Pacific regions, North America is lagging
- IPv4 and IPv6 paths could potentially be 90% similar, without deploying any additional infrastructure

Thanks! Questions?