Measuring the Adoption of IPv6

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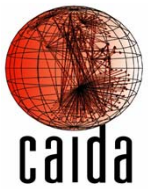


[simula . research laboratory]

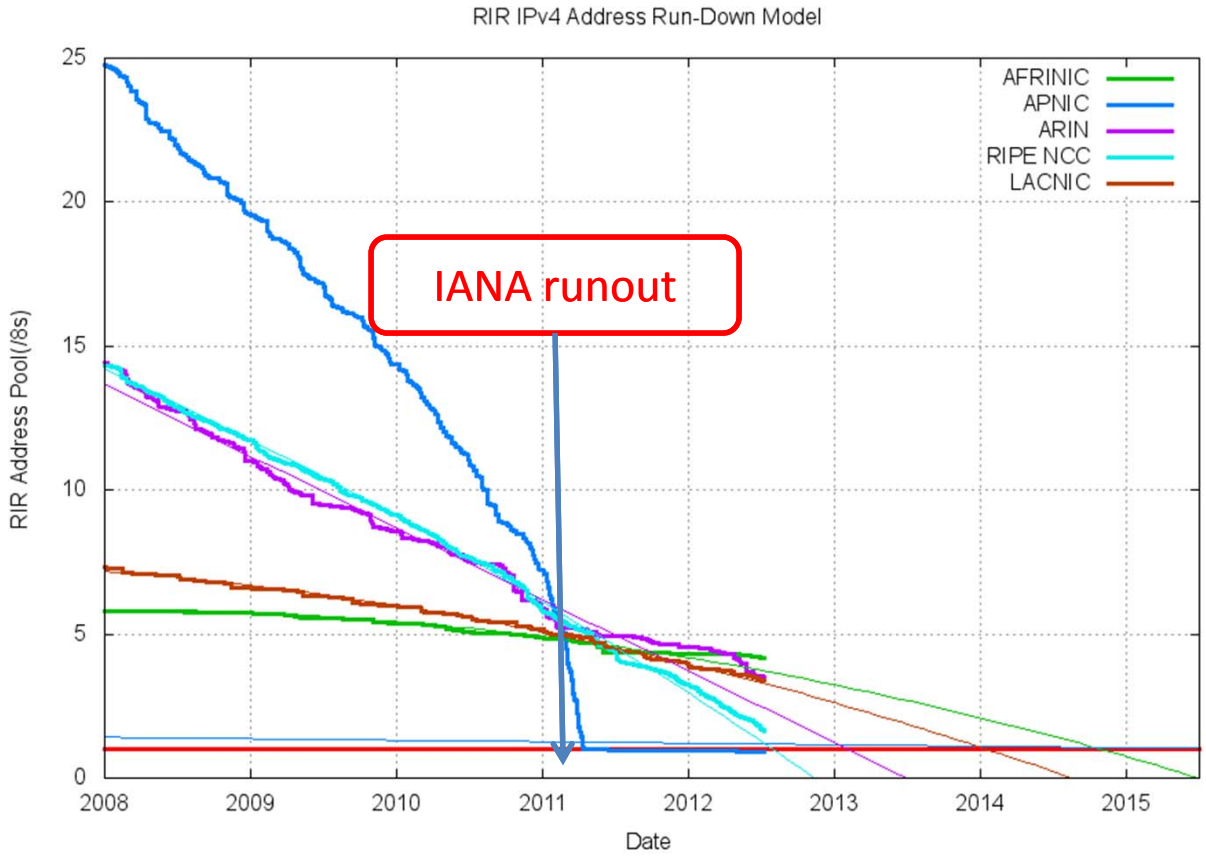
Outline

- Problem statement: Running out of Internet addresses, replacement protocol lacks deployment incentives (classic commons problem).
- How can we inform and guide the greatest architectural transition of the greatest man-made complex communications network?
- Measurement and modeling to the rescue ☺

Background – The Internet Numbering Architecture

- The Internet is a "network of networks"
  - About 40,000 networks, called Autonomous Systems (ASes)
- Each host in each network needs a unique identifier, (usually) its Internet Protocol (IP) address
- IANA allocates address space to Regional Internet Registries (RIRs), which allocate to organizations
- The "current" IP version 4 (IPv4) provides 4 billion addresses

When will we run out of addresses?



- IANA ran out of IPv4 addresses in 2011
- Regional Internet Registries (RIRs) are rationing but will soon run out too
- However, many underutilized IPv4 address will make their way to greater use via market mechanisms (people will sell what they don't need)

IPv6

- Address runout was anticipated back in the 1990s
- The “new” (15 years old) IPv6 was standardized in the late 90s
- IPv6 provides much more address space than our foreseeable addressing needs
- Operating systems and network hardware have supported IPv6 for many years now

So, 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
- Many costs, no tangible benefit!

Two Endgame Scenarios

- IPv6 gets deployed!
  - Existing measurement techniques and data will be ineffective
- IPv6 languishes
  - A world of large-scale NATs and poor performance
- We don't have a good idea which scenario will happen
  - Scant data about IPv6 deployment, performance, traffic
    - What data is available is cause for pessimism
  - No model to predict future, or reveal what is needed to reach a favorable outcome

CAIDA's IPv6 Efforts

- Measurement
  - IPv6 adoption, topology, routing, performance
  - Tools and techniques for IPv6 measurement
- Modeling
  - Quantitative model for the IPv4-IPv6 transition
  - Try to predict the outcome, or at least reveal insights into evolutionary dynamics

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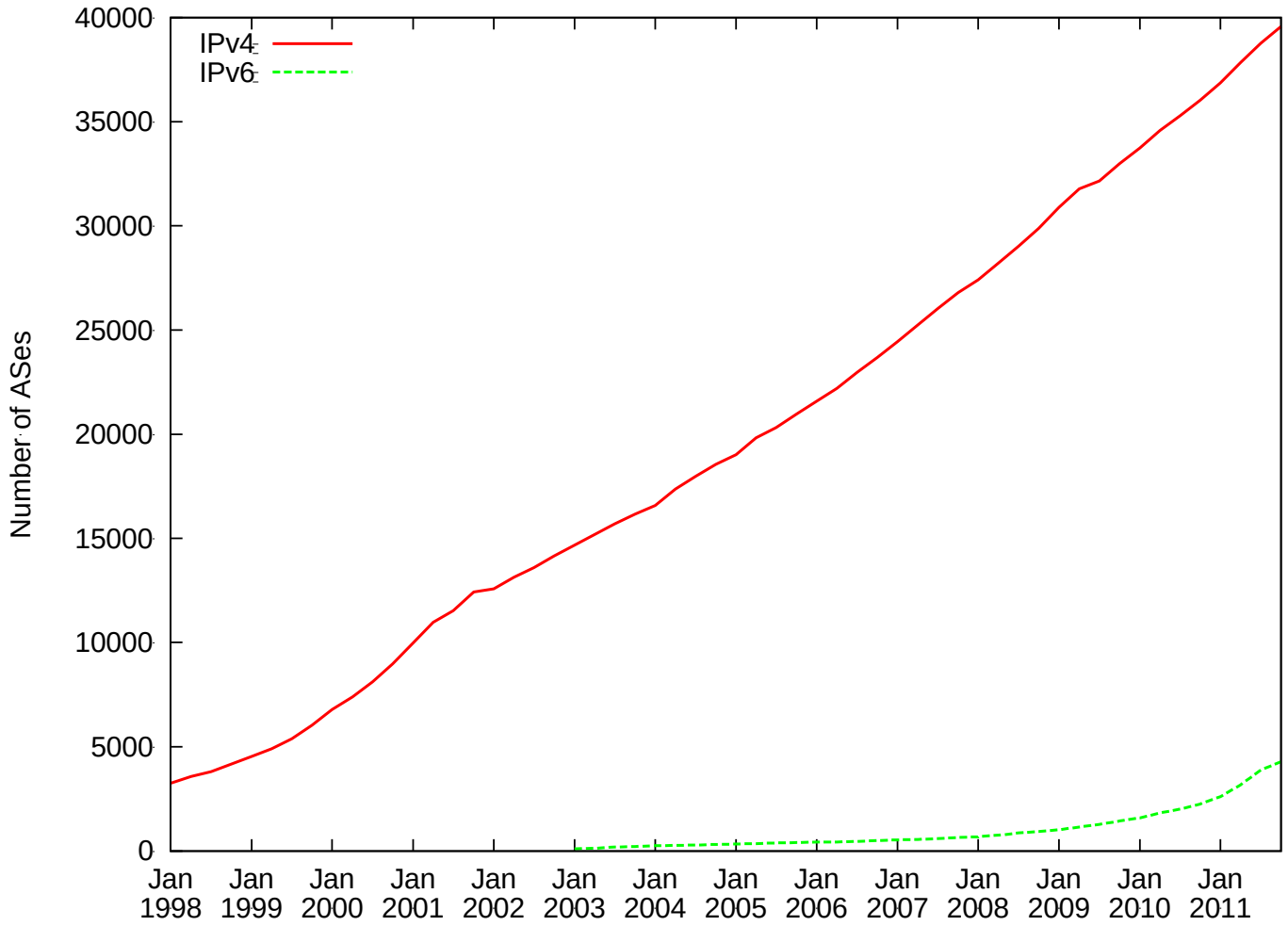
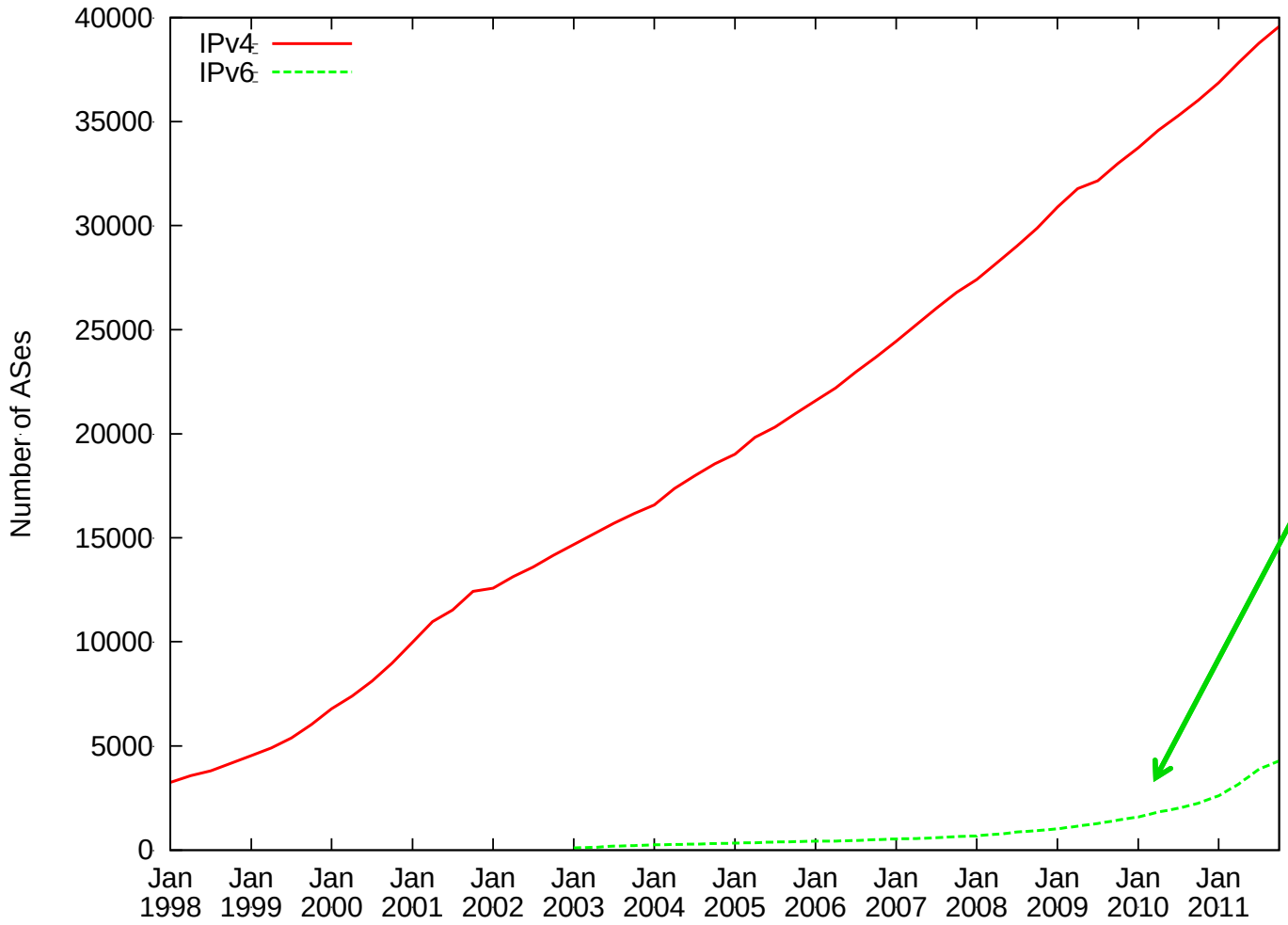
Measuring IPv6 Adoption

"IPv6 will be deployed any day now", to appear at the ACM SIGCOMM Internet Measurement Conference, Nov 2012.

IPv6 growth

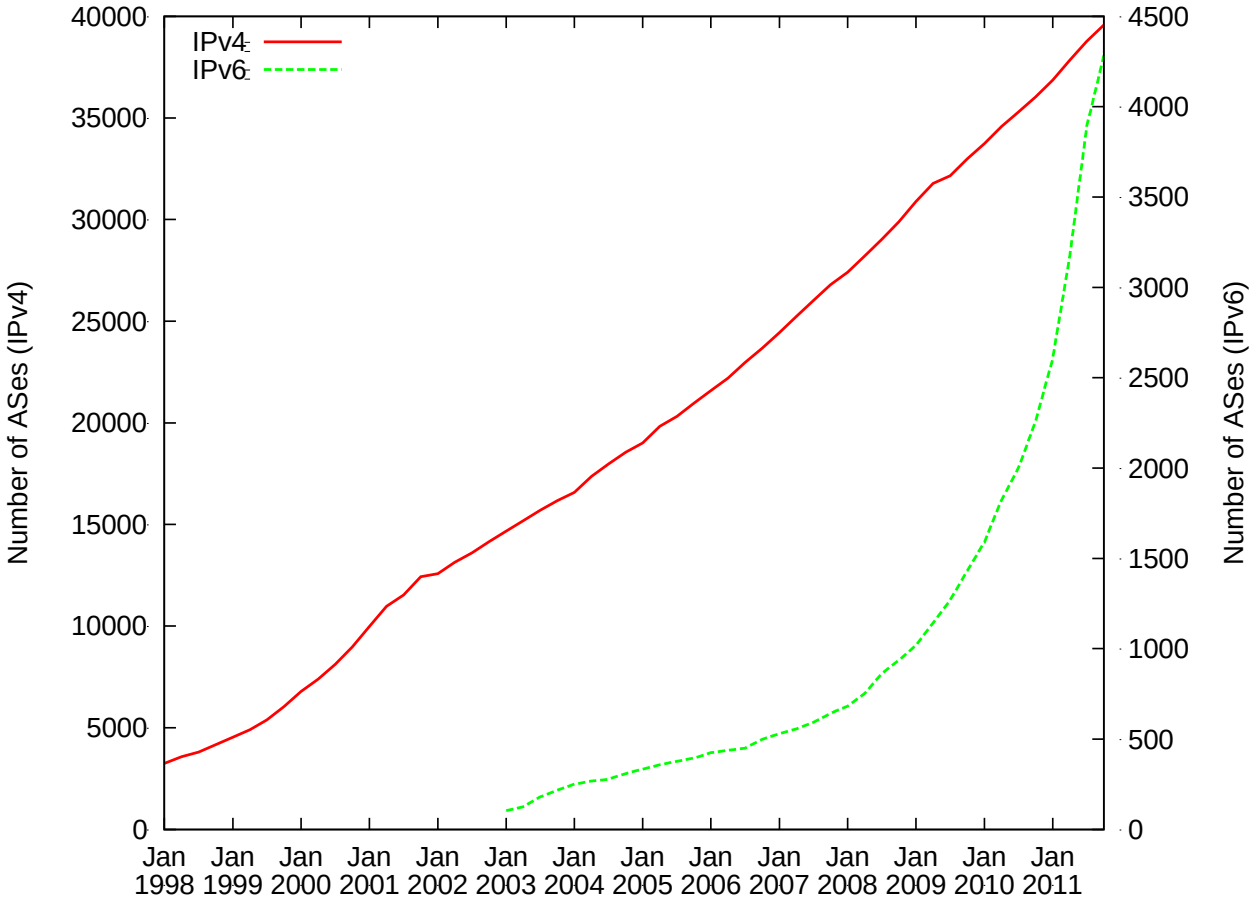

IPv4
IPv6
Number of ASes
40000
35000
30000
25000
20000
15000
10000
5000
0
Jan 1998
Jan 1999
Jan 2000
Jan 2001
Jan 2002
Jan 2003
Jan 2004
Jan 2005
Jan 2006
Jan 2007
Jan 2008
Jan 2009
Jan 2010
Jan 2011

IPv6 growth



IPv6 is here

IPv6 growth: we need to zoom in..



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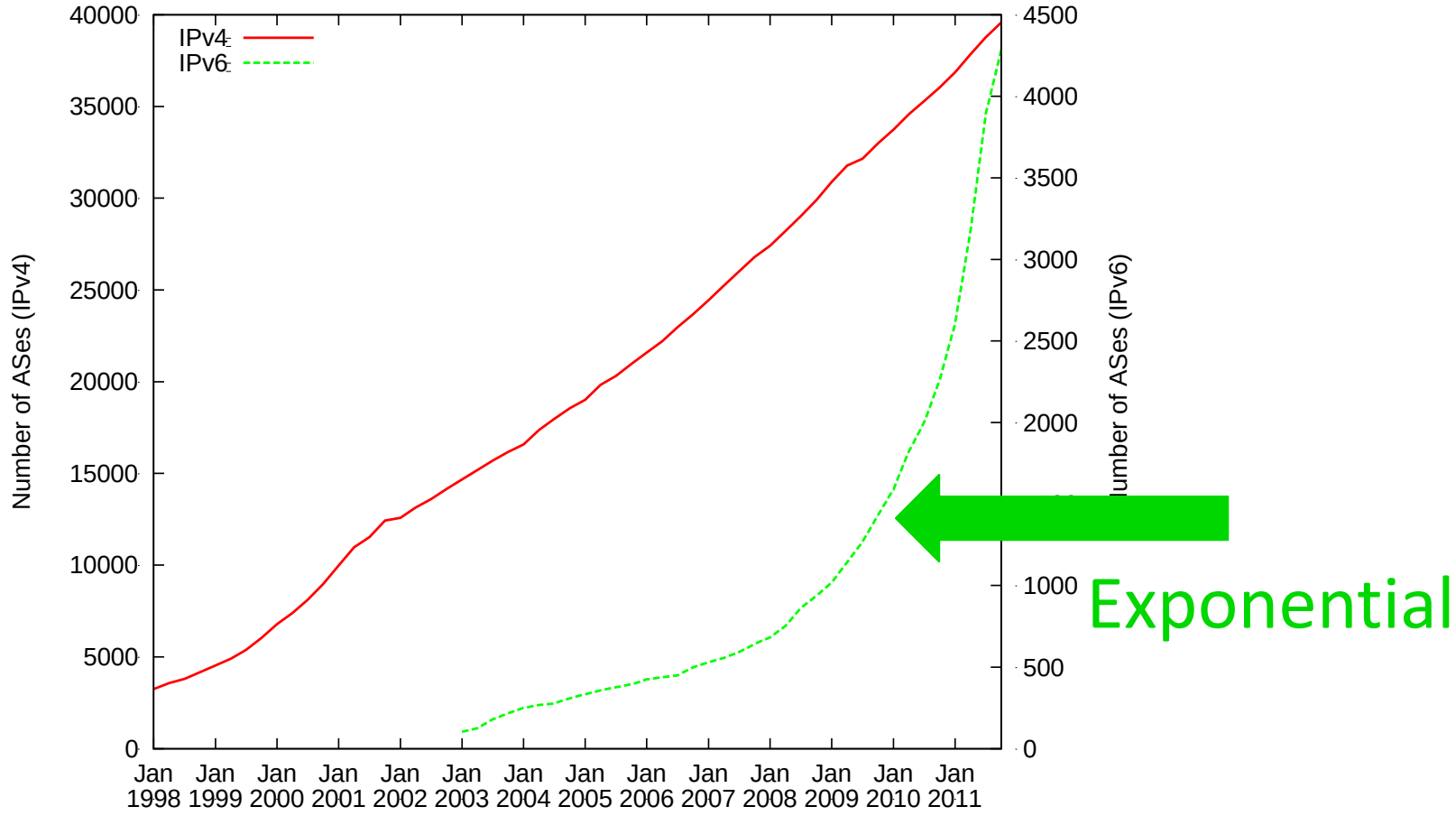
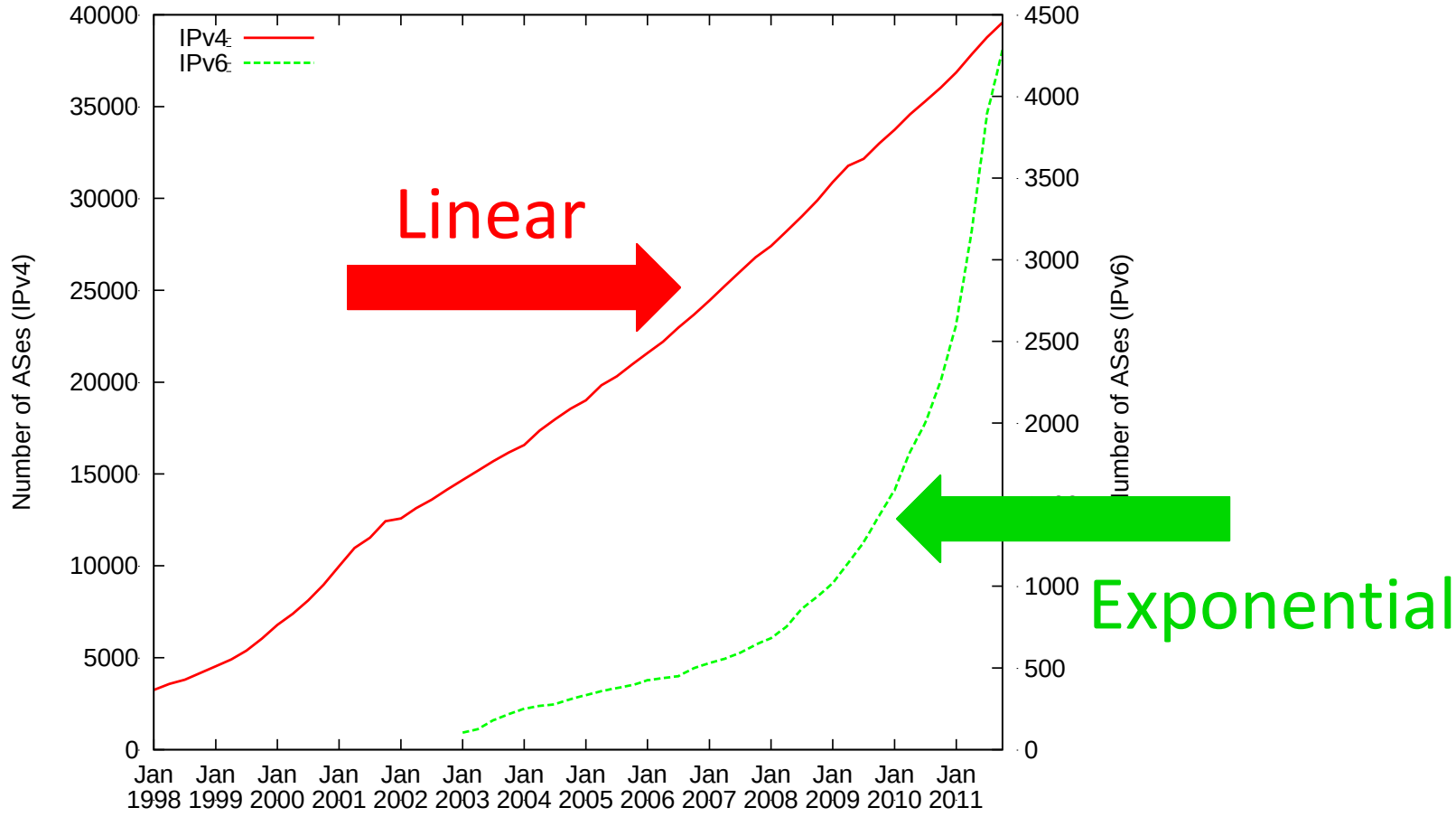


Exponential

IPv6 growth: we need to zoom in..



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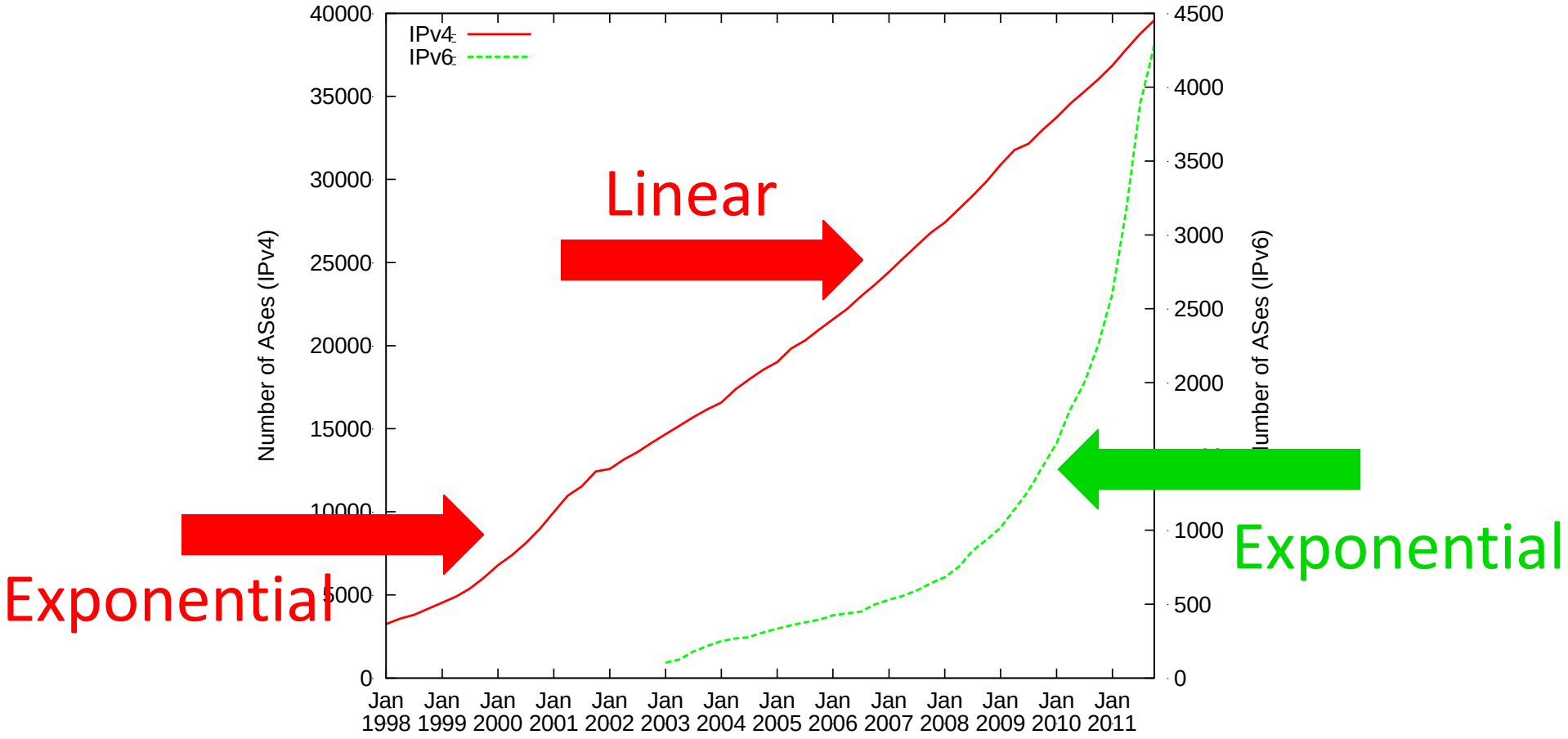

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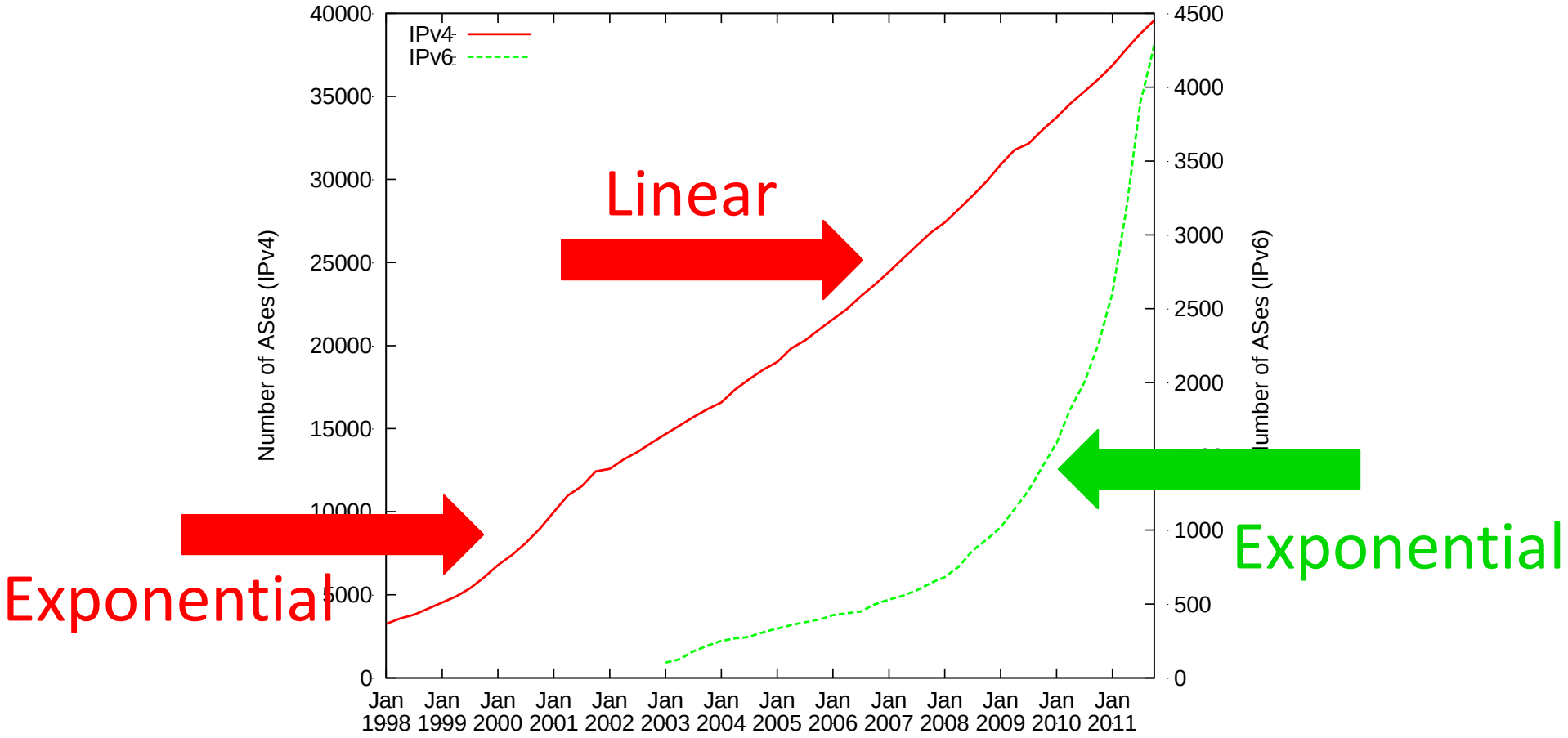


- The IPv6 topology grows exponentially while the IPv4 topology now grows linearly

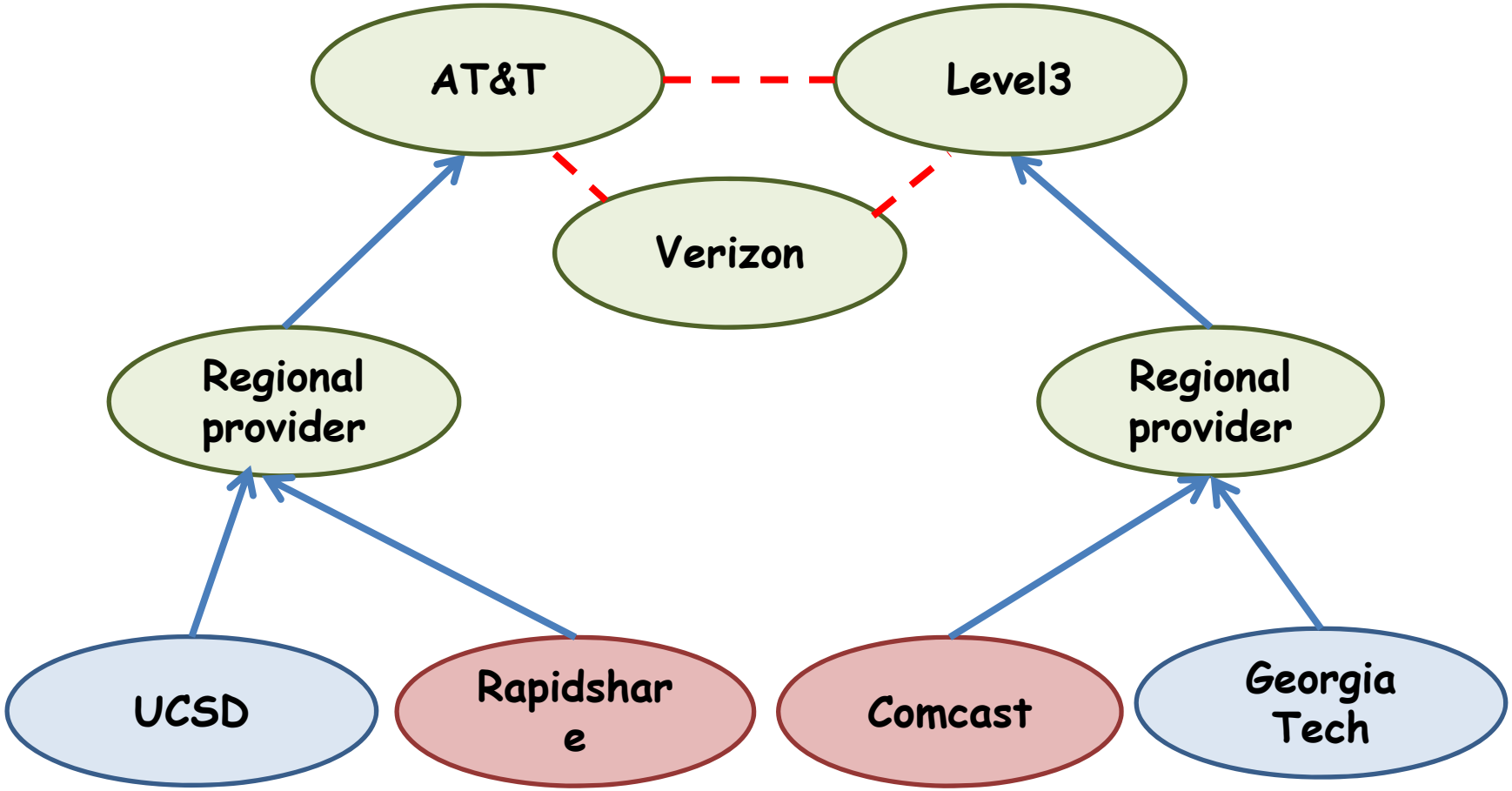
Digging deeper

- 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 from BGP routing datasets from 1998-present
  - Routeviews and RIPE repositories
- Annotated topology with business relationships on each inter-AS link
- Geographical region for each AS
  - ARIN: North America
  - RIPE: Europe
  - APNIC: Asia-Pacific

AS Business Types



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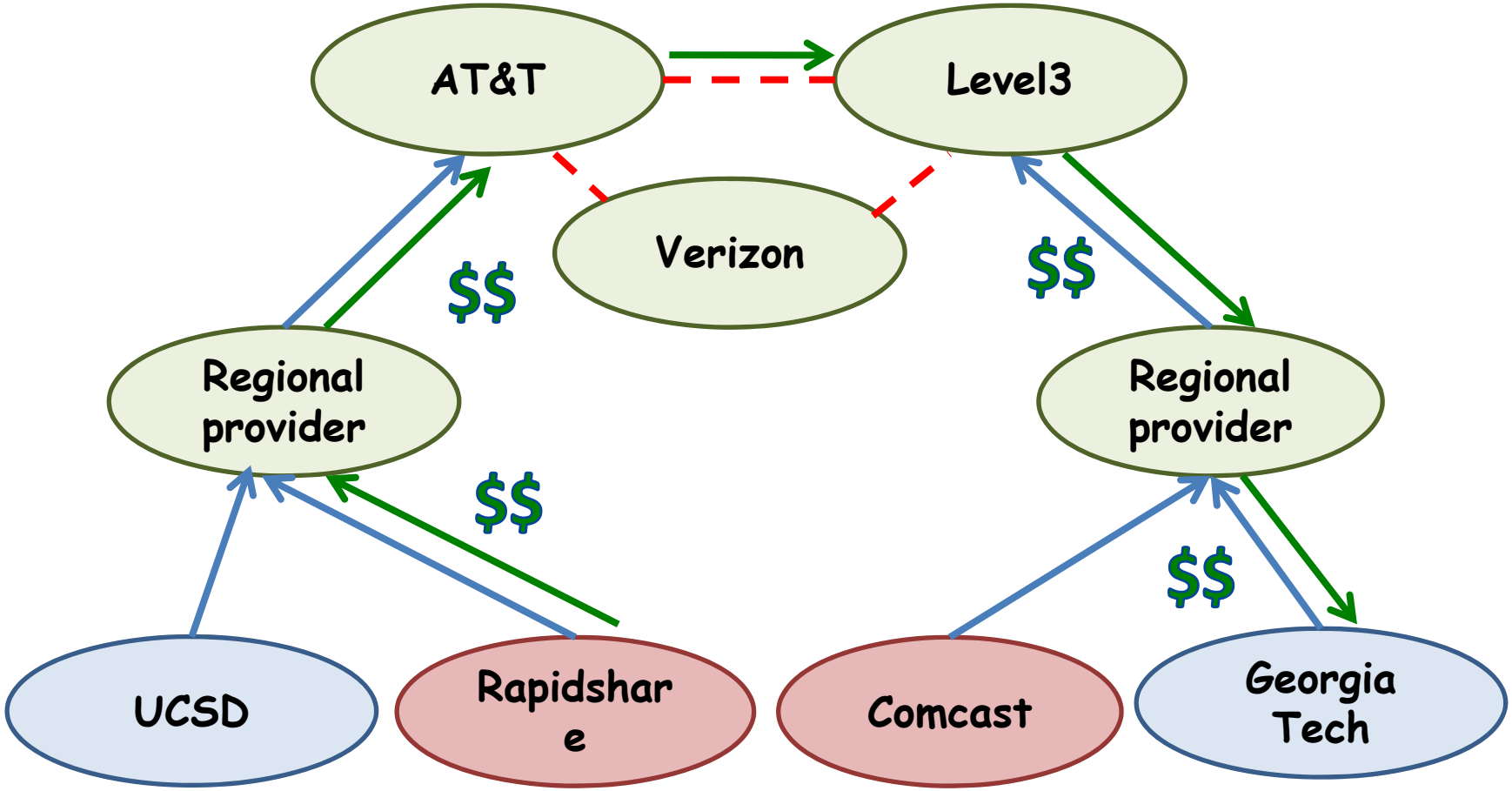

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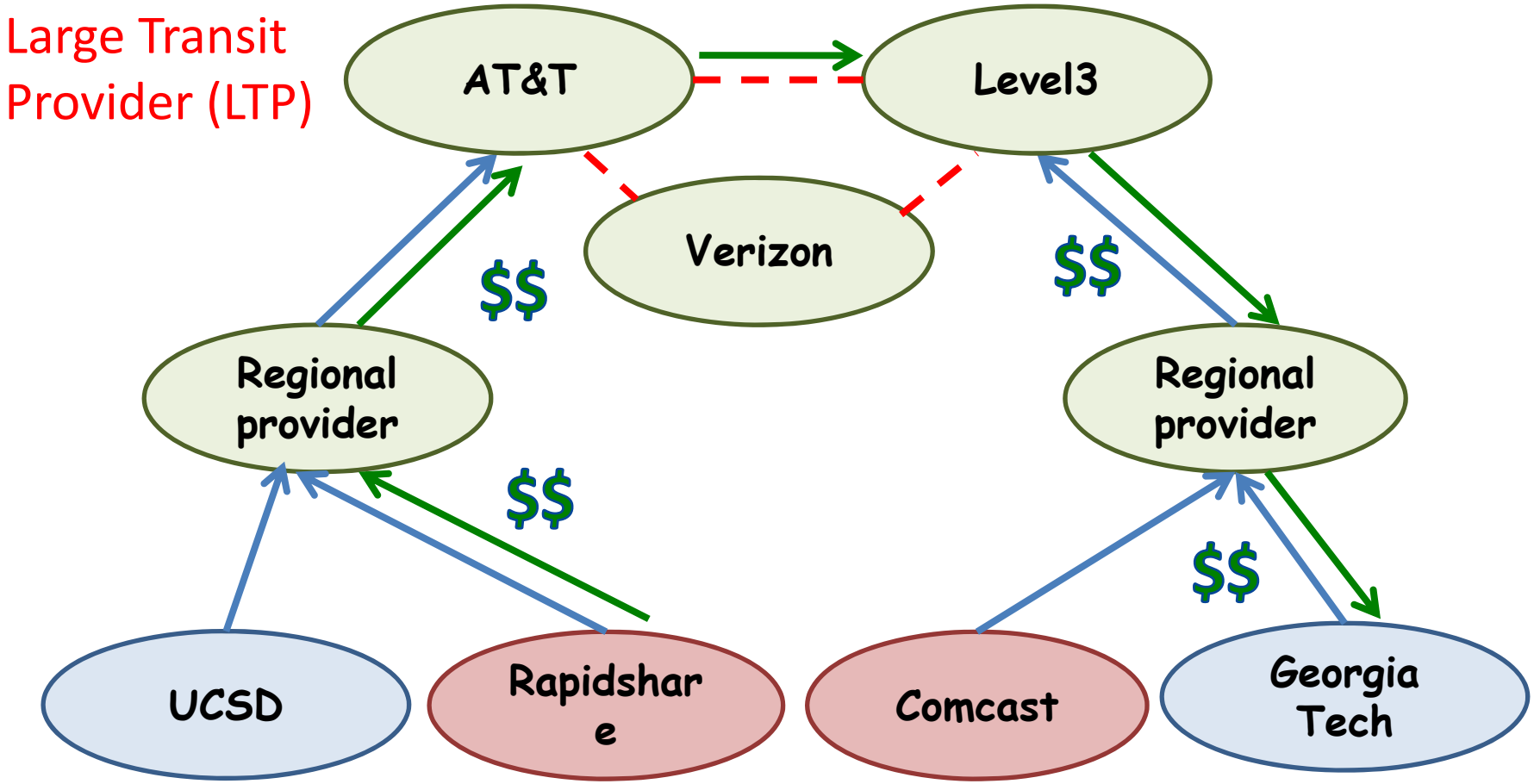

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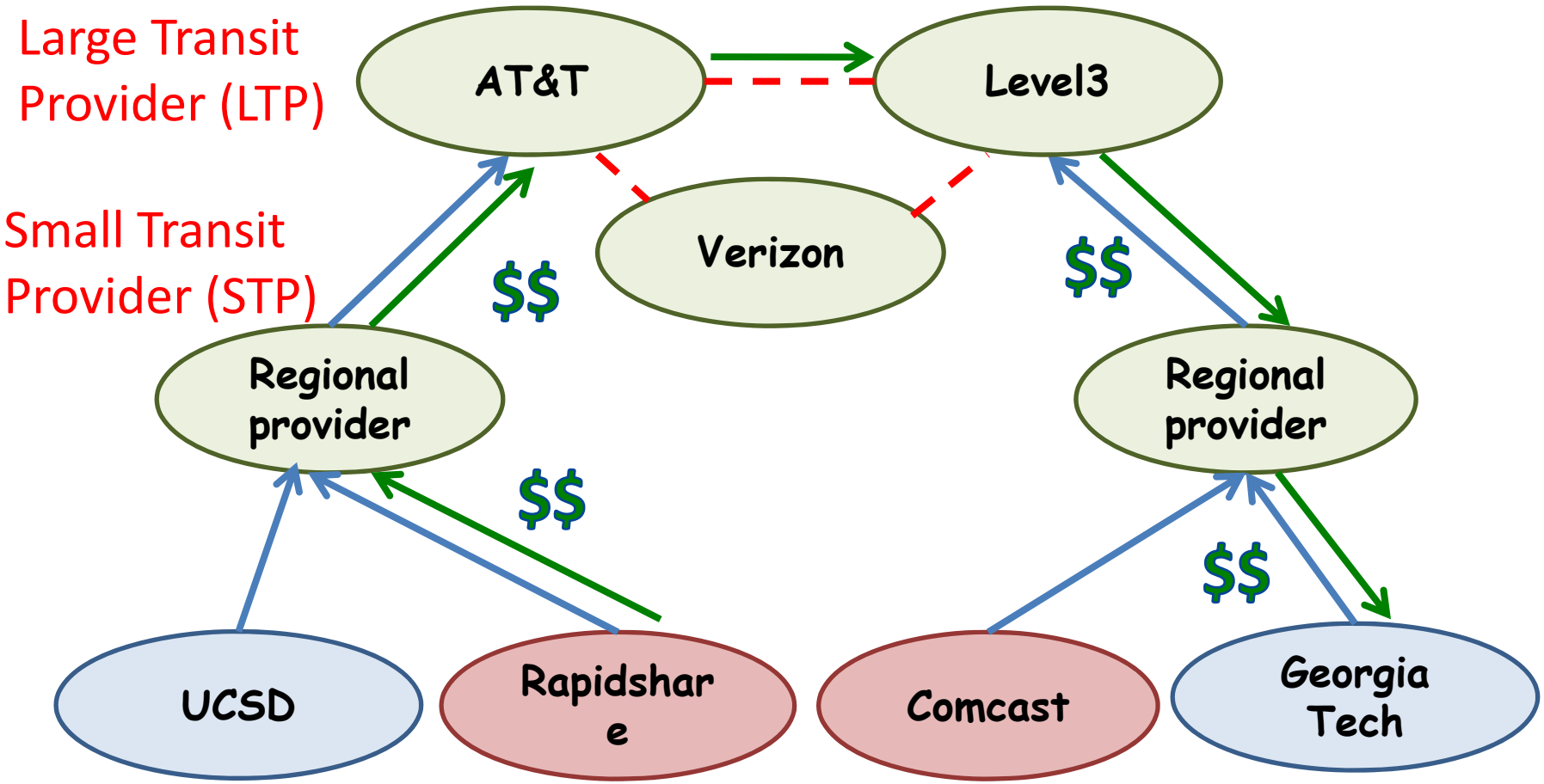

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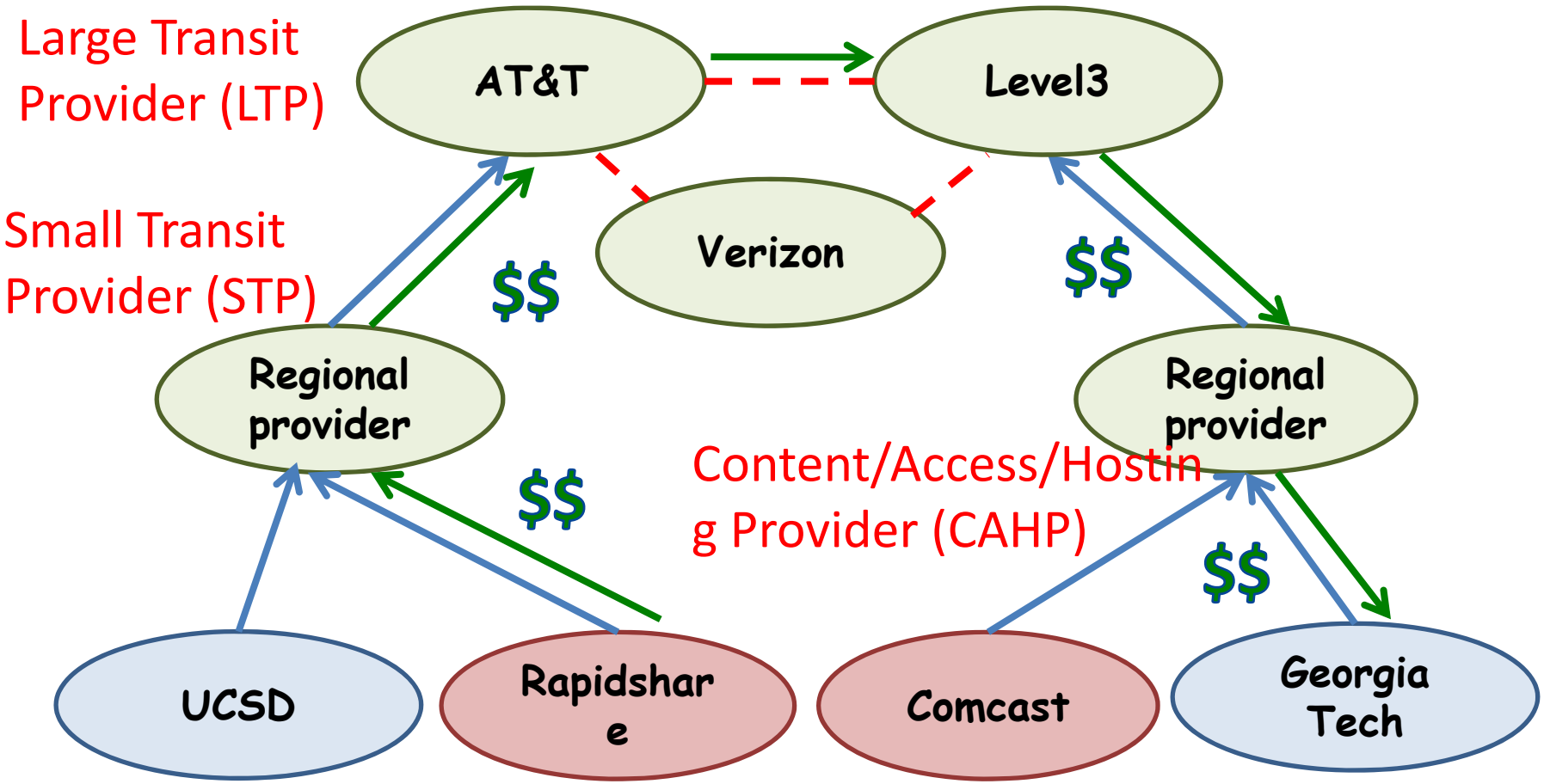

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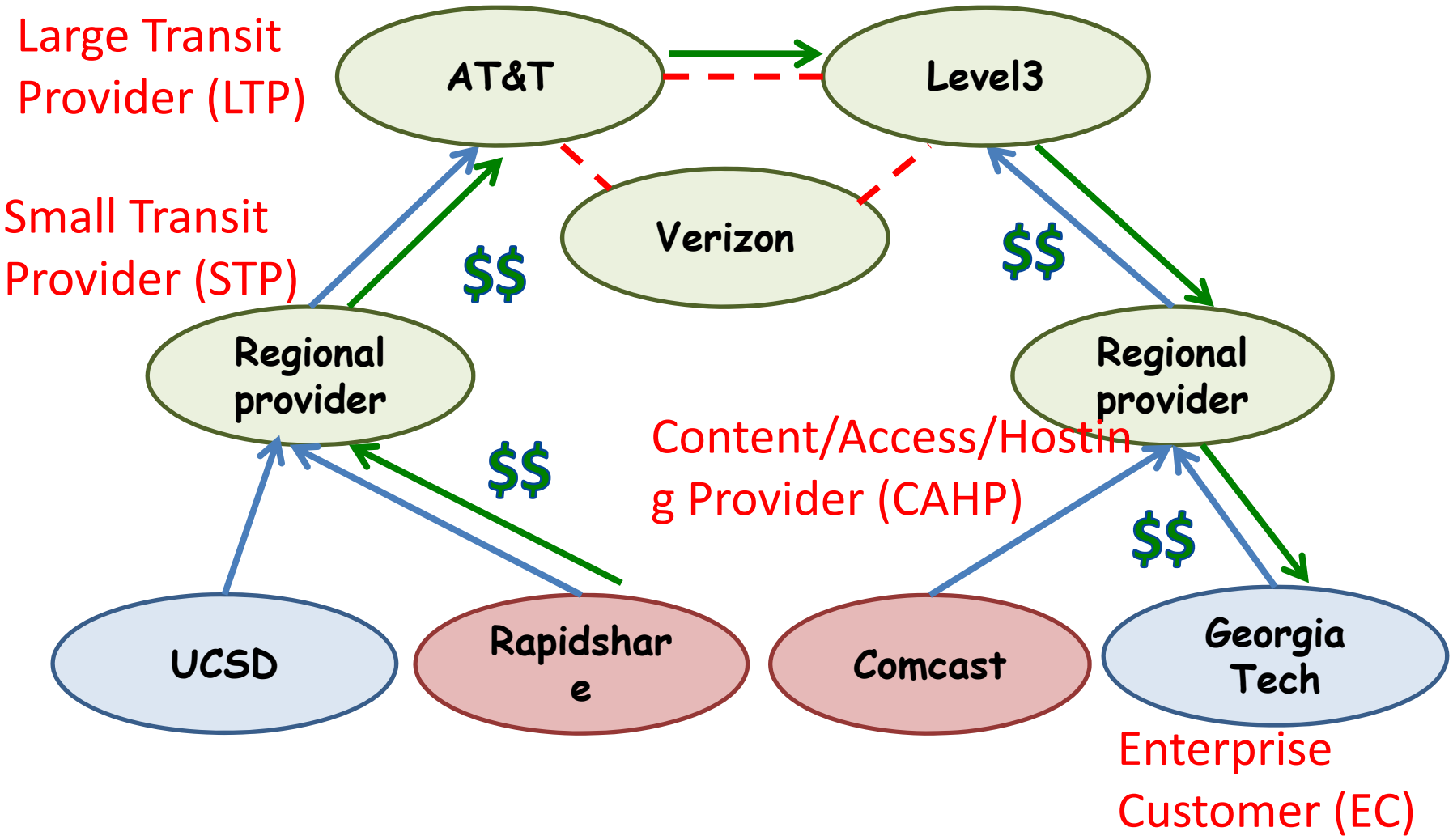
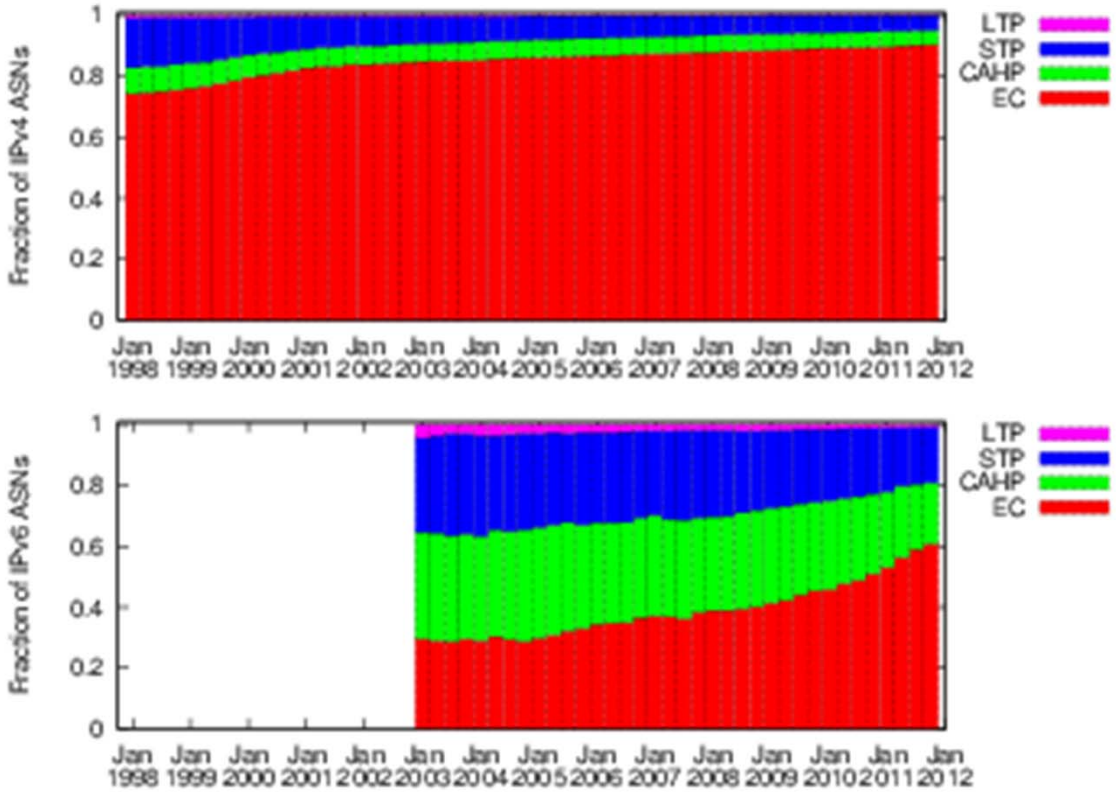


Evolution of the business mix



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

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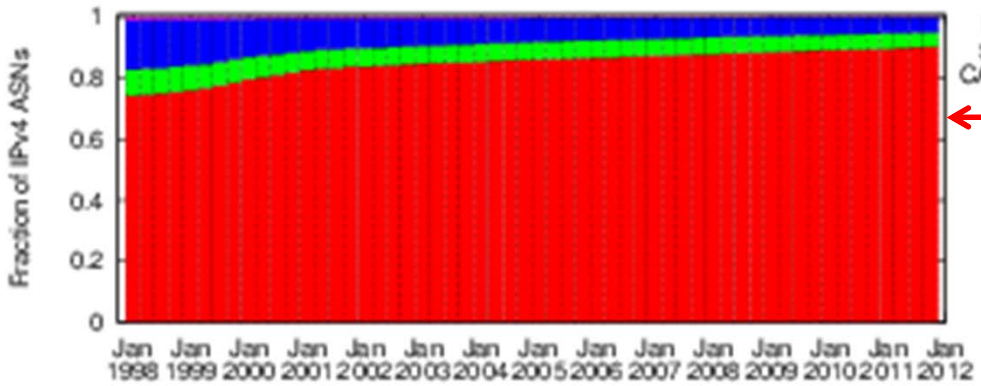

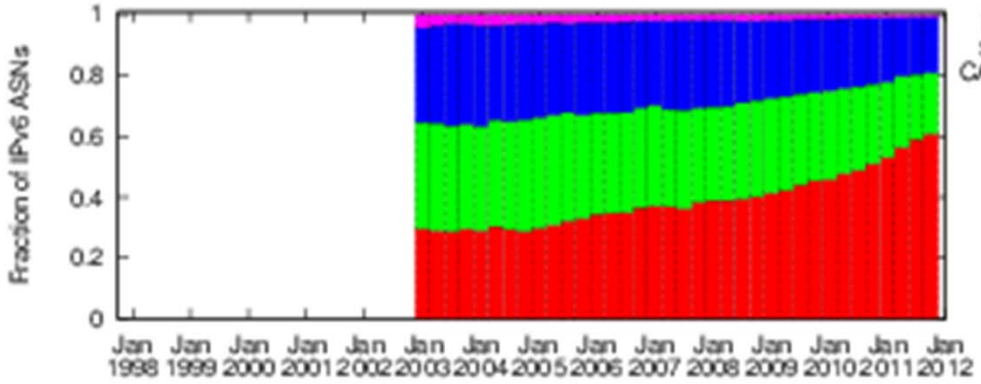

IPv4 network is dominated by ECs

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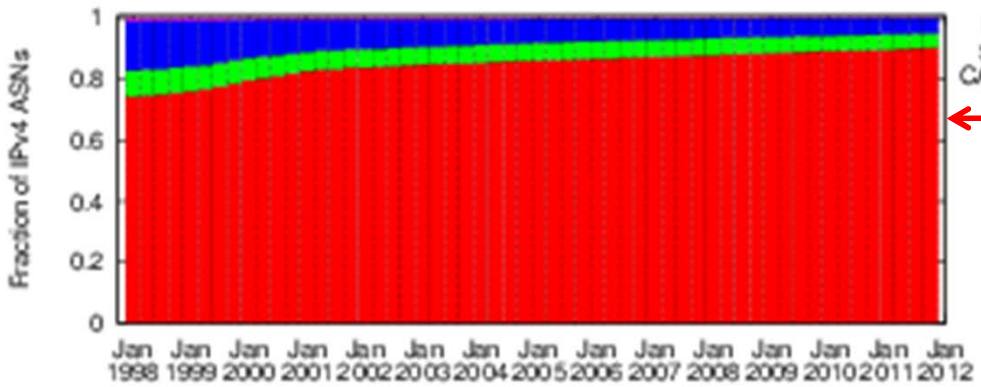

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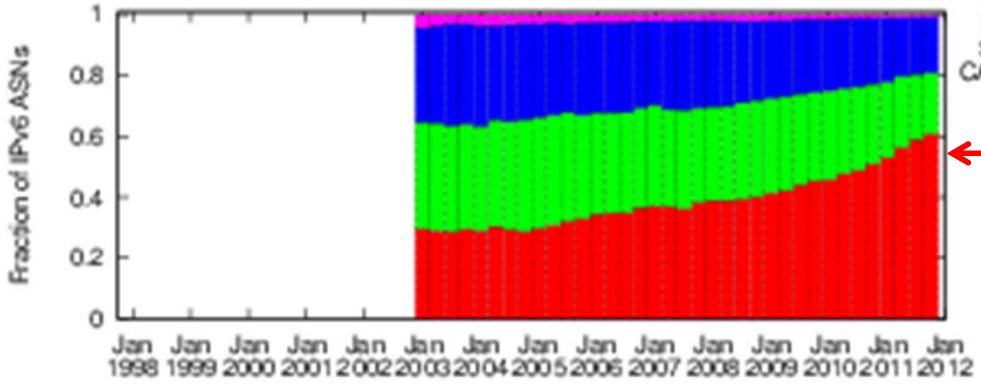

Lower fraction of ECs in IPv6

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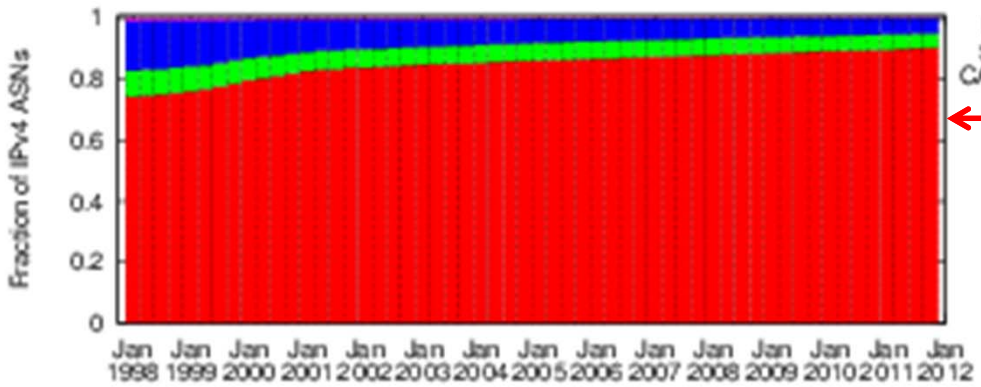

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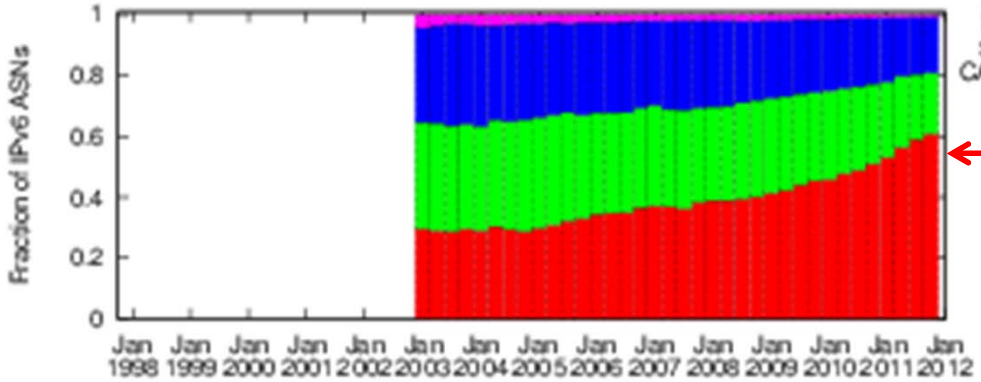

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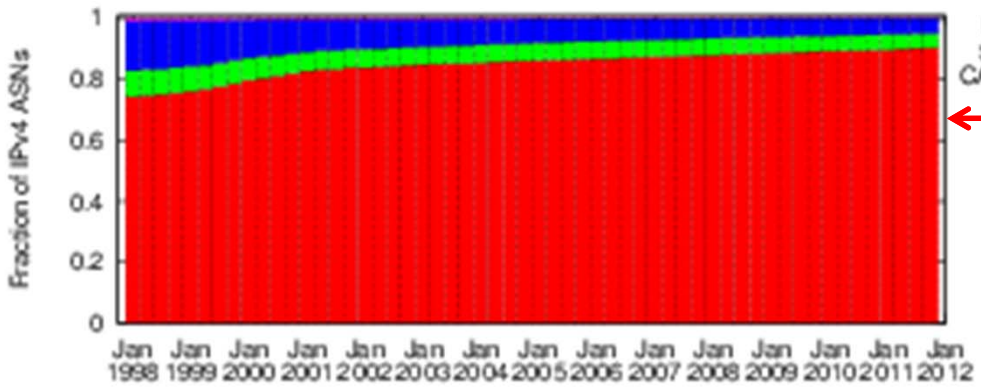

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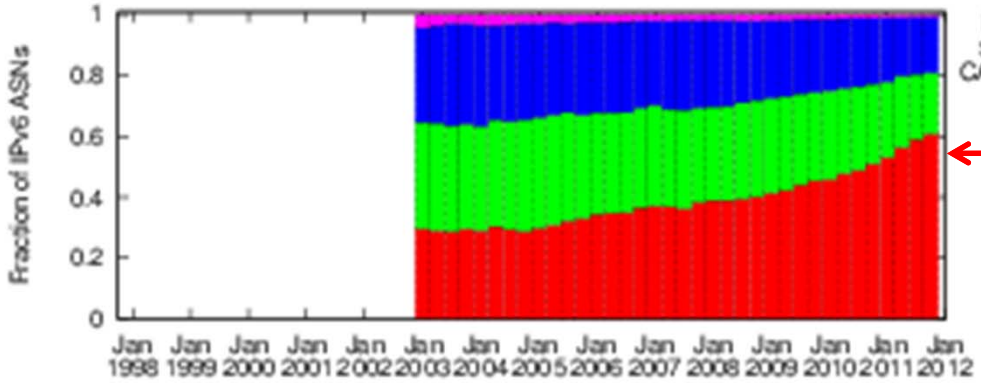

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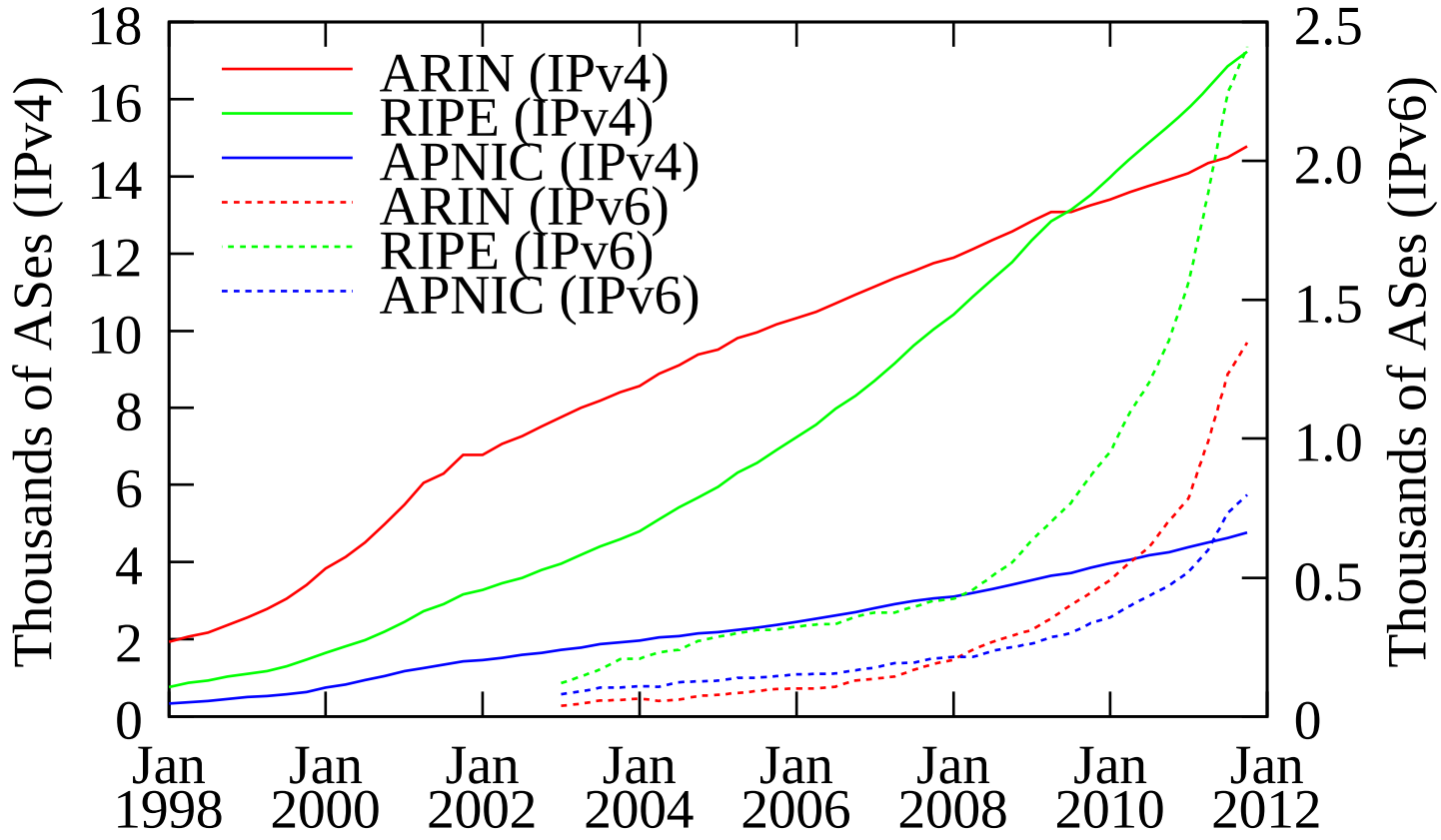
IPv6 deployment at the edges is lagging

Growth trends by geographical region



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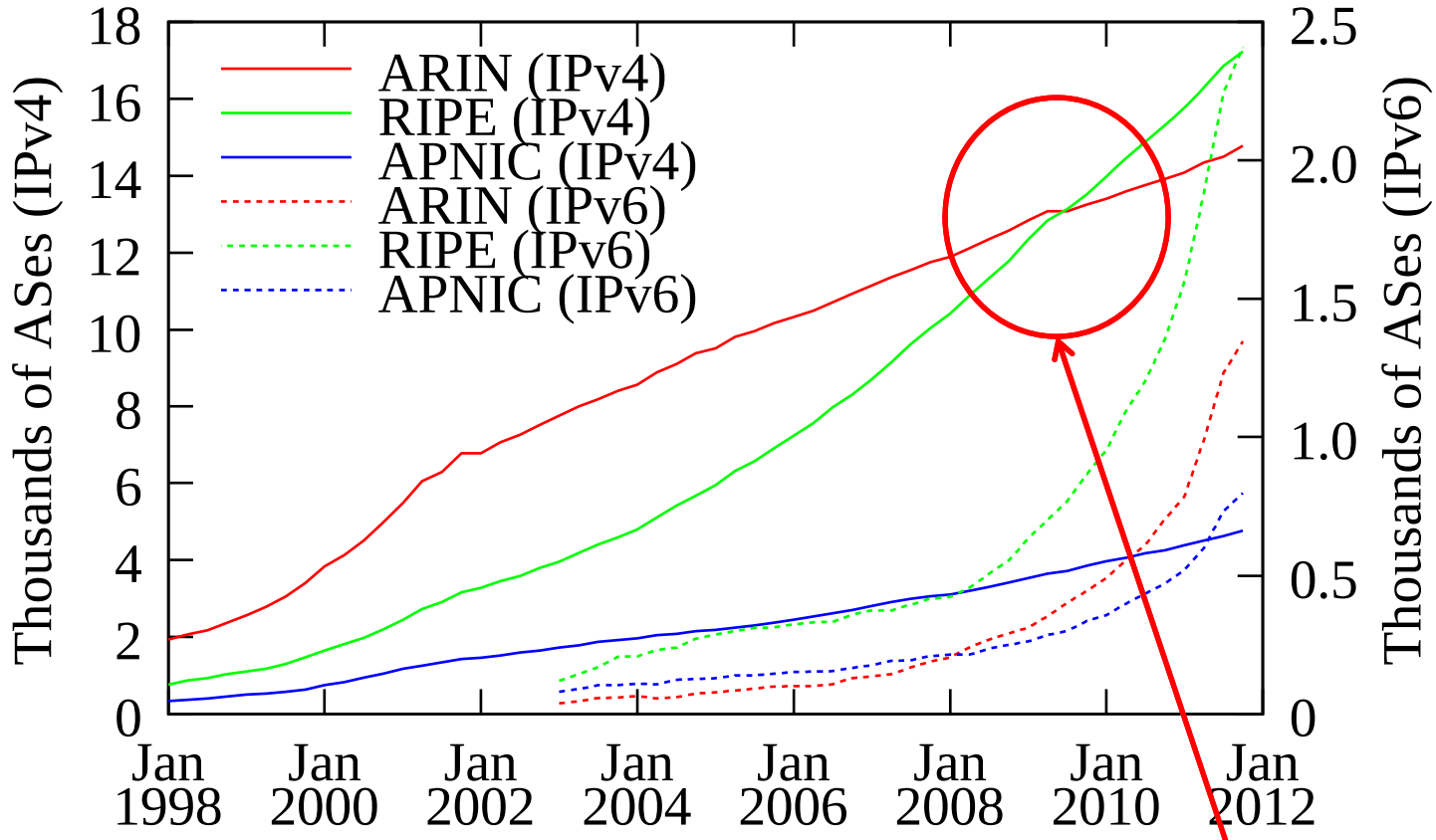

IPv4: More ASes in RIPE region than ARIN since 2009

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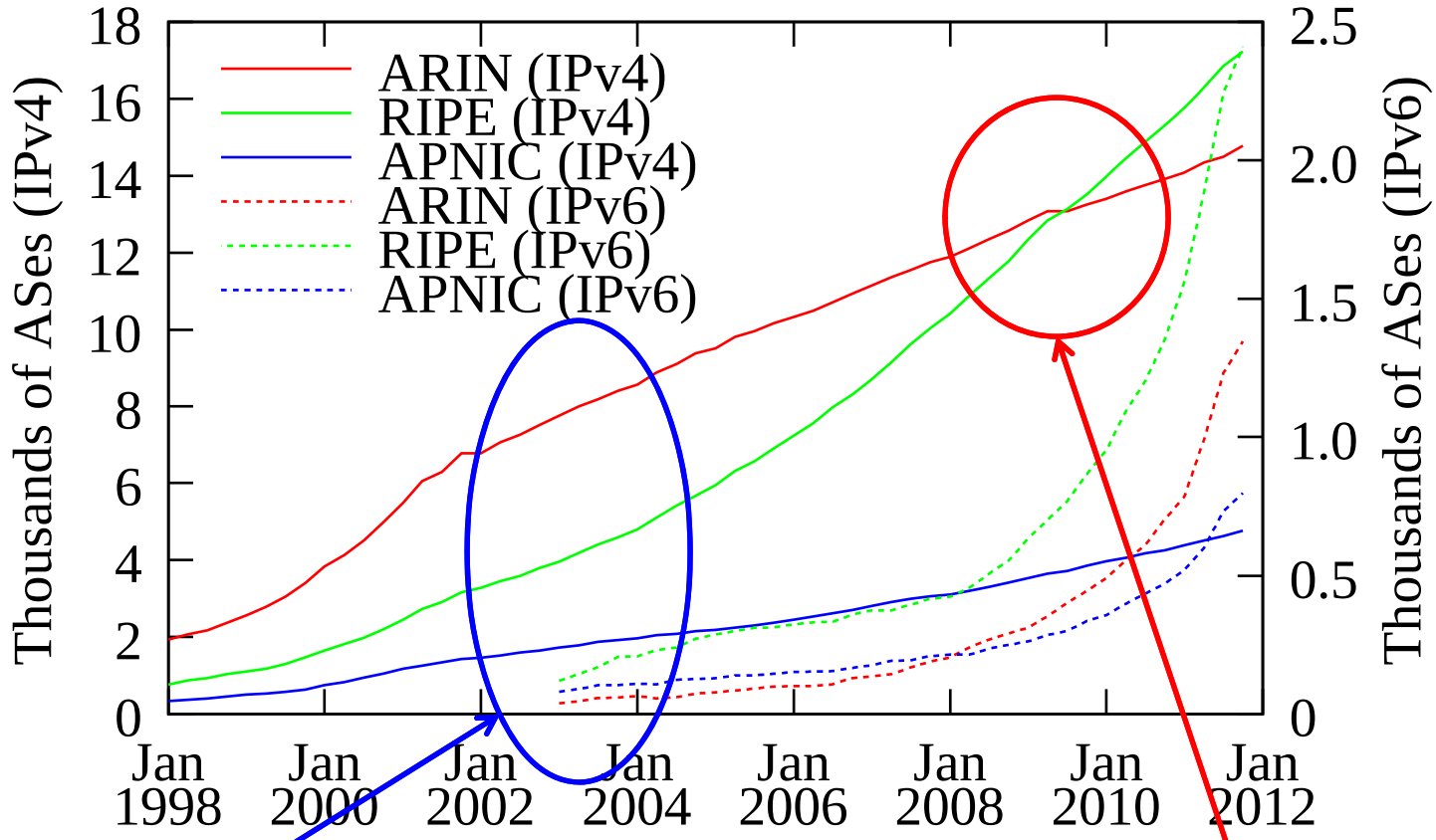

IPv6: RIPE region was always ahead of ARIN

IPv4: More ASes in RIPE region than ARIN since 2009

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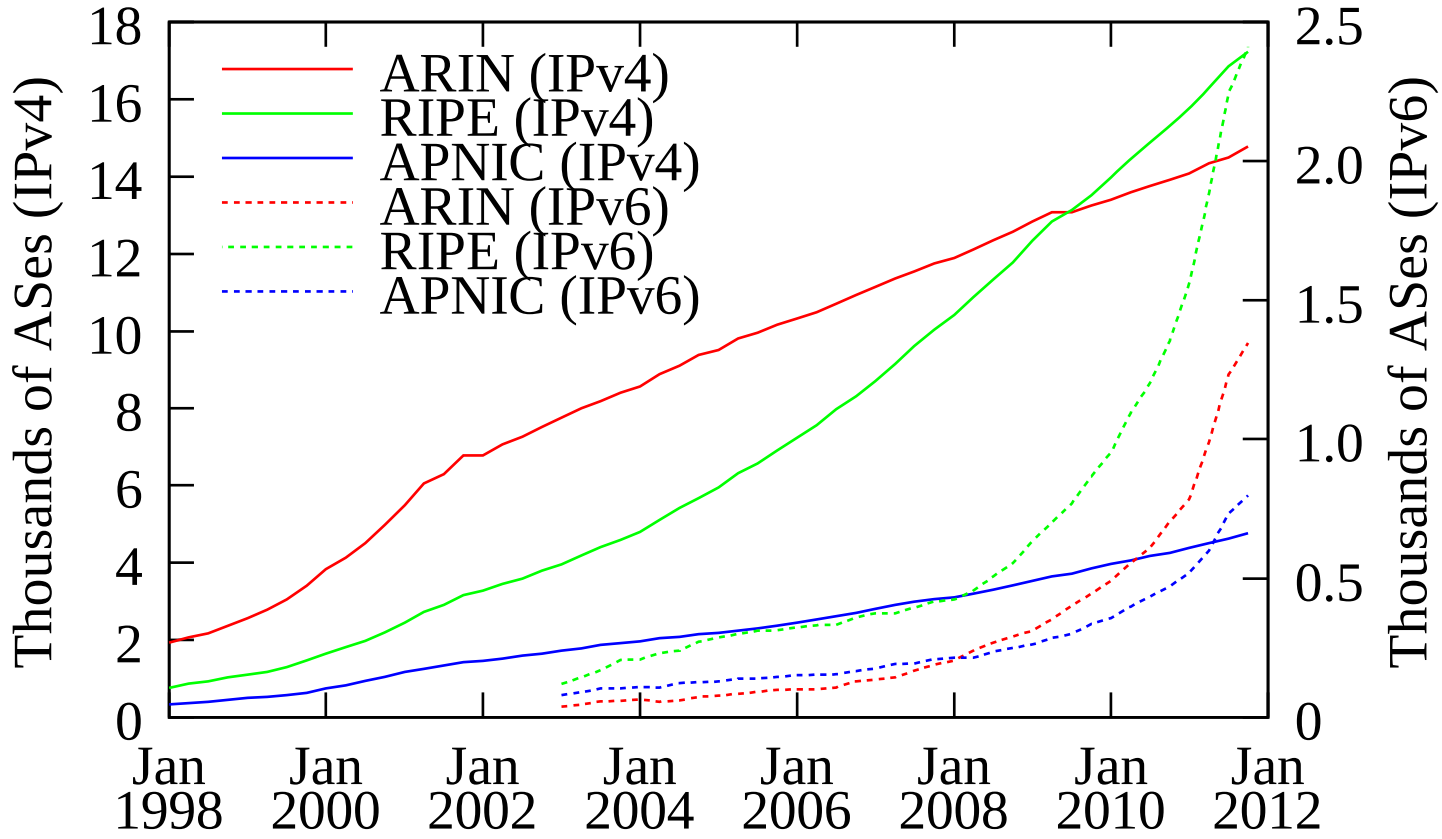


The ARIN region is lagging in IPv6 deployment

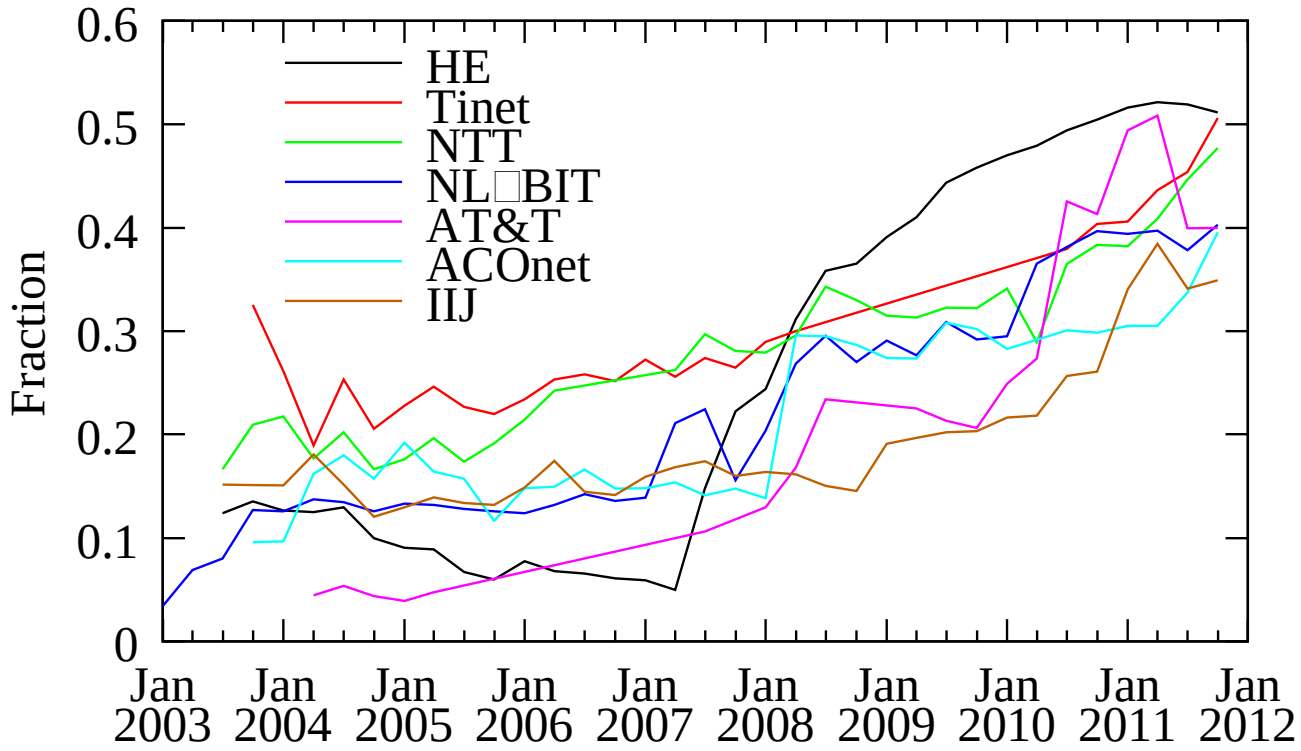
Structure of AS-level paths

- 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



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

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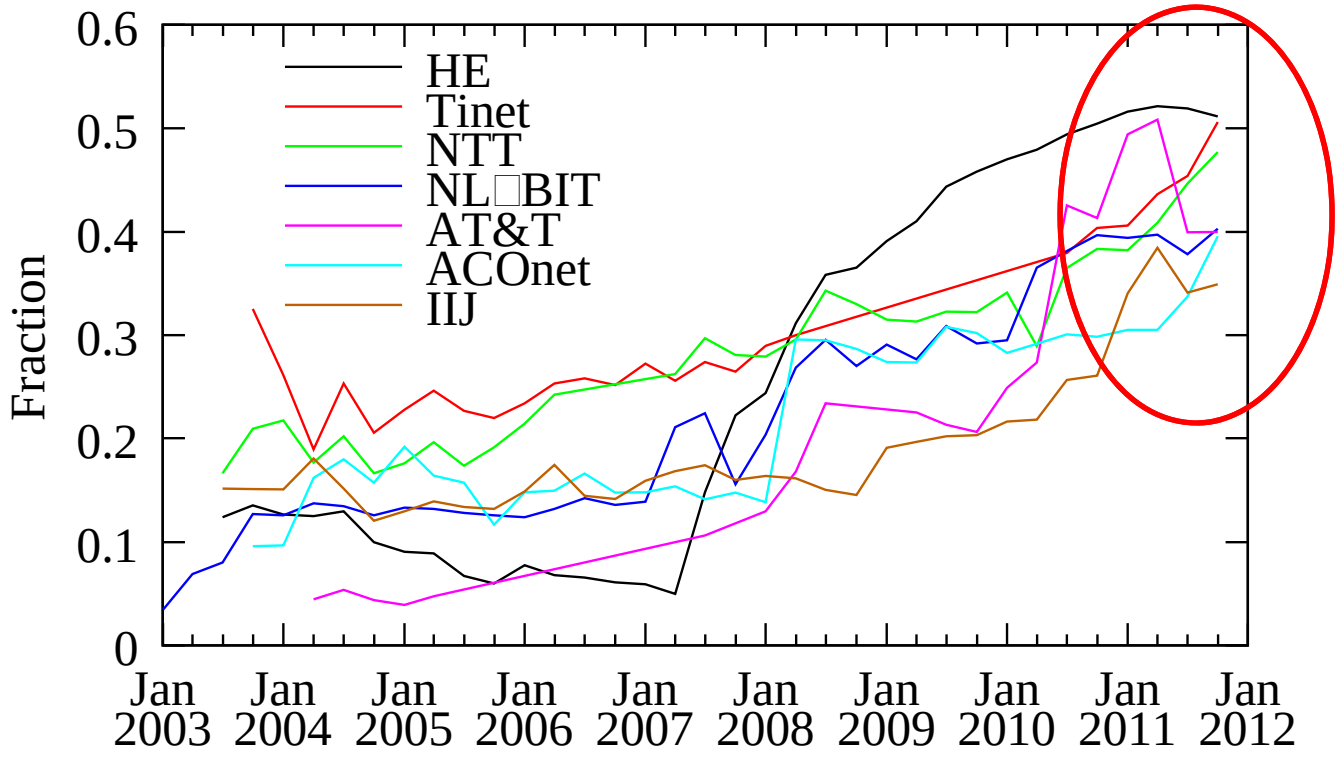

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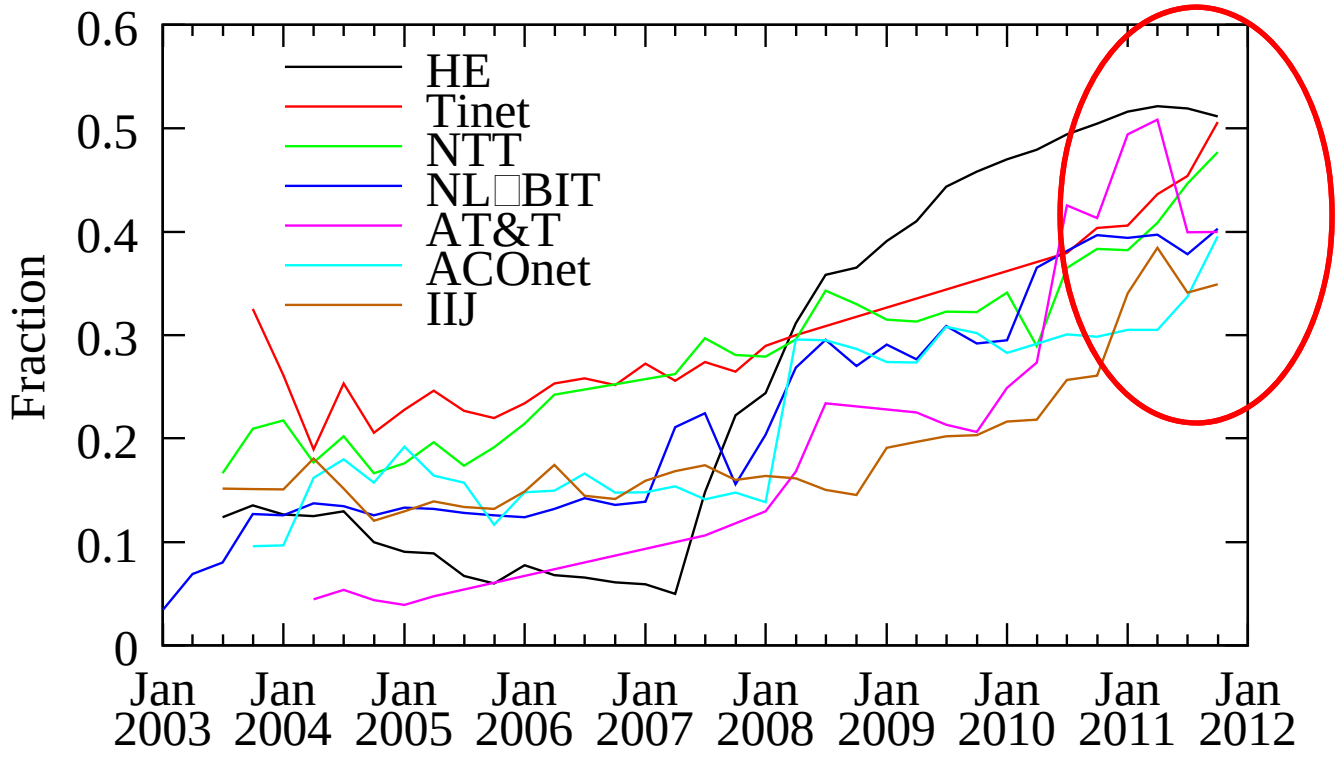

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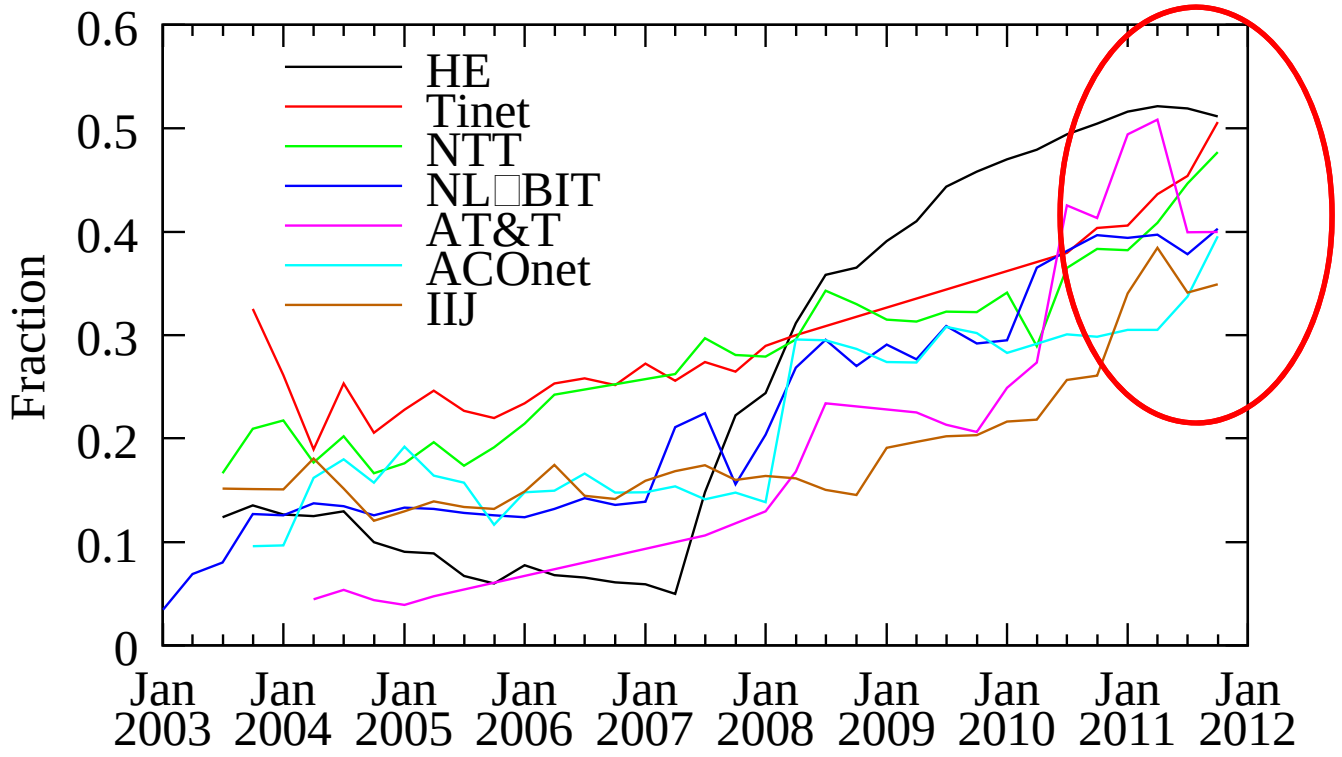
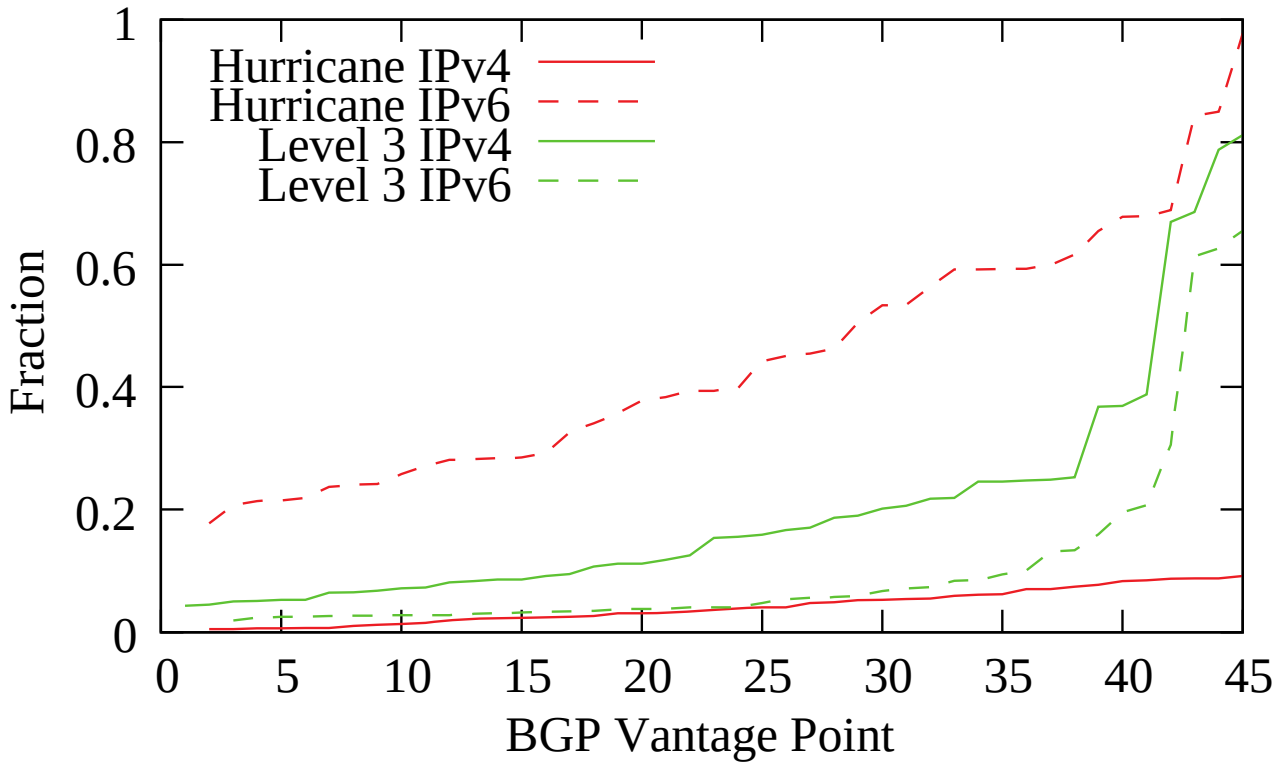


The IPv6 network is maturing, but slowly

ASes most often seen in paths



- For each VP, measured the fraction of paths that traverse a certain AS

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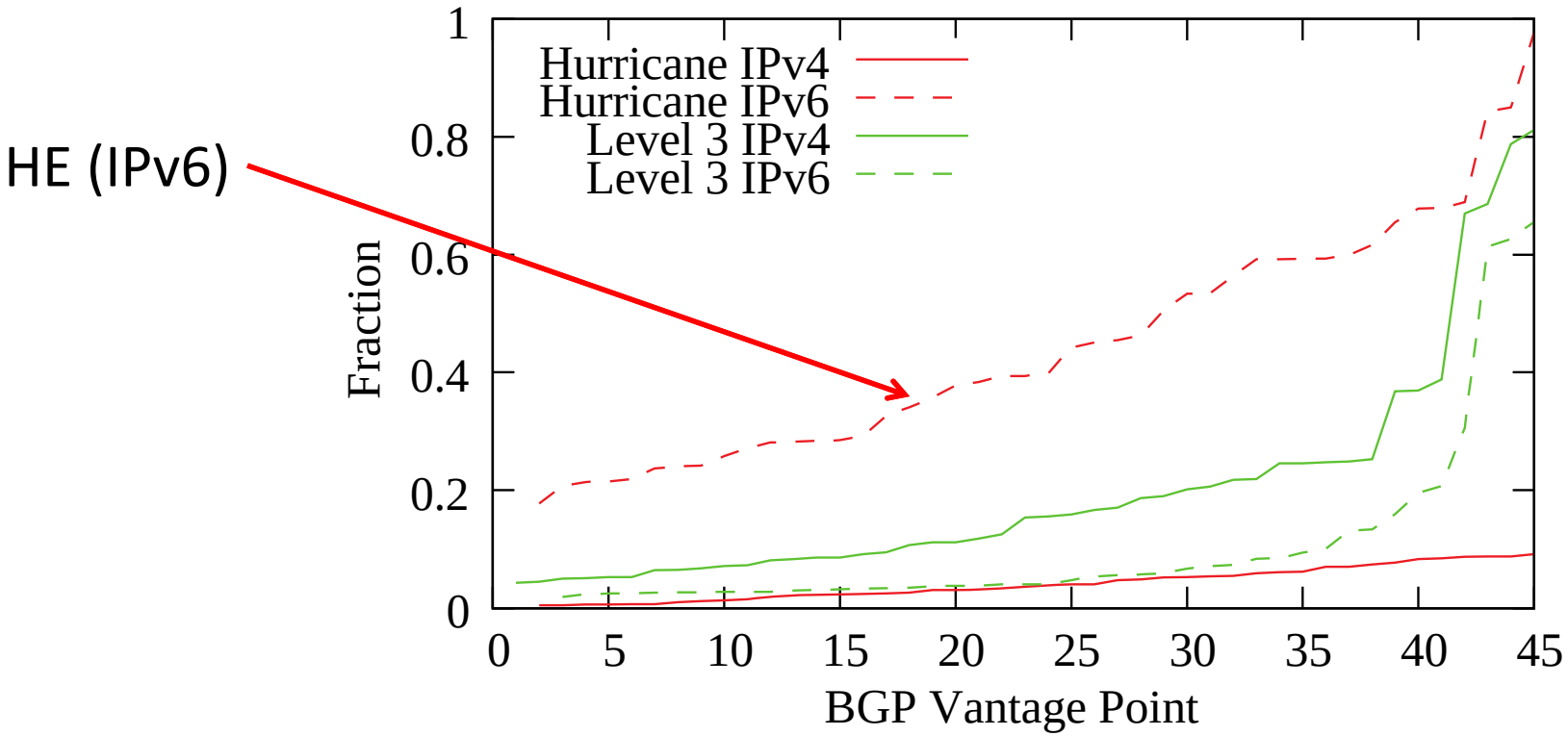

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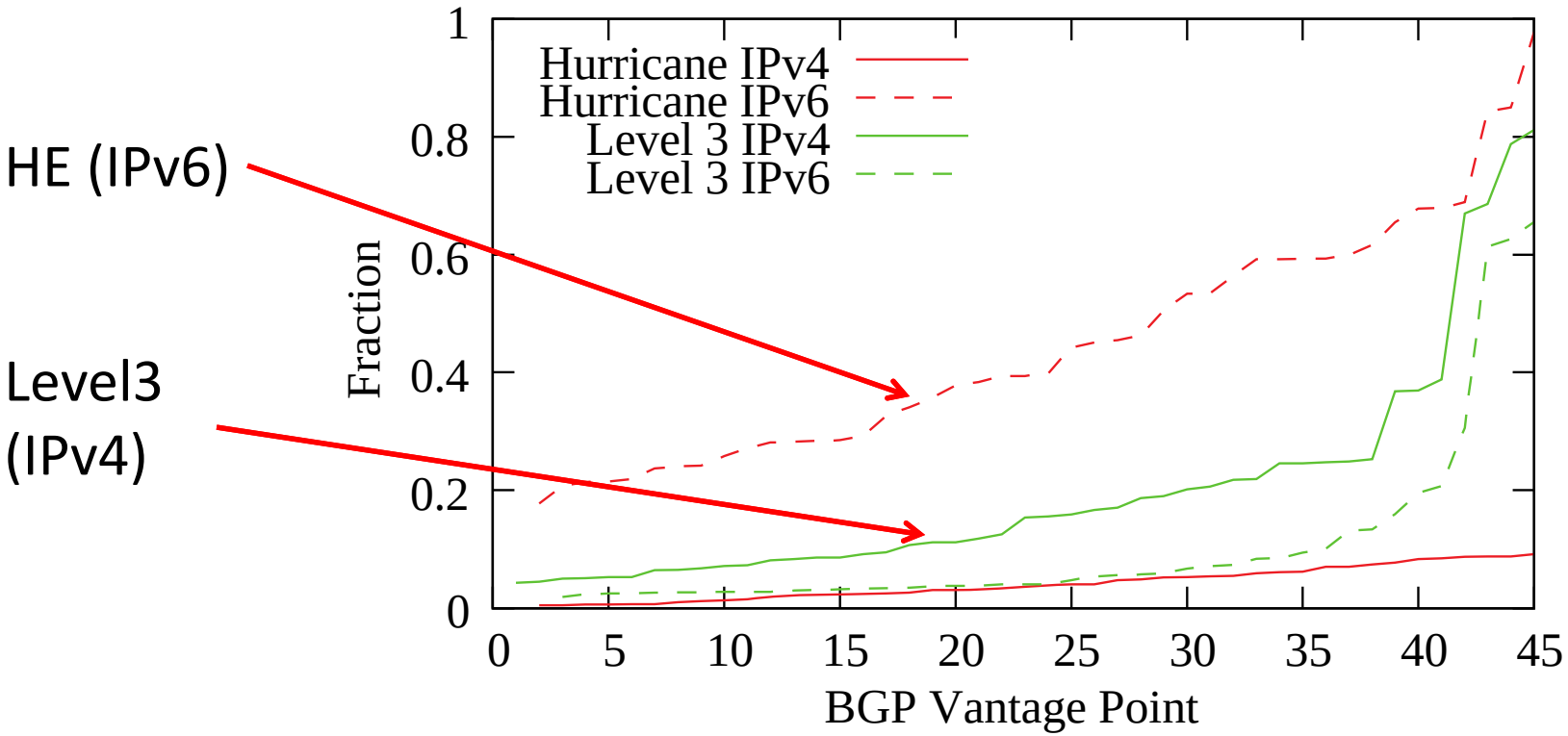

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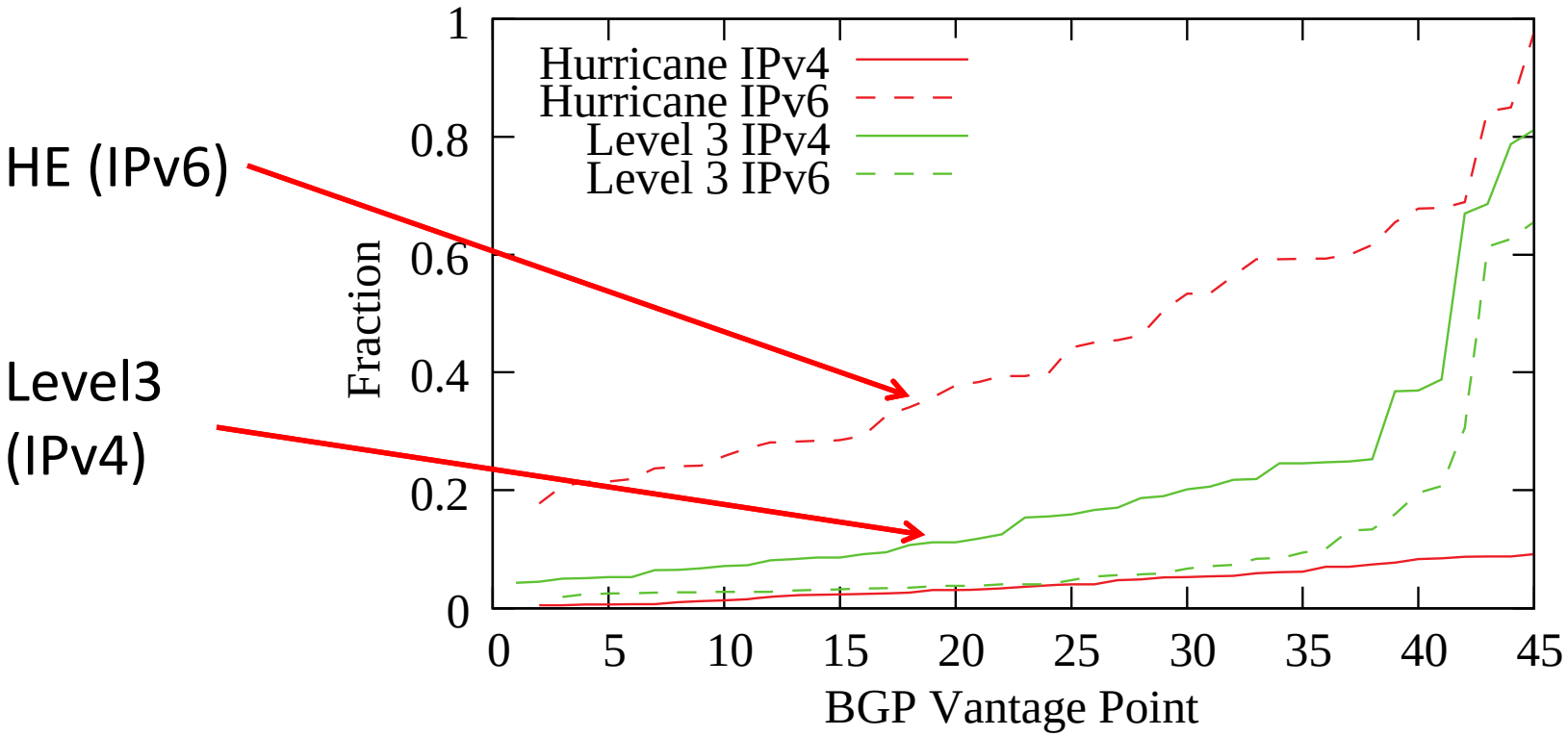

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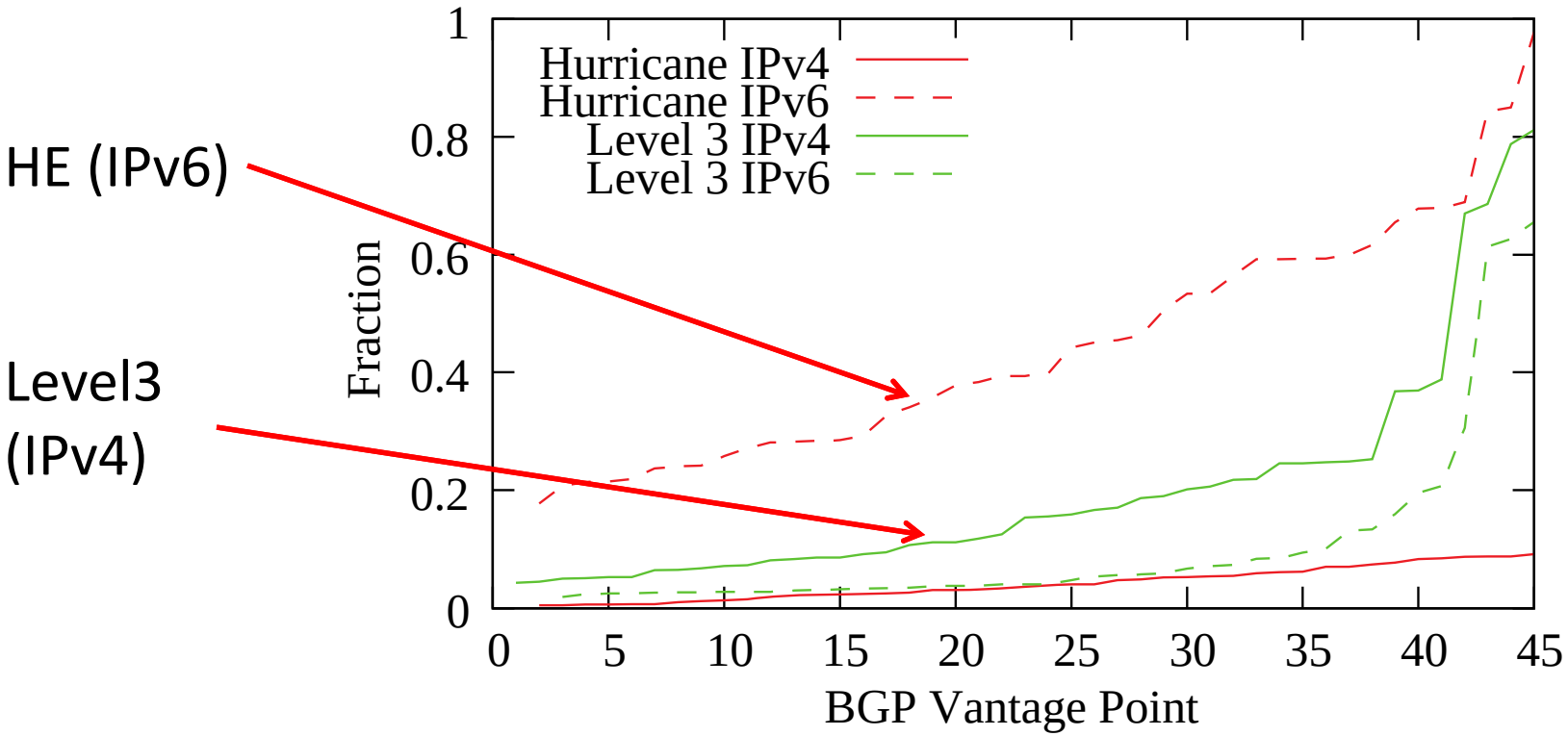
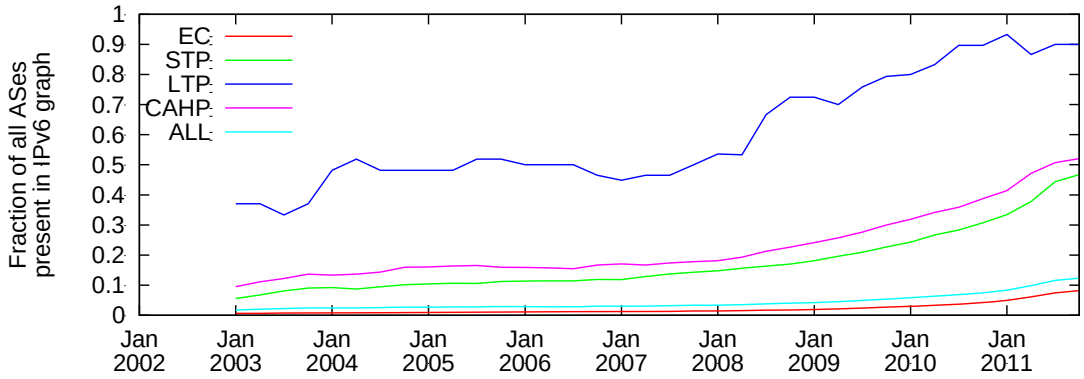


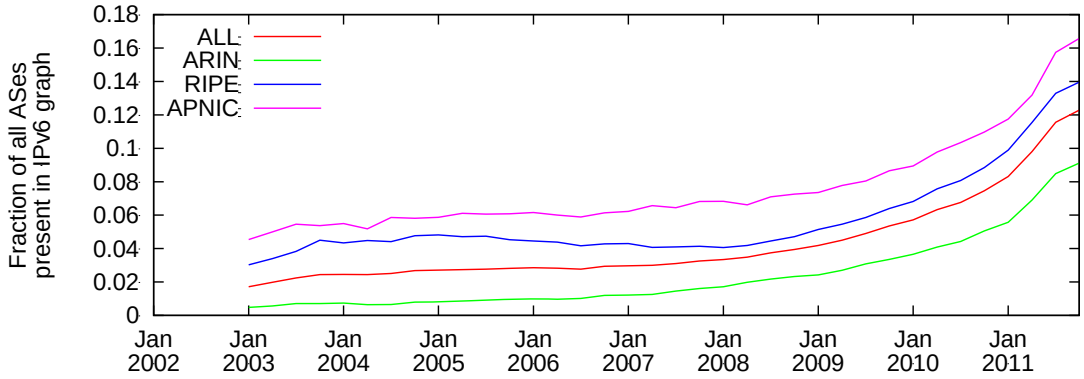
- HE is more dominant in IPv6 than the most dominant network (Level3) in IPv4

IPv4 and IPv6 topology convergence

Classification: business type



Classification: geographical region



- 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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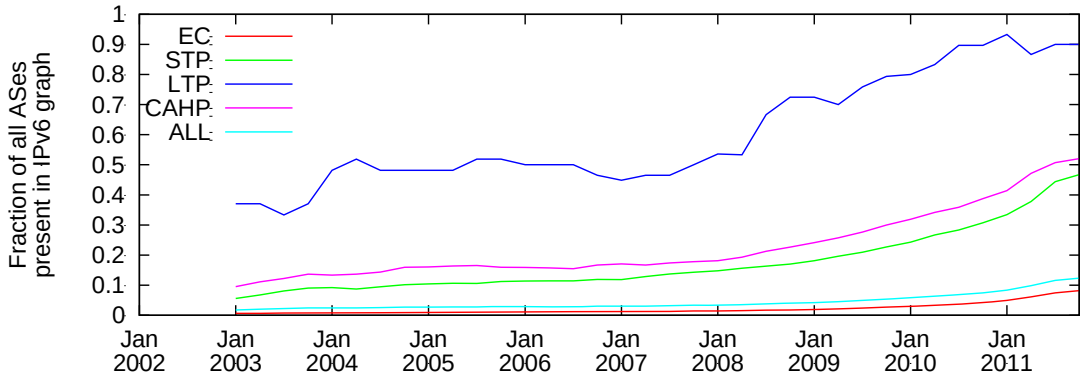

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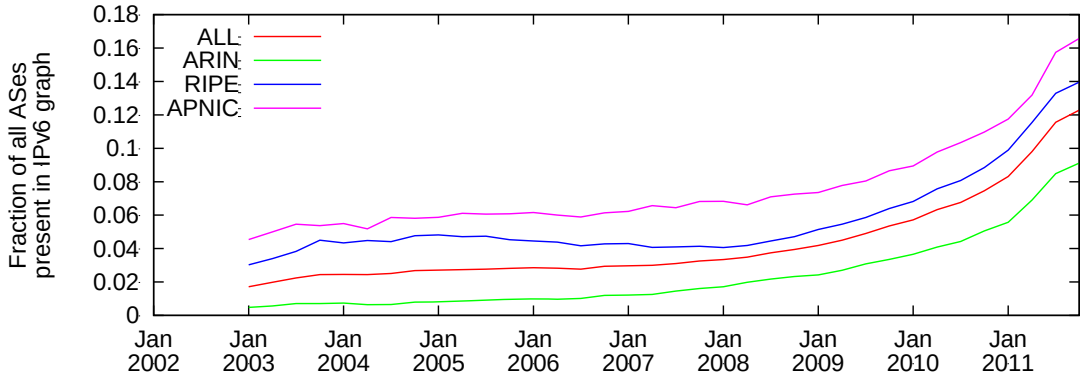

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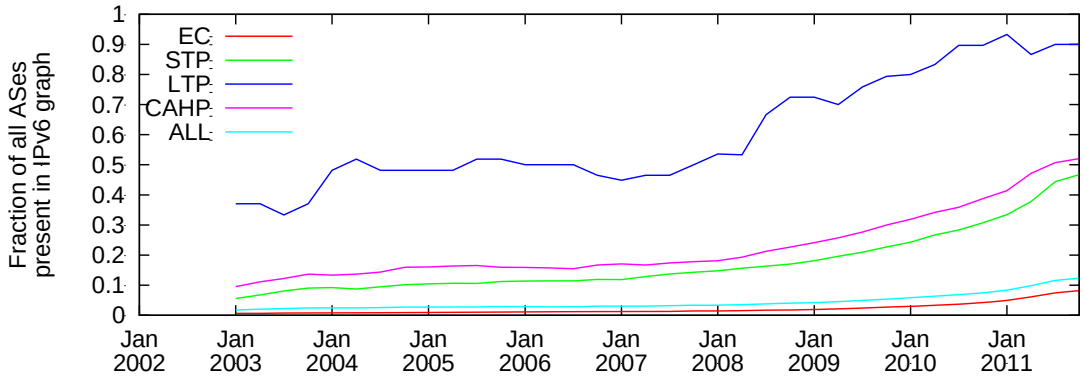

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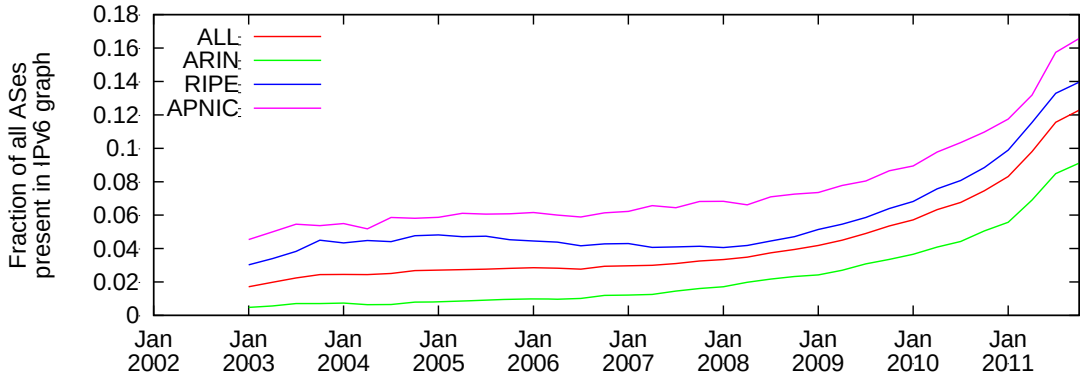
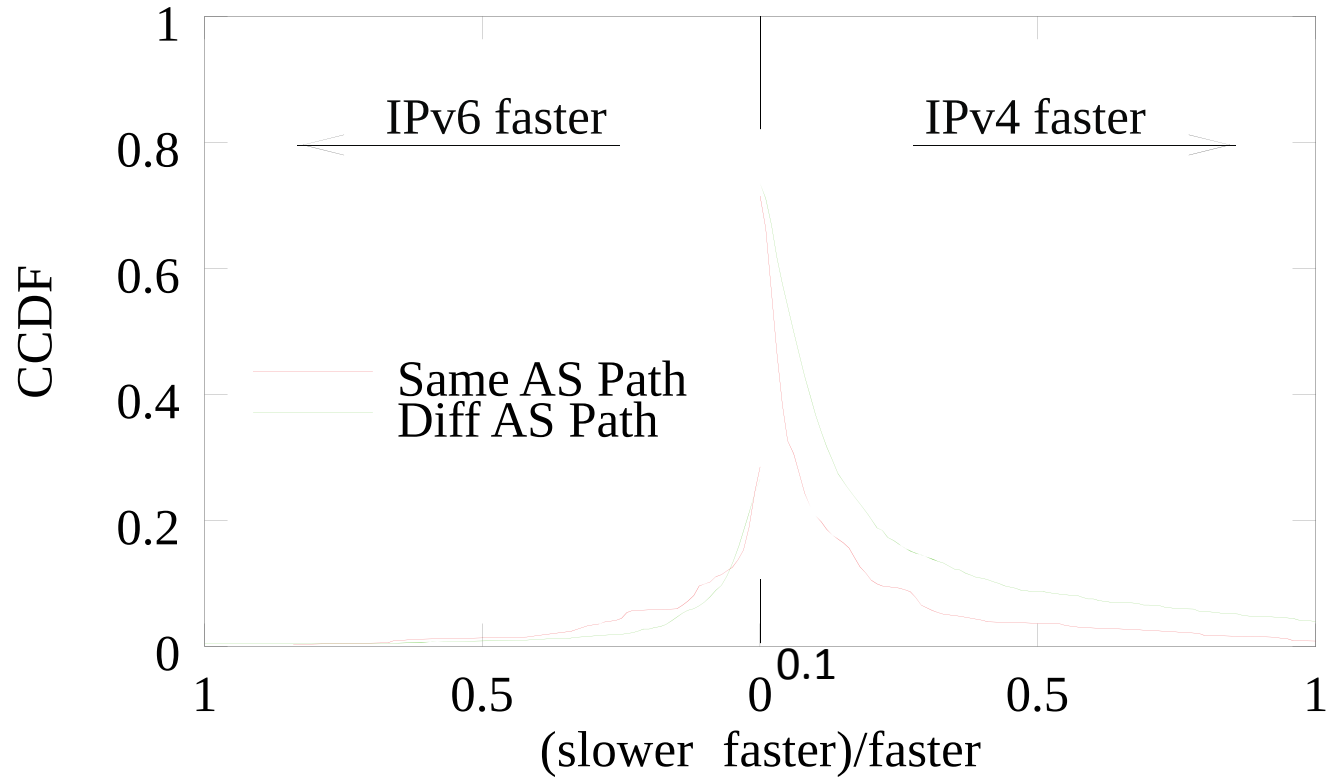


IPv6 deployment is not uniform across business types and geographical regions

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 to dual-stacked websites
  - Webpage download times
  - Forwarding paths to those websites

Performance: Webpage downloads



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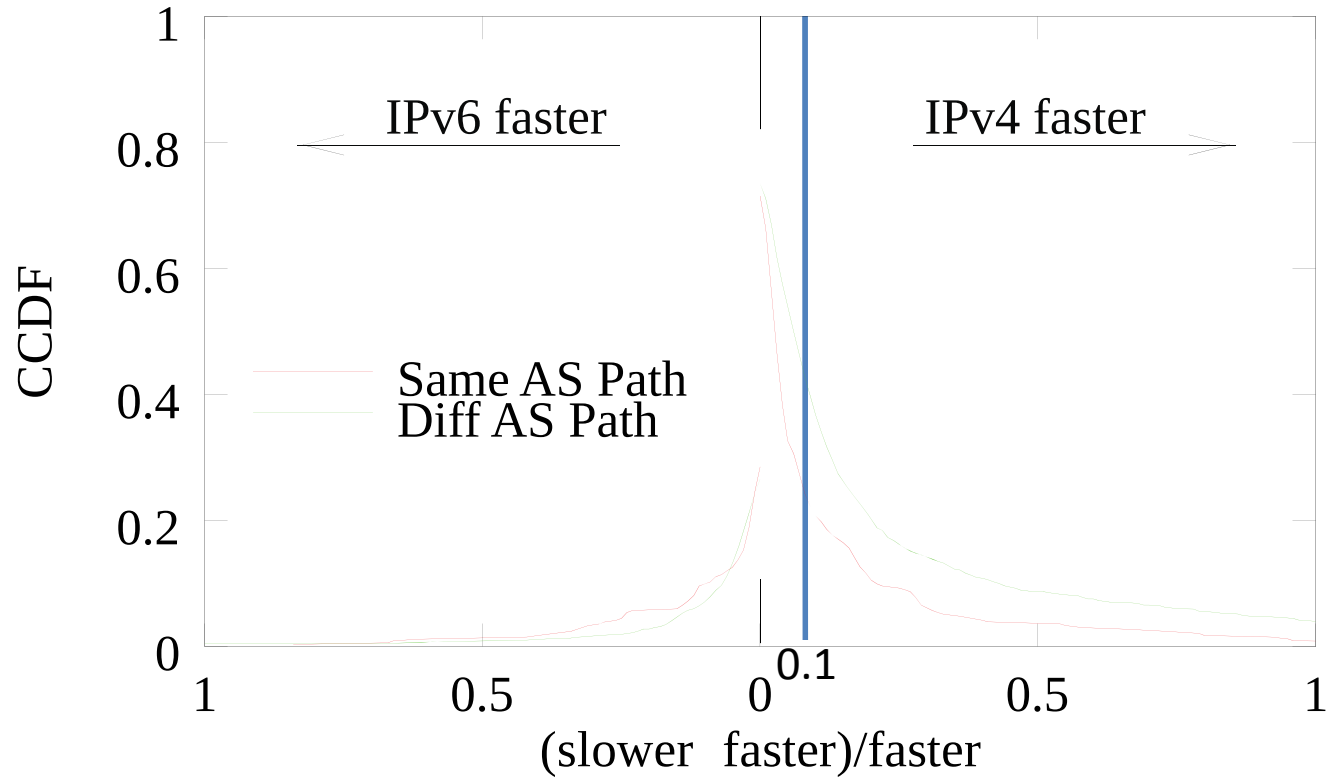

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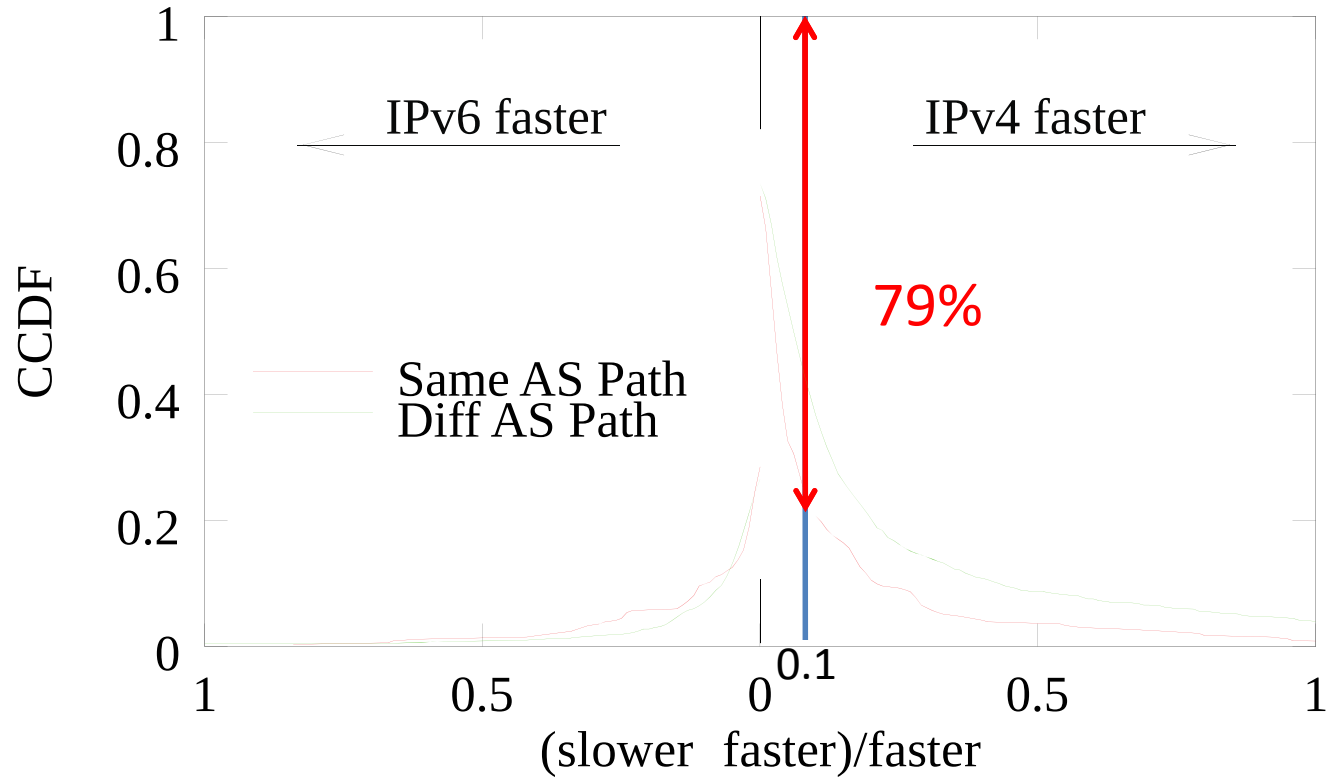

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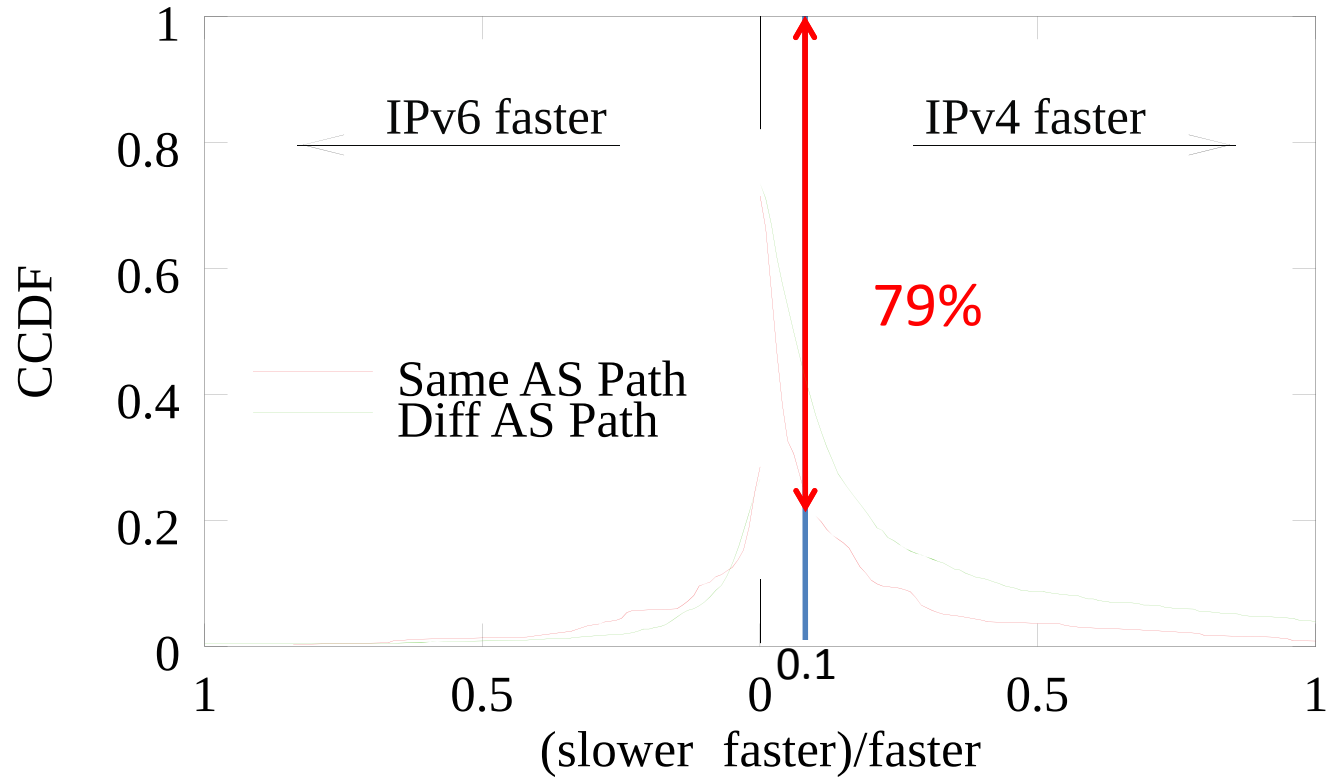
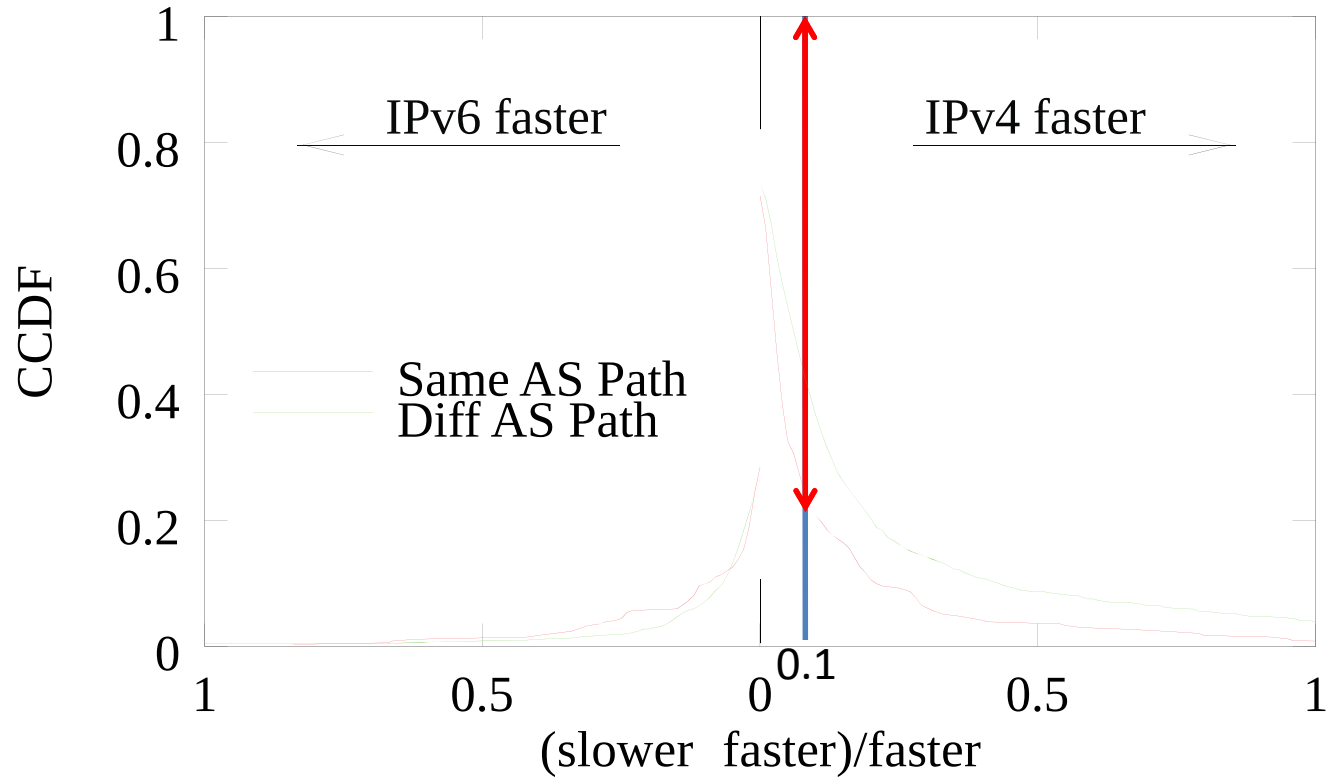


- 79% of paths had IPv6 performance within 10% of IPv4 performance when AS paths were the same

Performance: Webpage downloads



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

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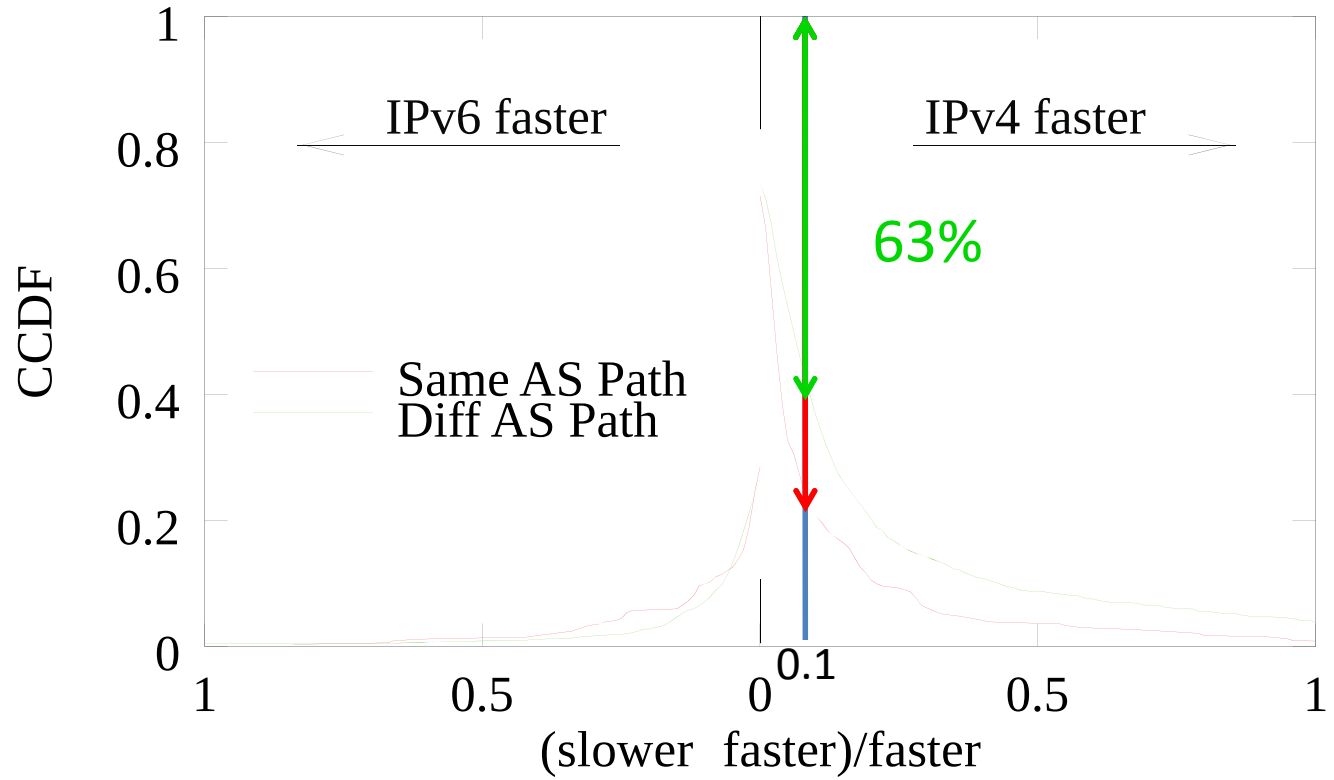

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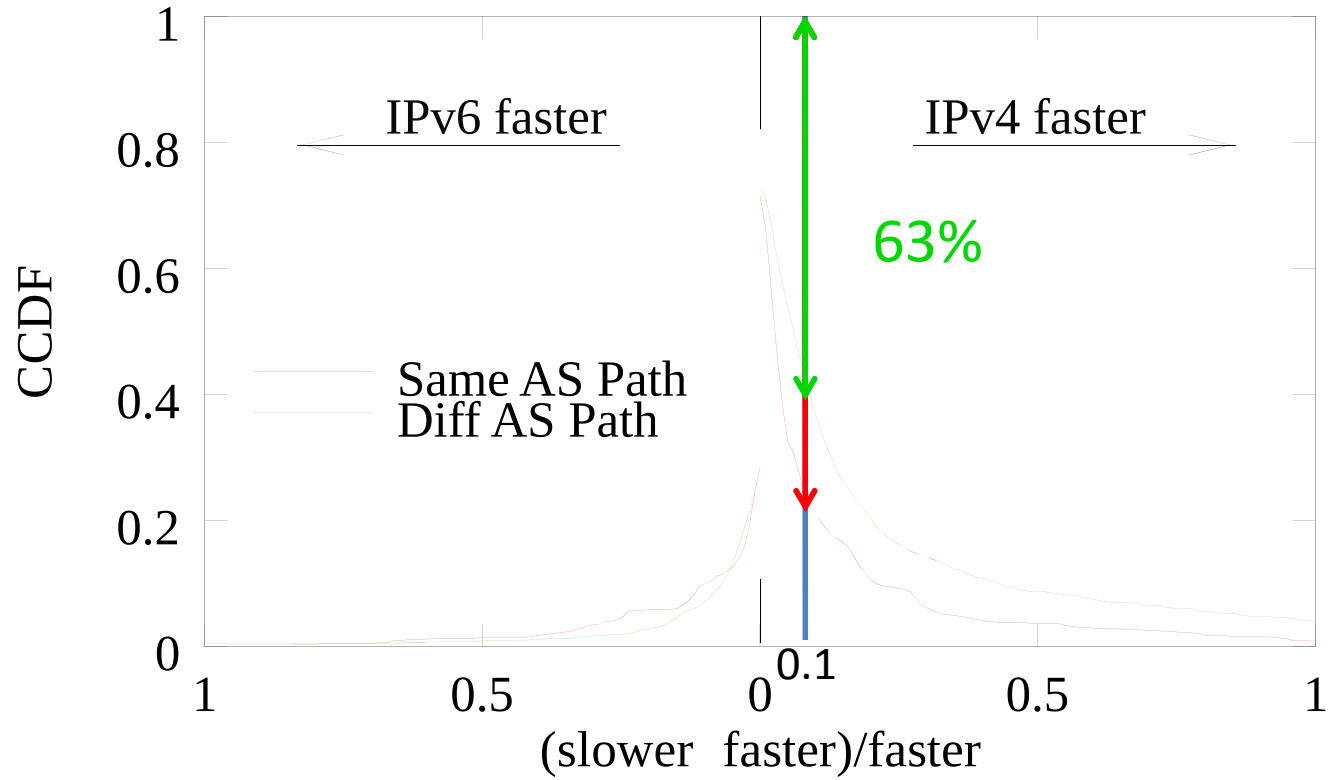
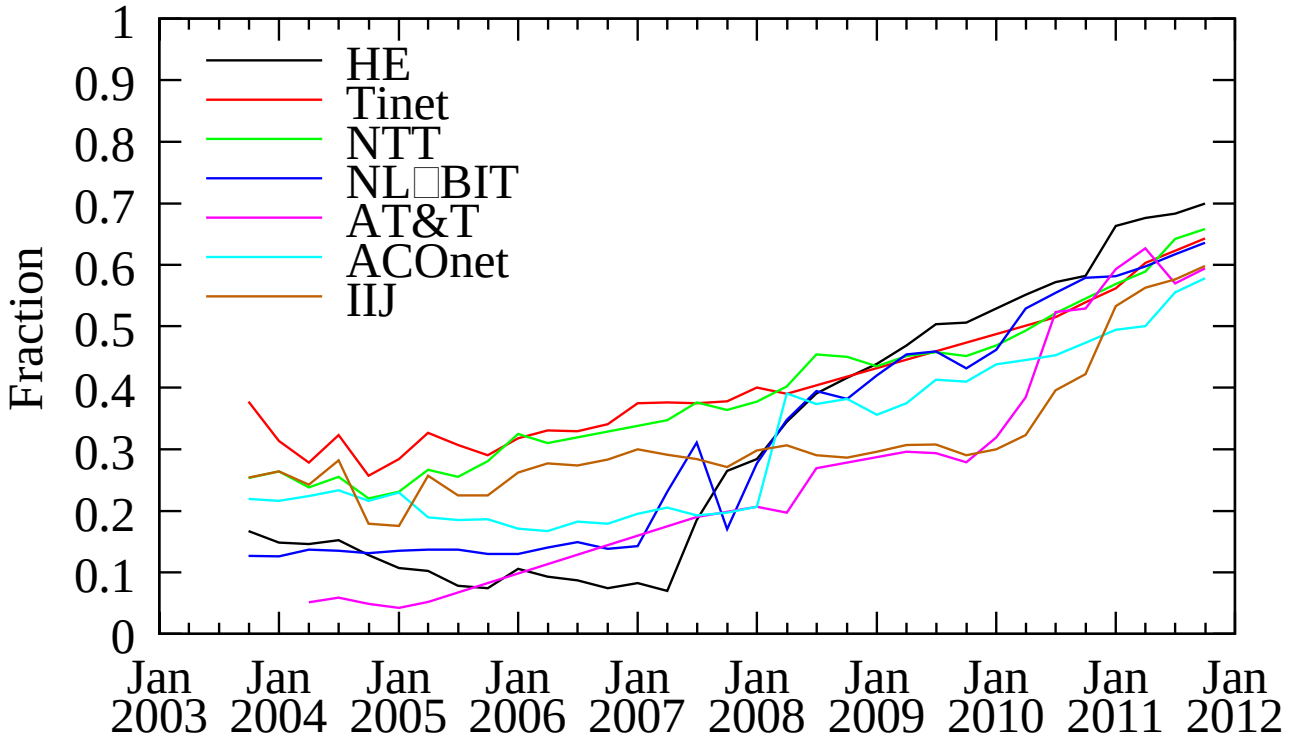


- 79% of paths had IPv6 performance within 10% of IPv4 performance when AS paths were the same
- Only 63% of paths had similar performance when AS paths differed

Relation between performance and AS-level paths

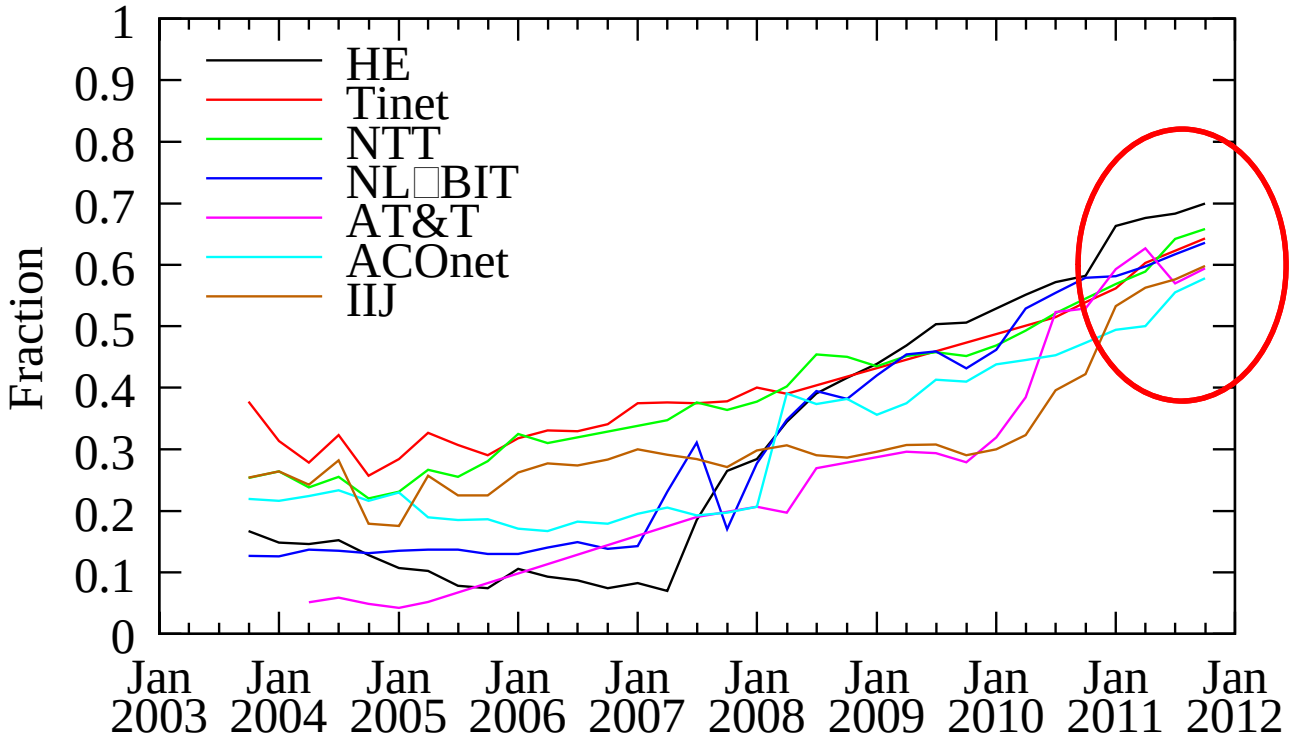
- IPv6 performance is similar to IPv4 performance, if AS-level paths are the same
  - Can be much worse if paths are different
- Less than 50% of AS paths from dual-stacked vantage points are currently the same in IPv4 and IPv6
- Insight: increasing congruence between IPv4 and IPv6 topology will improve performance and thus deployment incentives

Potential AS-path congruence



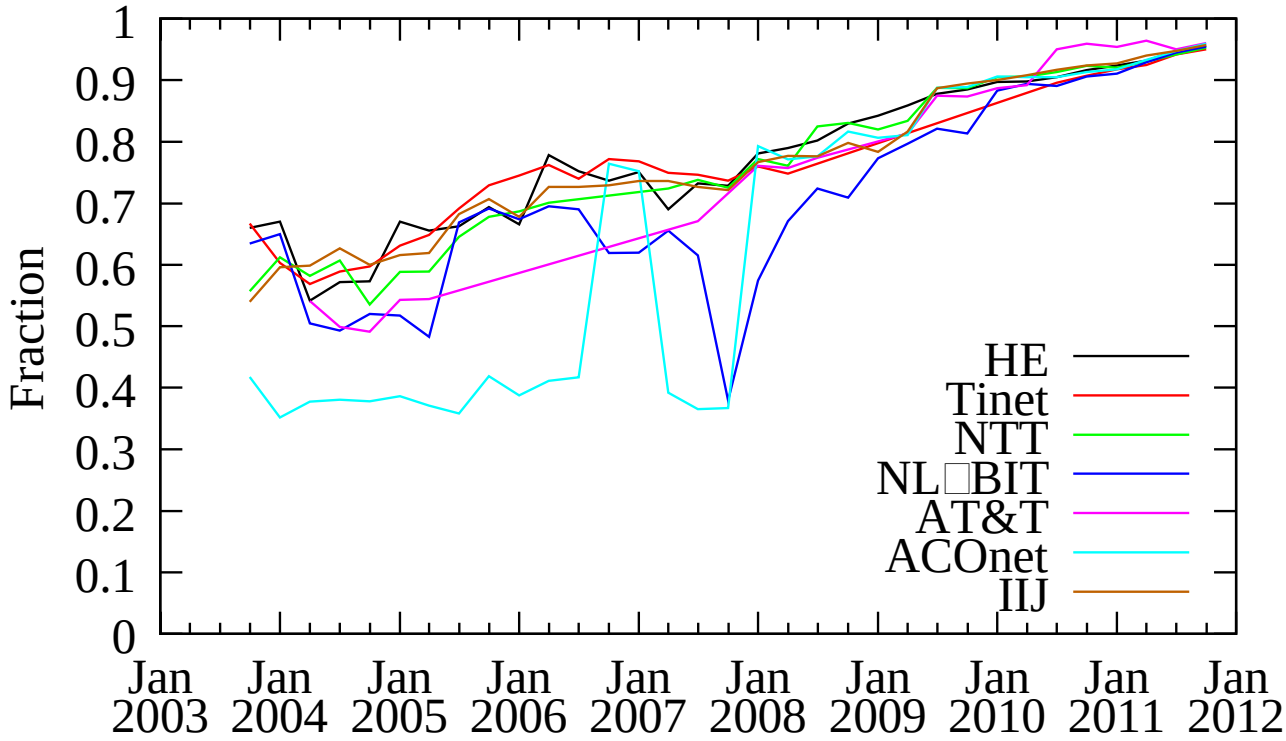
- For each link in an IPv4 AS path, is that link present in the IPv6 topology (anywhere)?

Potential AS-path congruence



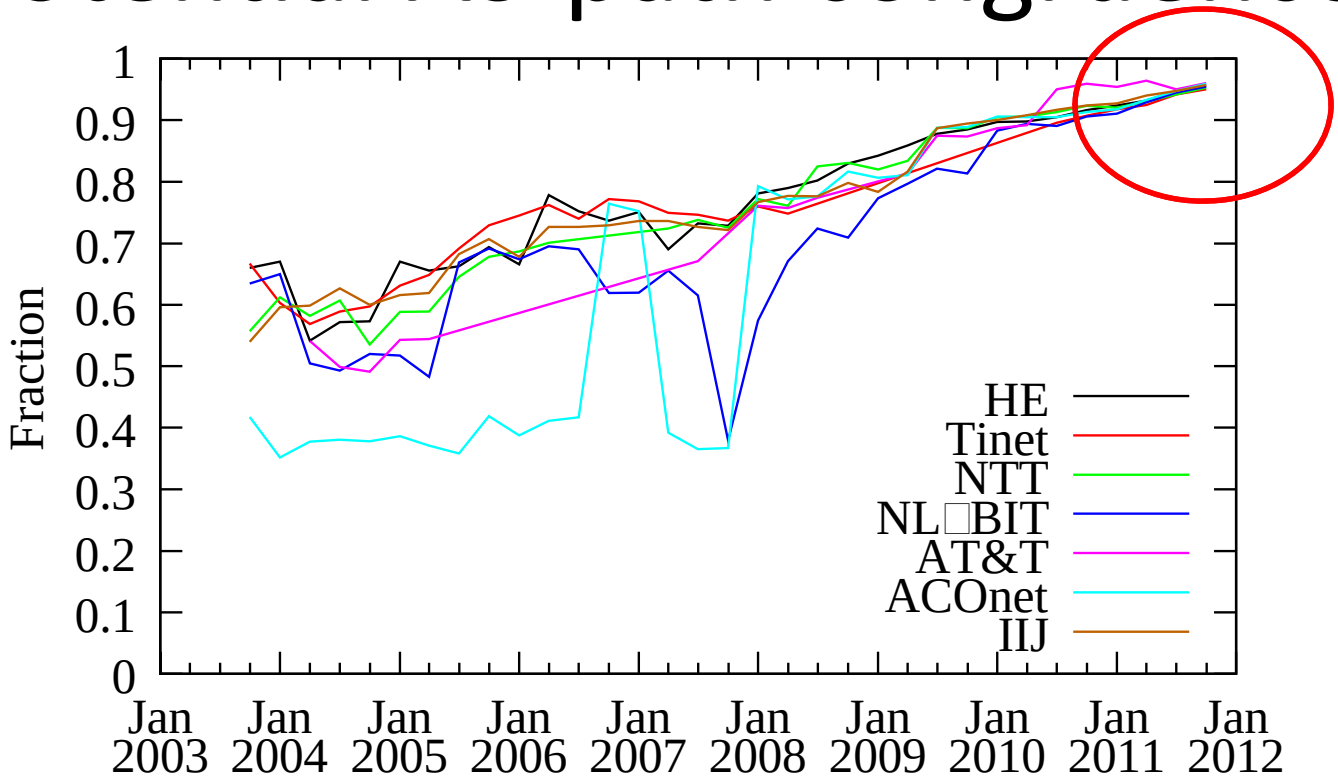
- For each link in an IPv4 AS path, is that link present in the IPv6 topology (anywhere)?
- Based on links that already exist, up to 70% of paths could be identical (without building any new infrastructure)

Potential AS-path congruence



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

Potential AS-path congruence



- 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, up to 90% of paths could be identical

Summary of measurement 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?

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