Hypothesis-based Comparison of IPv6 and IPv4 Path Distances

David Hasselquist, *Linköping University, Sweden*

Christian Wahl, *TUM, Germany and Linköping University, Sweden*

Otto Bergdal, *Linköping University, Sweden*

Niklas Carlsson, *Linköping University, Sweden*

LINKÖPING UNIVERSITY

Motivation

Are there even performance incentives to use IPv6?

- Much work have focused on the IPv6 adoption
  - Relatively less work on its end-to-end performance

- Client performance important
  - Ideally: Short end-to-end paths and round-trip-times (RTTs)
  - Earlier work (mostly 5-10 years old) suggest IPv6 is catching up ...

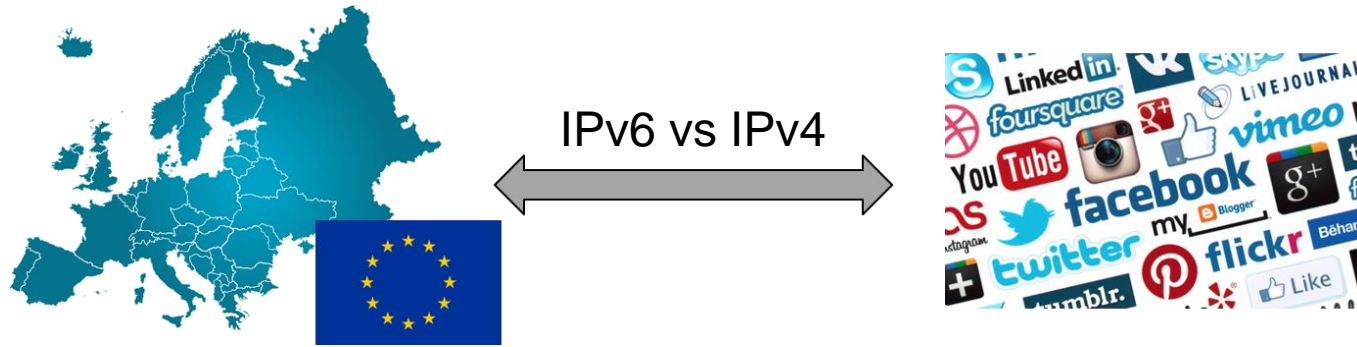Also: Understand IPv6 adoption within PlanetLab Europe
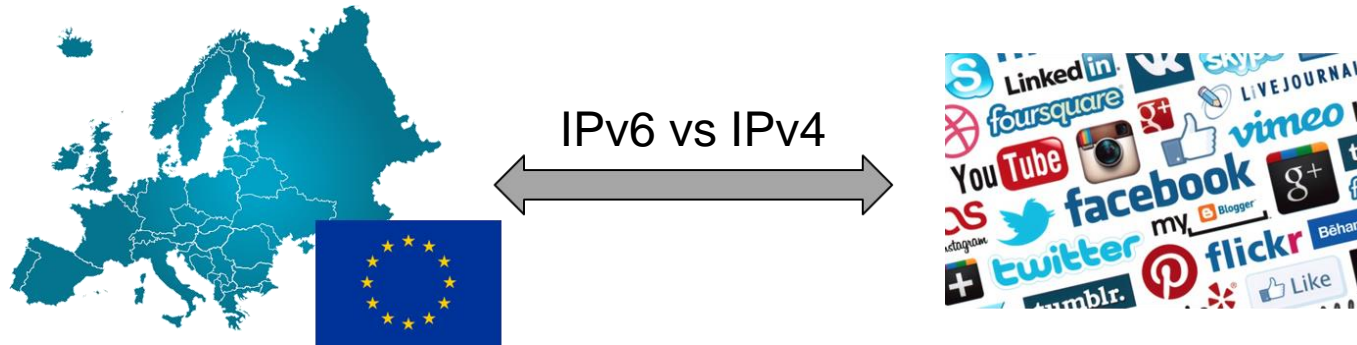
Contributions

IPv6 vs IPv4

- First report on using IPv6 for experiments on PlanetLab Europe
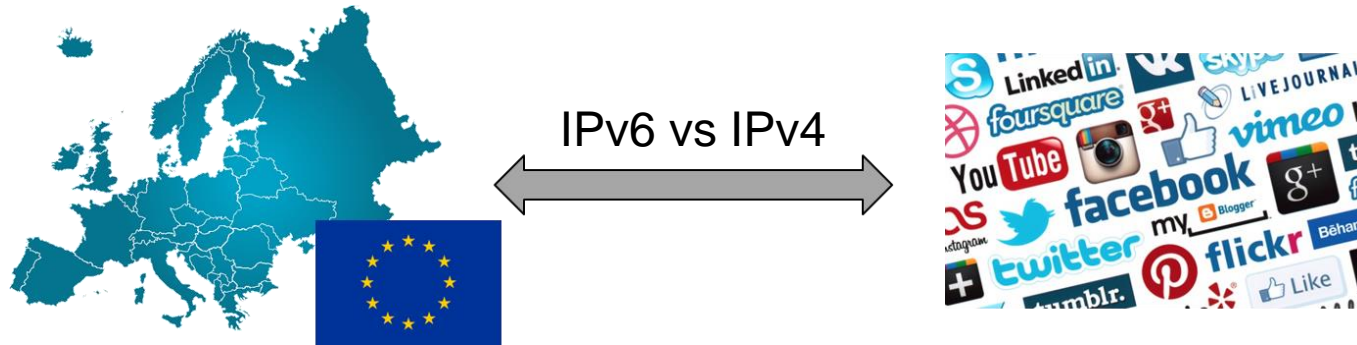
Contributions

IPv6 vs IPv4

- First report on using IPv6 for experiments on PlanetLab Europe

- Hypothesis-based methodology and the results from applying this on datasets collected using traceroutes from PlanetLab Europe nodes

Contributions

IPv6 vs IPv4

- First report on using IPv6 for experiments on PlanetLab Europe

- Hypothesis-based methodology and the results from applying this on datasets collected using traceroutes from PlanetLab Europe nodes

- Findings shows (among other things) that
  - IPv6 paths currently faster than the corresponding IPv4 paths, and
  - pairings for which this is the case is quickly increasing across a wide range of domain popularities and domain categories

Contributions

IPv6 vs IPv4

- First report on using IPv6 for experiments on PlanetLab Europe

- Hypothesis-based methodology and the results from applying this on datasets collected using traceroutes from PlanetLab Europe nodes

- Findings shows (among other things) that
  - IPv6 paths currently faster than the corresponding IPv4 paths, and
  - pairings for which this is the case is quickly increasing across a wide range of domain popularities and domain categories

- Findings suggest that there is incentive to use IPv6 ...

Running IPv6 experiments on PlanetLab Europe …

PlanetLab Europe

- Originally an excellent testbed to run distributed experiments
- Today, many nodes are old, out of date, and often not even reachable
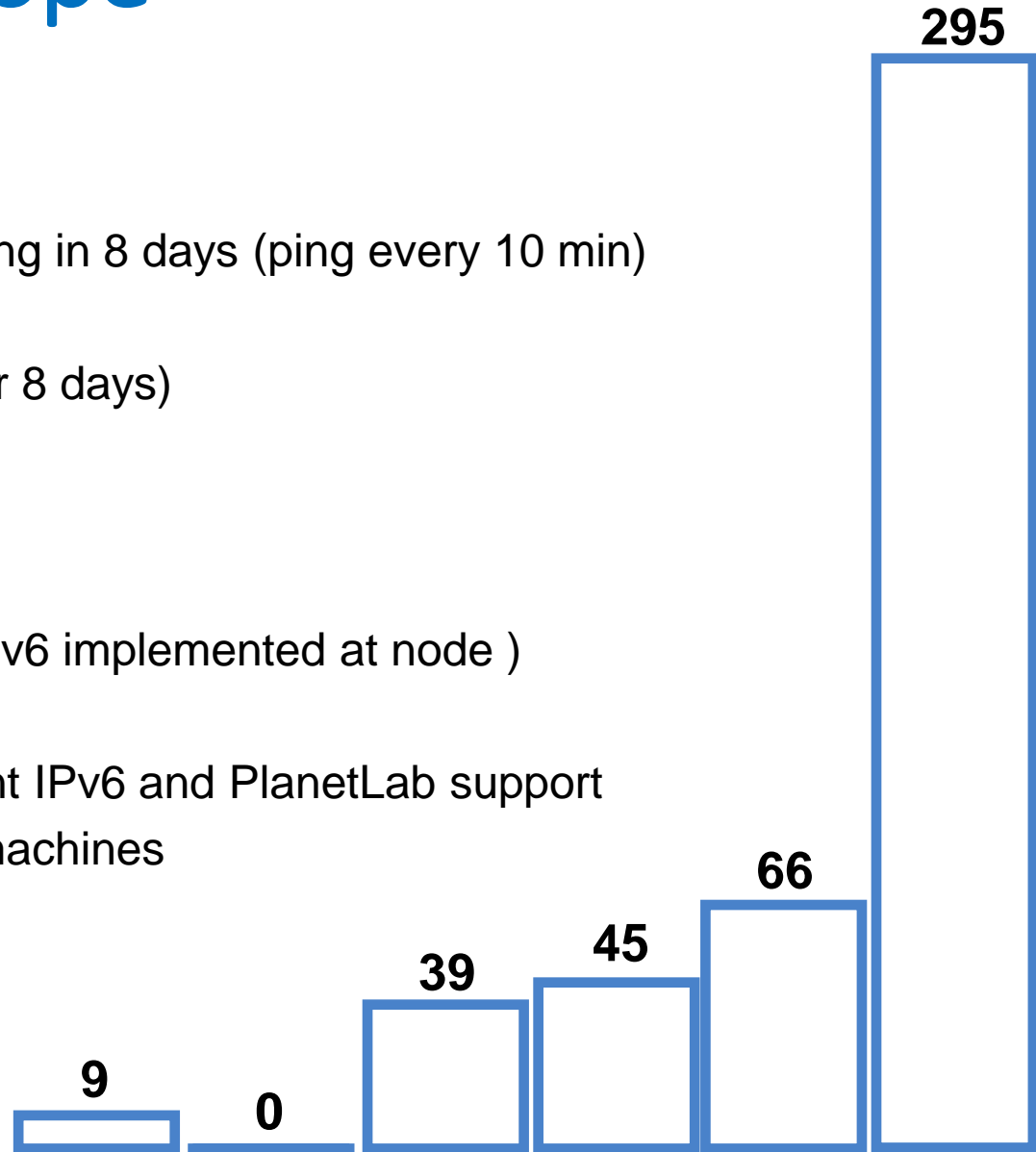
PlanetLab Europe

295: Nodes we had access to

66: Responded to at least one ping in 8 days (ping every 10 min)

45: Responding to every ping (for 8 days)

39: Allowed access via ssh

0: Allowed use of IPv6 (even if IPv6 implemented at node)

9: Fortunately, 9 nodes implement IPv6 and PlanetLab support gave use access to all these machines

9   0   39   45   66   295

Collection methodology

IPv6 vs IPv4

Collection methodology
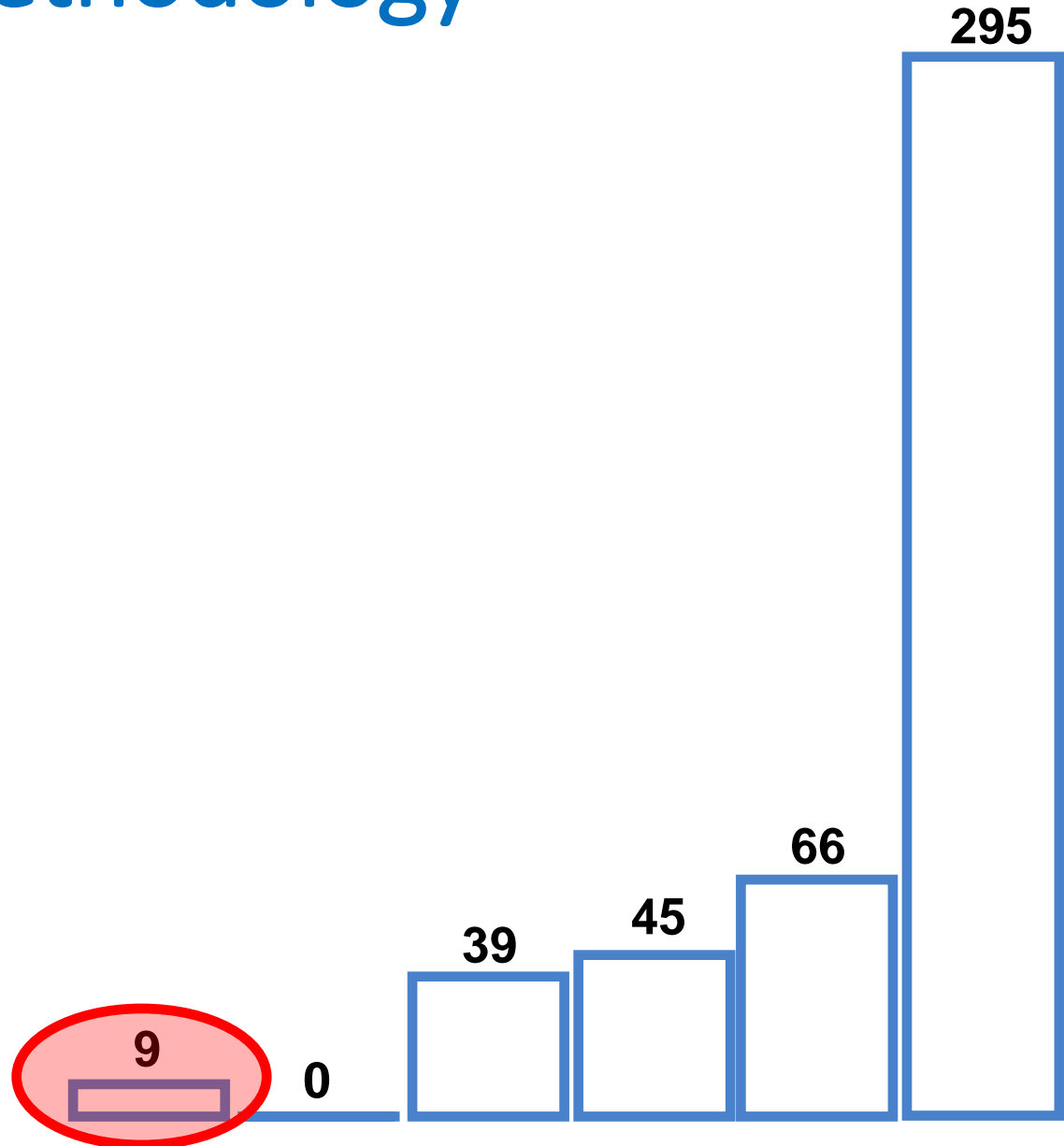
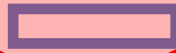# Measurement locations

4 x Paris, FR

2 x Rostock, DE

1 x Gottingen, DE

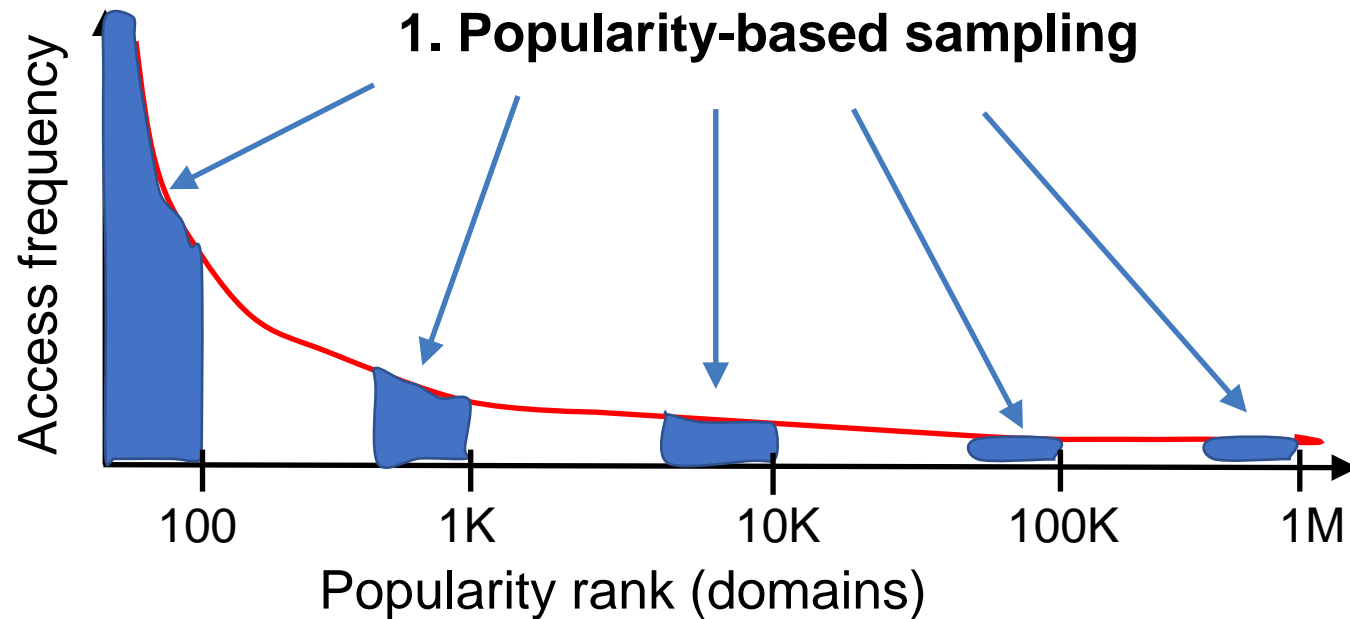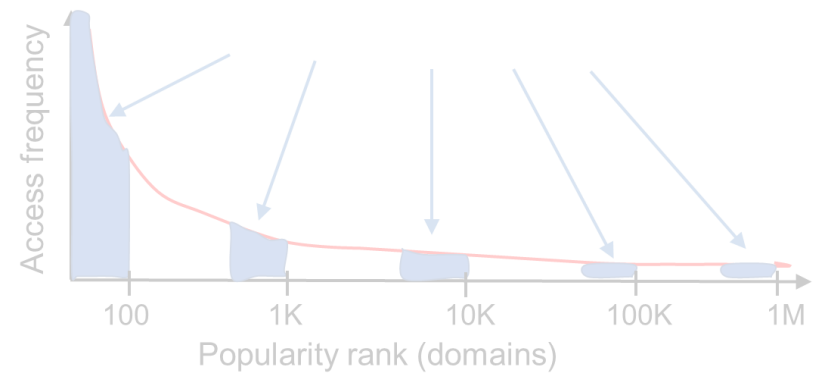2 x Prague, CZ

9

Domain sampling (from Alexa)

4 x Paris, FR

2 x Rostock, DE

1 x Gottingen, DE

2 x Prague, CZ

1. Popularity-based sampling

Access frequency

Popularity rank (domains)

100   1K   10K   100K   1M

Domain sampling (from Alexa)

4 x Paris, FR

2 x Rostock, DE

1 x Gottingen, DE

2 x Prague, CZ

1. Popularity-based sampling

Access frequency

100   1K   10K   100K   1M

Popularity rank (domains)

2. Category-based sampling

Arts
Business
Kids+Teens
Reference
Health
Shopping
Sports
Recreation
Regional
Adult
Home
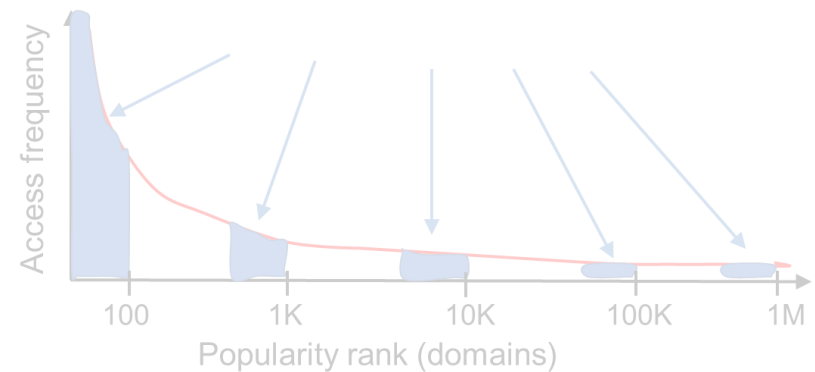Games
Computers
Society
News
Science

Pairwise traceroutes

4 x Paris, FR

2 x Rostock, DE

1 x Gottingen, DE

2 x Prague, CZ

1. Popularity-based sampling

Access frequency

Popularity rank (domains)

100   1K   10K   100K   1M

2. Category-based sampling

Arts Business Kids+Teens Reference Health Shopping Sports Recreation Regional Adult Home Games Computers Society News Science

IPv6 vs IPv4
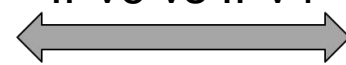
Main datasets

| Short name	Duration	Dates (all 2019)	Method	Nodes	Traceroutes	Success
May 2019	1 week	May 14-20	Baseline	8	1,966,793	74%
Paris	4 weeks	Aug. 11 - Sept. 8	Paris	6	265,206	22%
Sept. 2019	1 week	Sept. 18 - 24	Baseline	8	1,773,553	78%

For each pair …

- Both IPv6 and IPv4 (close in time)
- Repeat many times from each location …
- Tried different traceroute techniques
  - Here, focus on Baselines version: May 2019 vs Sept. 2019
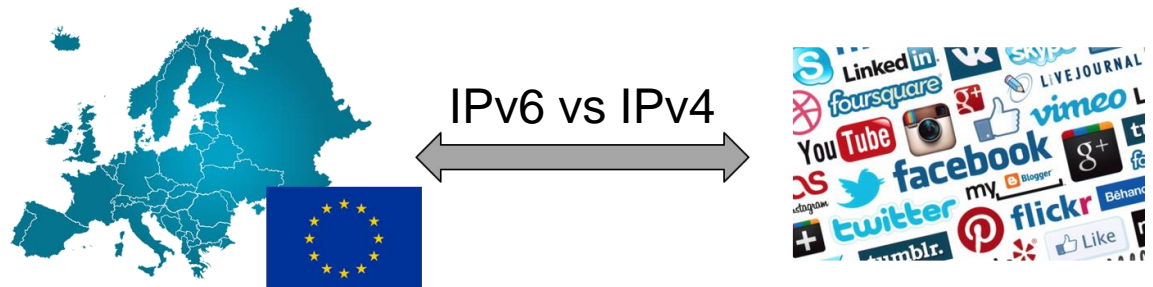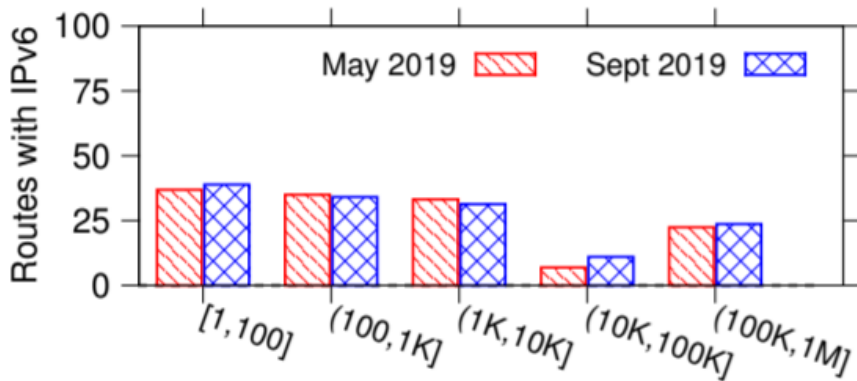
IPv6 vs IPv4
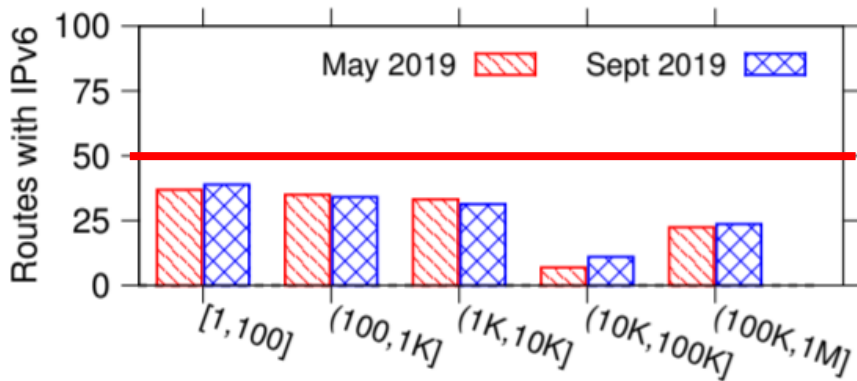
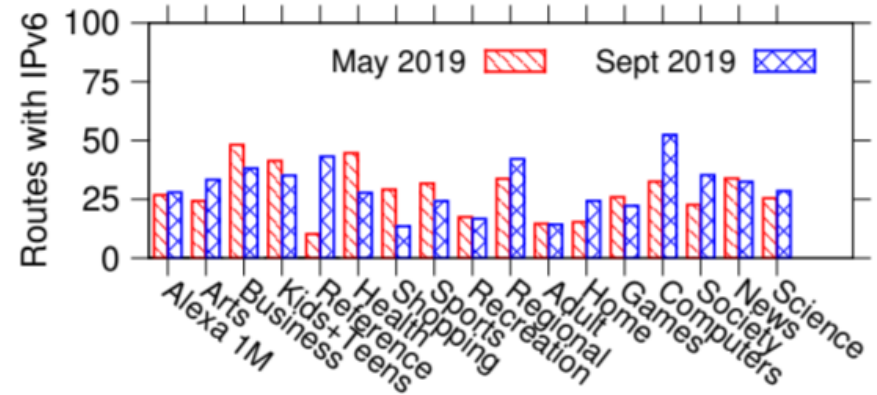# IPv6 deployment

(a) Alexa top-1M popularity ranking
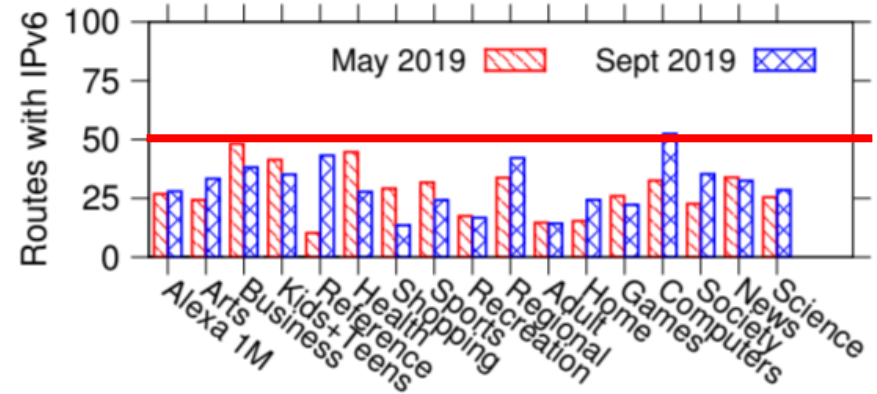
(b) Domain category

- Only one category has more than 50% deployment ("Computers")

IPv6 deployment

(a) Alexa top-1M popularity ranking

(b) Domain category

- Only one category has more than 50% deployment ("Computers")
- Small overall increase (1.44%)

Methodology + Results

Pairwise comparisons

	Metric	Median winner (%)			Average winner (%)			95% conf. win. (%)		
		v.4	v.6	tie	v.4	v.6	tie	v.4	v.6	none
May'19	IP hops	15.4	**77.5**	7.0	21.1	**78.7**	0.2	19.9	**77.5**	2.6
	AS hops	14.3	**59.3**	26.4	17.1	**79.6**	3.3	16.0	**78.0**	6.0
	RTTs	46.0	**54.0**	0.0	47.2	**52.8**	0.0	33.1	**44.7**	22.2
Sep'19	IP hops	14.4	**77.6**	8.0	20.2	**79.8**	0.0	19.4	**79.0**	1.6
	AS hops	10.3	**55.4**	34.3	15.4	**81.5**	3.1	13.3	**78.7**	8.1
	RTTs	36.2	**63.8**	0.0	31.3	**68.7**	0.0	25.7	**59.0**	15.3

- For each pair and metric, pick a "winner" using three different statistics
  - Median, average, 95-confidence test (one-side t-test)

Pairwise comparisons

|		Median winner (%)			Average winner (%)			95% conf. win. (%)		
	Metric	v.4	v.6	tie	v.4	v.6	tie	v.4	v.6	none
May'19	IP hops	15.4	**77.5**	7.0	21.1	**78.7**	0.2	19.9	**77.5**	2.6
	AS hops	14.3	**59.3**	26.4	17.1	**79.6**	3.3	16.0	**78.0**	6.0
	RTTs	46.0	**54.0**	0.0	47.2	**52.8**	0.0	33.1	**44.7**	22.2
Sep'19	IP hops	14.4	**77.6**	8.0	20.2	**79.8**	0.0	19.4	**79.0**	1.6
	AS hops	10.3	**55.4**	34.3	15.4	**81.5**	3.1	13.3	**78.7**	8.1
	RTTs	36.2	**63.8**	0.0	31.3	**68.7**	0.0	25.7	**59.0**	15.3

- For each pair and metric, pick a "winner" using three different statistics
  - Median, average, 95-confidence test (one-side t-test)

Pairwise comparisons

|	Metric	Median winner (%)			Average winner (%)			95% conf. win. (%)		
		v.4	v.6	tie	v.4	v.6	tie	v.4	v.6	none
May'19	IP hops	15.4	**77.5**	7.0	21.1	**78.7**	0.2	19.9	**77.5**	2.6
	AS hops	14.3	**59.3**	26.4	17.1	**79.6**	3.3	16.0	**78.0**	6.0
	RTTs	46.0	**54.0**	0.0	47.2	**52.8**	0.0	33.1	**44.7**	22.2
Sep'19	IP hops	14.4	**77.6**	8.0	20.2	**79.8**	0.0	19.4	**79.0**	1.6
	AS hops	10.3	**55.4**	34.3	15.4	**81.5**	3.1	13.3	**78.7**	8.1
	RTTs	36.2	**63.8**	0.0	31.3	**68.7**	0.0	25.7	**59.0**	15.3

- For each pair and metric, pick a "winner" using three different statistics
  - Median, average, 95-confidence test (one-side t-test)

Pairwise comparisons

	Metric	Median winner (%)			Average winner (%)			95% conf. win. (%)		
		v.4	v.6	tie	v.4	v.6	tie	v.4	v.6	none
May'19	IP hops	15.4	**77.5**	7.0	21.1	**78.7**	0.2	19.9	**77.5**	2.6
May'19	AS hops	14.3	**59.3**	26.4	17.1	**79.6**	3.3	16.0	**78.0**	6.0
May'19	RTTs	46.0	**54.0**	0.0	47.2	**52.8**	0.0	33.1	**44.7**	22.2
Sep'19	IP hops	14.4	**77.6**	8.0	20.2	**79.8**	0.0	19.4	**79.0**	1.6
Sep'19	AS hops	10.3	**55.4**	34.3	15.4	**81.5**	3.1	13.3	**78.7**	8.1
Sep'19	RTTs	36.2	**63.8**	0.0	31.3	**68.7**	0.0	25.7	**59.0**	15.3

- For each pair and metric, pick a "winner" using three different statistics
    - Median, average, 95-confidence test (one-side t-test)
- IPv6 most frequent "winner" in all cases

Pairwise comparisons

	Metric	Median winner (%)			Average winner (%)			95% conf. win. (%)		
		v.4	v.6	tie	v.4	v.6	tie	v.4	v.6	none
May'19	IP hops	15.4	**77.5**	7.0	21.1	**78.7**	0.2	19.9	**77.5**	2.6
	AS hops	14.3	**59.3**	26.4	17.1	**79.6**	3.3	16.0	**78.0**	6.0
	RTTs	46.0	**54.0**	0.0	47.2	**52.8**	0.0	33.1	**44.7**	22.2
Sep'19	IP hops	14.4	**77.6**	8.0	20.2	**79.8**	0.0	19.4	**79.0**	1.6
	AS hops	10.3	**55.4**	34.3	15.4	**81.5**	3.1	13.3	**78.7**	8.1
	RTTs	36.2	**63.8**	0.0	31.3	**68.7**	0.0	25.7	**59.0**	15.3

- For each pair and metric, pick a "winner" using three different statistics
  - Median, average, 95-confidence test (one-side t-test)
- IPv6 most frequent "winner" in all cases
- IP and AS hops are significantly shorter (e.g., 95% confidence)

Pairwise comparisons

	Metric	Median winner (%)			Average winner (%)			95% conf. win. (%)		
		v.4	v.6	tie	v.4	v.6	tie	v.4	v.6	none
May'19	IP hops	15.4	**77.5**	7.0	21.1	**78.7**	0.2	19.9	**77.5**	2.6
	AS hops	14.3	**59.3**	26.4	17.1	**79.6**	3.3	16.0	**78.0**	6.0
	RTTs	46.0	**54.0**	0.0	47.2	**52.8**	0.0	33.1	**44.7**	22.2
Sep'19	IP hops	14.4	**77.6**	8.0	20.2	**79.8**	0.0	19.4	**79.0**	1.6
	AS hops	10.3	**55.4**	34.3	15.4	**81.5**	3.1	13.3	**78.7**	8.1
	RTTs	36.2	**63.8**	0.0	31.3	**68.7**	0.0	25.7	**59.0**	15.3

- For each pair and metric, pick a "winner" using three different statistics
  - Median, average, 95-confidence test (one-side t-test)
- IPv6 most frequent "winner" in all cases
- IP and AS hops are significantly shorter (e.g., 95% confidence)
- RTT: Relatively lower, but **increasing** fraction of "winners"

Pairwise comparisons
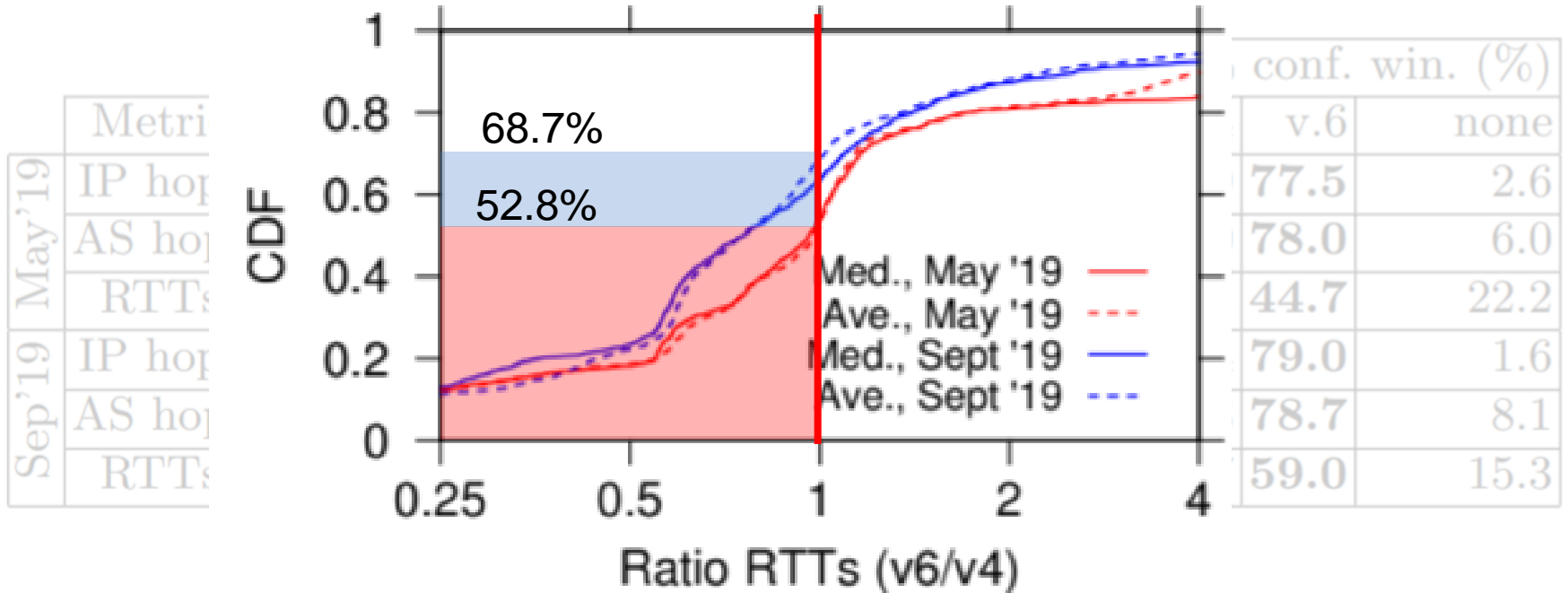
- For each pair and metric, pick a "winner" using three different statistics
  - Median, average, 95-confidence test (one-side t-test)
- IPv6 most frequent "winner" in all cases
- IP and AS hops are significantly shorter (e.g., 95% confidence)
- RTT: Relatively lower, but **increasing** fraction of "winners"
  - In fact, entire distribution shifted …

Popularity-based comparison

IP hops
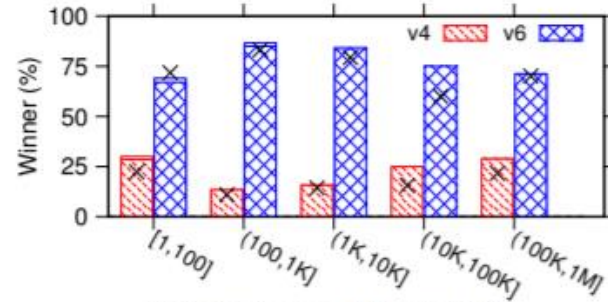
AS hops
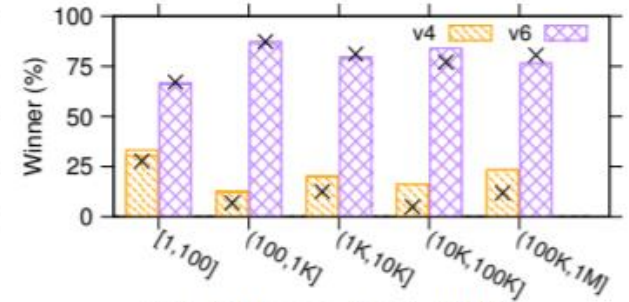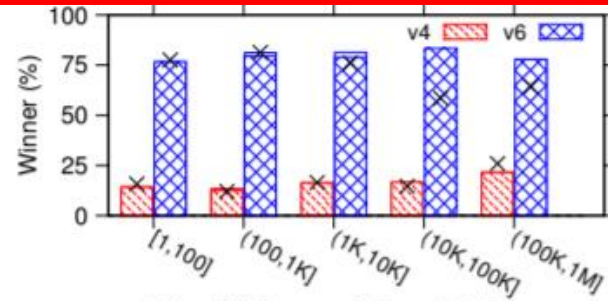
RTTs

(a) IP hops, May 2019

(b) IP hops, Sept. 2019
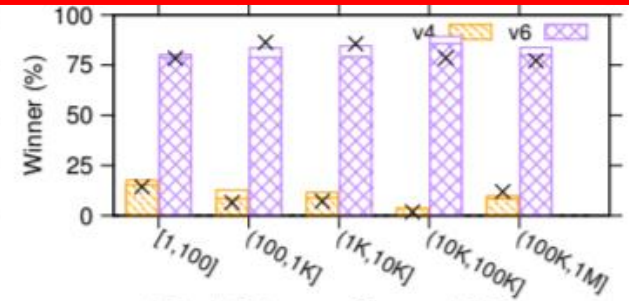
(c) AS hops, May 2019
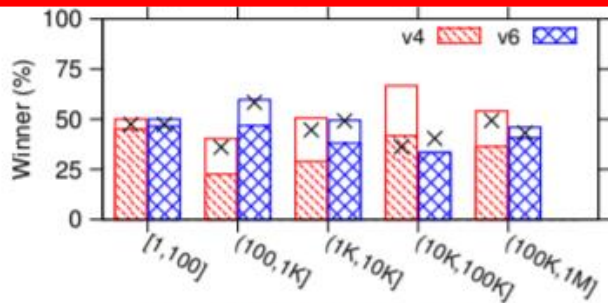
(d) AS hops, Sept. 2019
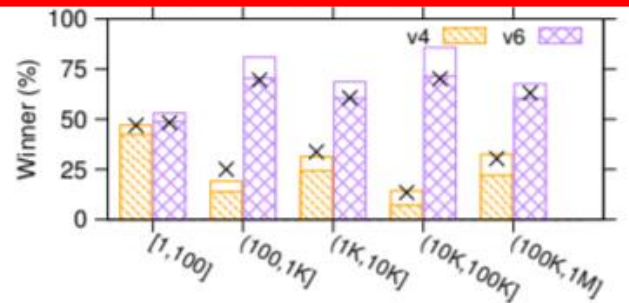
(e) RTTs, May 2019

(f) RTTs, Sept. 2019

Popularity-based comparison
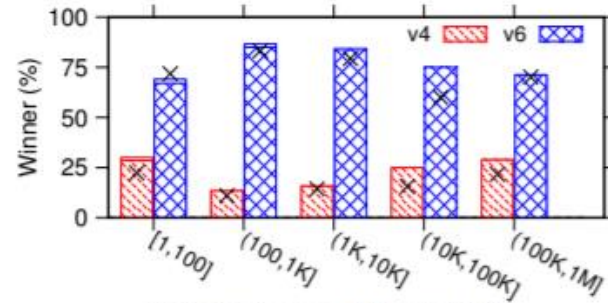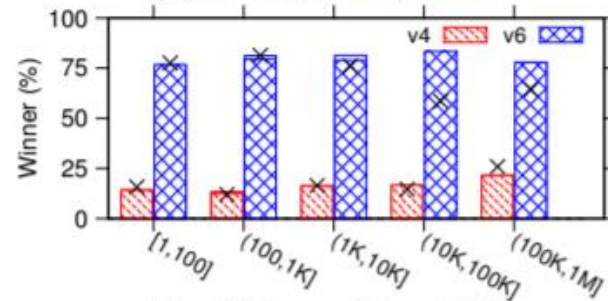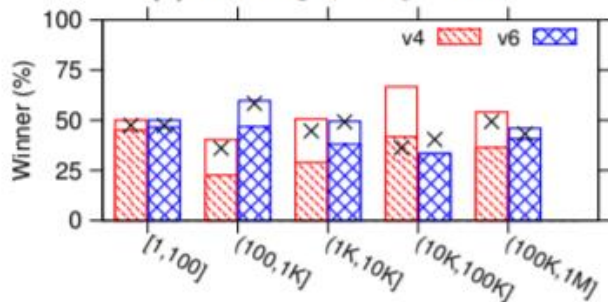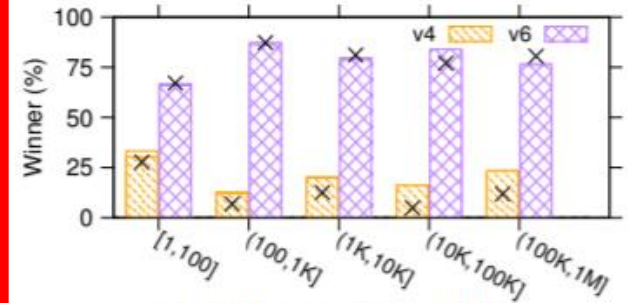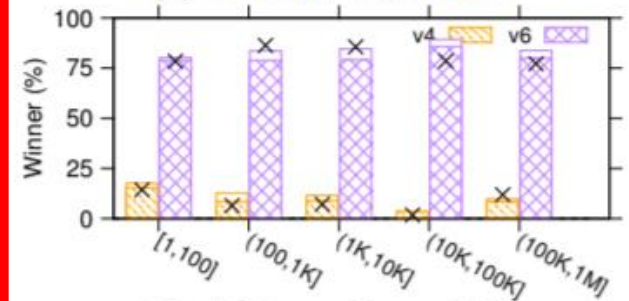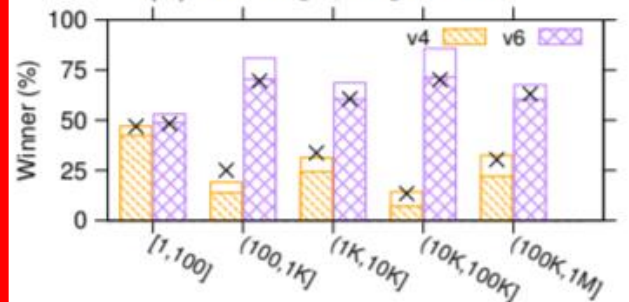
(a) IP hops, May 2019
(b) IP hops, Sept. 2019
(c) AS hops, May 2019
(d) AS hops, Sept. 2019
(e) RTTs, May 2019
(f) RTTs, Sept. 2019

May 2019

Sept. 2019

Popularity-based comparison
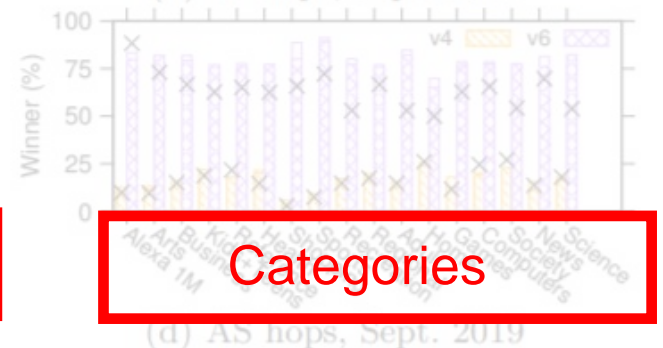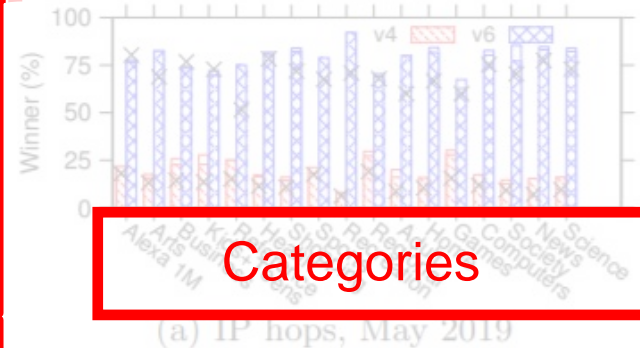

(e) RTTs, May 2019

(f) RTTs, Sept. 2019

Popularity-based comparison
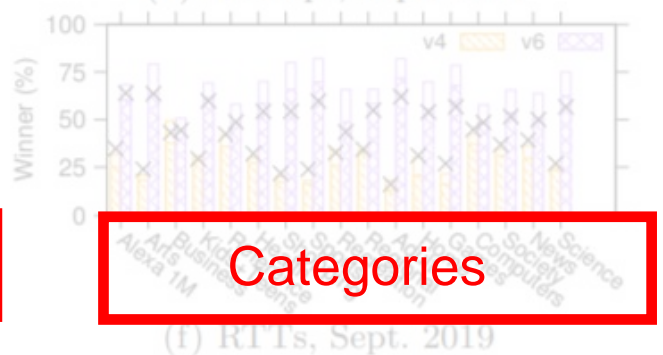
IP and AS hops:
- IPv6 clear winner
- Not much change

RTTs:
- Except top-100, significant increase in IPv6 winners

(a) IP hops, May 2019

(b) IP hops, Sept. 2019

(c) AS hops, May 2019

(d) AS hops, Sept. 2019
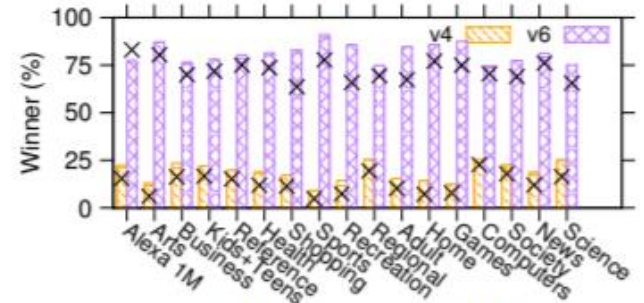
(e) RTTs, May 2019
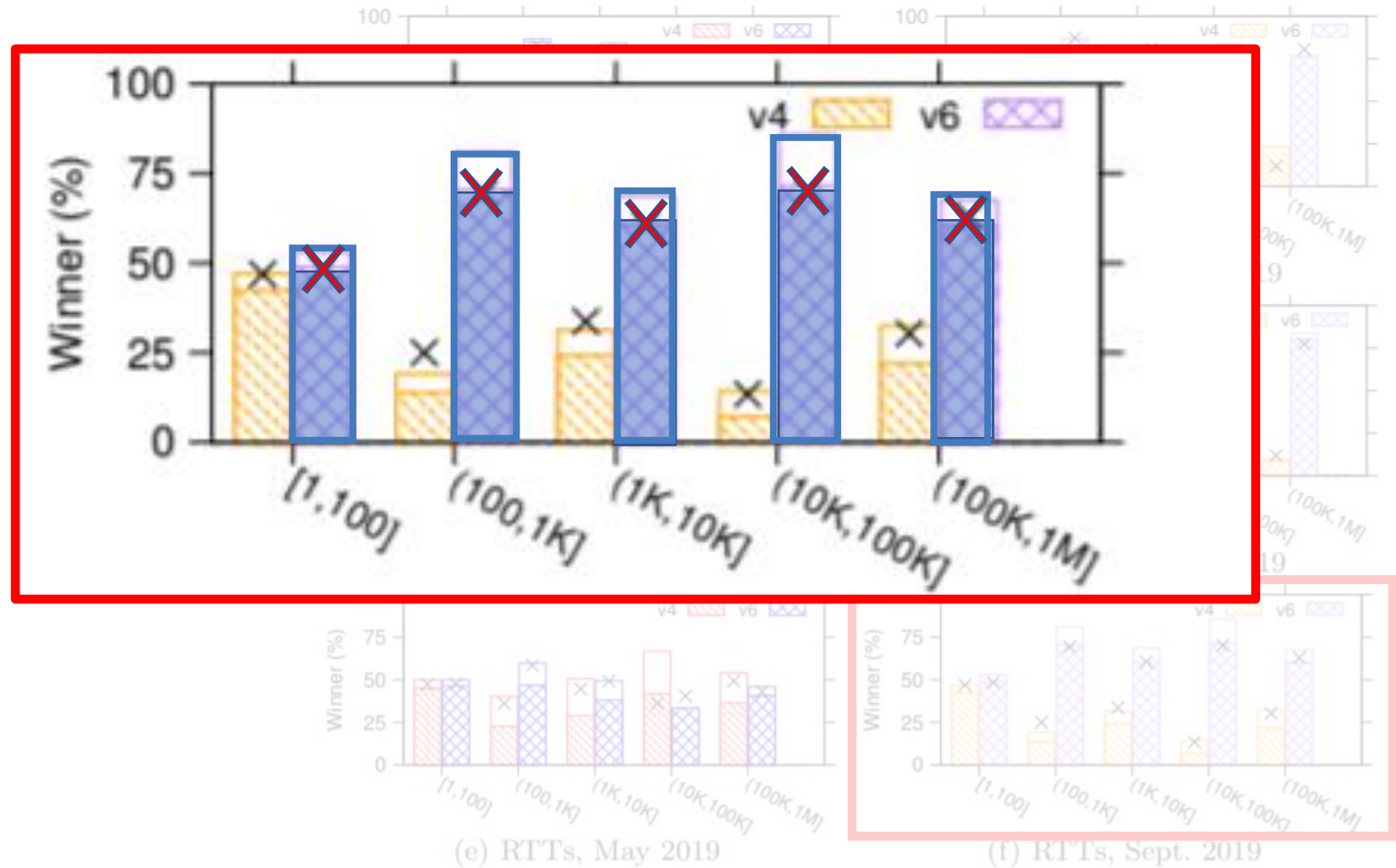
(f) RTTs, Sept. 2019

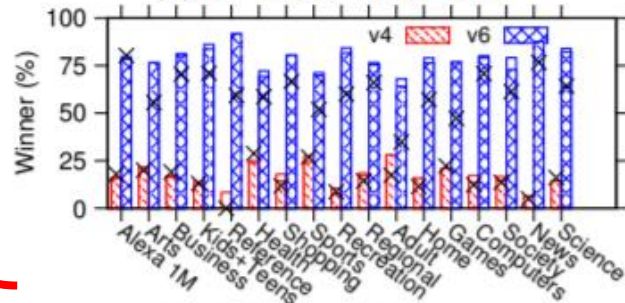# Popularity-based comparison

IP and AS hops:
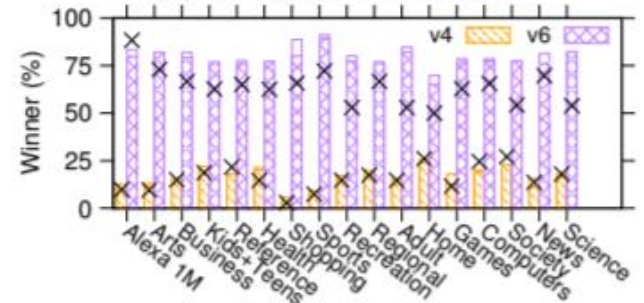- IPv6 clear winner
- Not much change
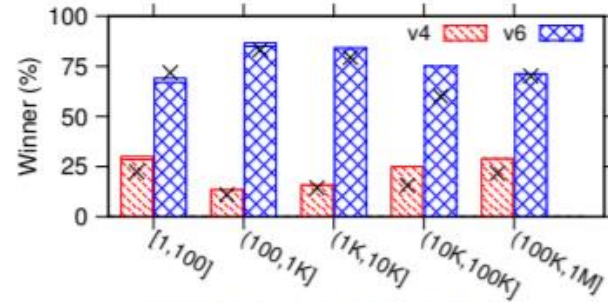
(a) IP hops, May 2019
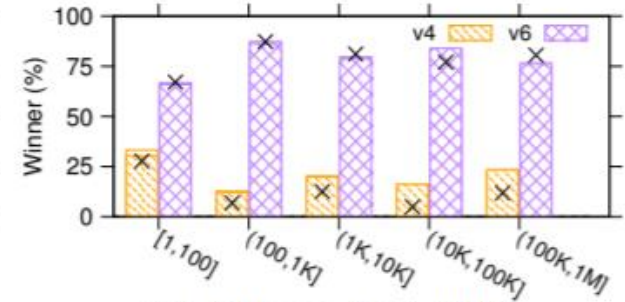
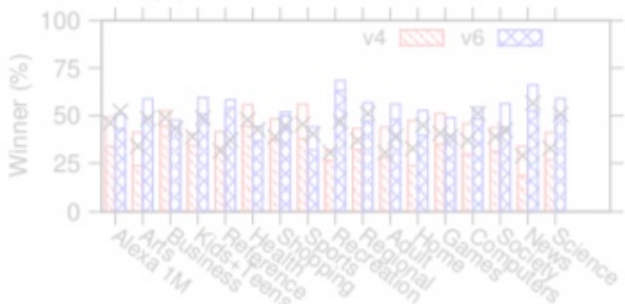(b) IP hops, Sept. 2019
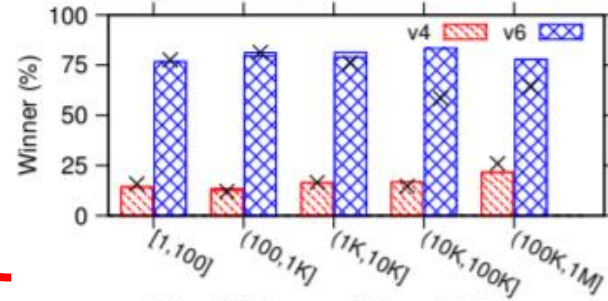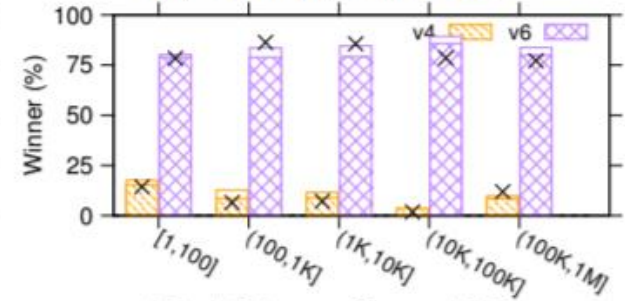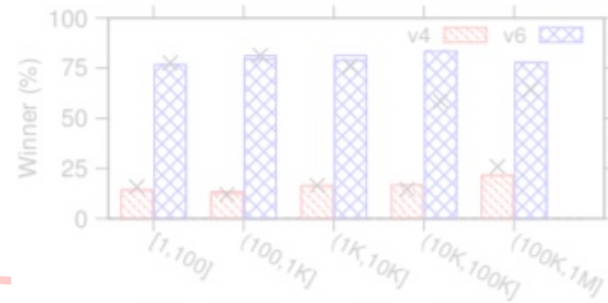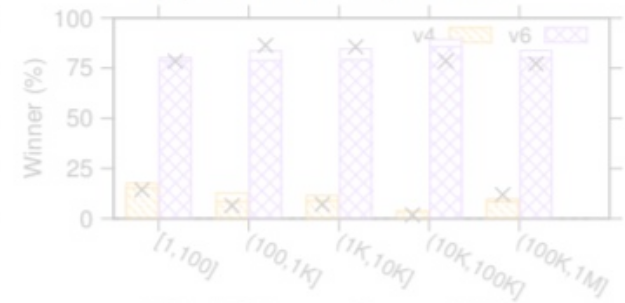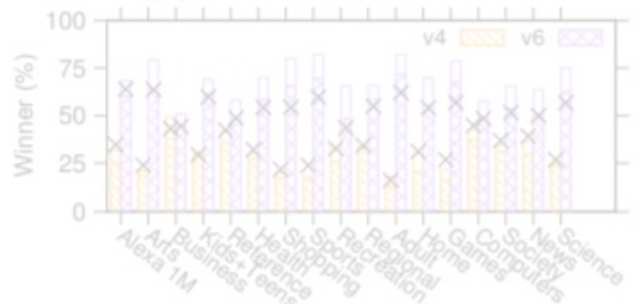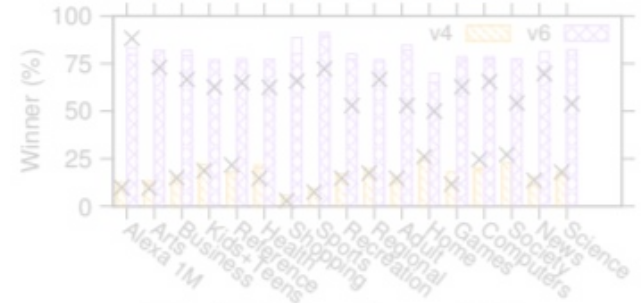
(c) AS hops, May 2019

(d) AS hops, Sept. 2019

RTTs:

- Except top-100, significant increase in IPv6 winners
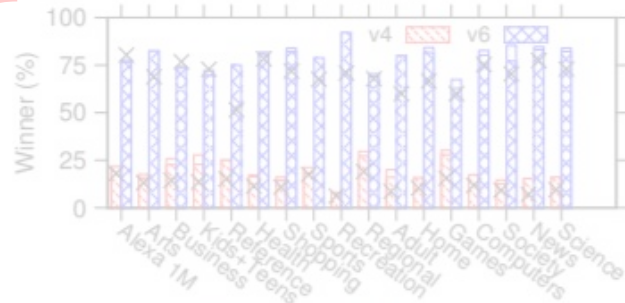
(e) RTTs, May 2019

(f) RTTs, Sept. 2019

Category-based comparison

IP and AS hops:
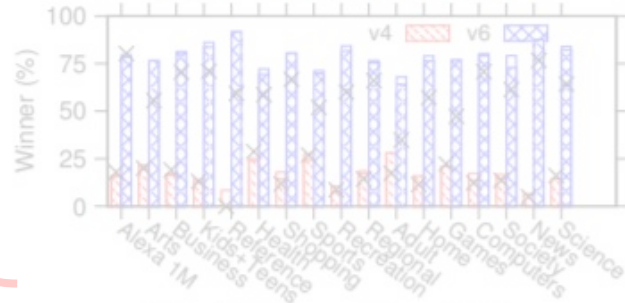- IPv6 clear winner
- Not much change

RTTs:
- Except top-100, significant increase in IPv6 winners

(a) IP hops, May 2019

(b) IP hops, Sept. 2019

(c) AS hops, May 2019

(d) AS hops, Sept. 2019

(e) RTTs, May 2019

(f) RTTs, Sept. 2019

Category-based comparison

IP and AS hops:

- IPv6 clear winner
- Not much change

RTTs:

- Except top-100, significant increase in IPv6 winners

(a) IP hops, May 2019

(b) IP hops, Sept. 2019

(c) AS hops, May 2019

(d) AS hops, Sept. 2019

(e) RTTs, May 2019

(f) RTTs, Sept. 2019

Category-based comparison

IP and AS hops:
- IPv6 clear winner
- Not much change

RTTs:
- Except top-100, significant increase in IPv6 winners

(a) IP hops, May 2019

(b) IP hops, Sept. 2019

(c) AS hops, May 2019

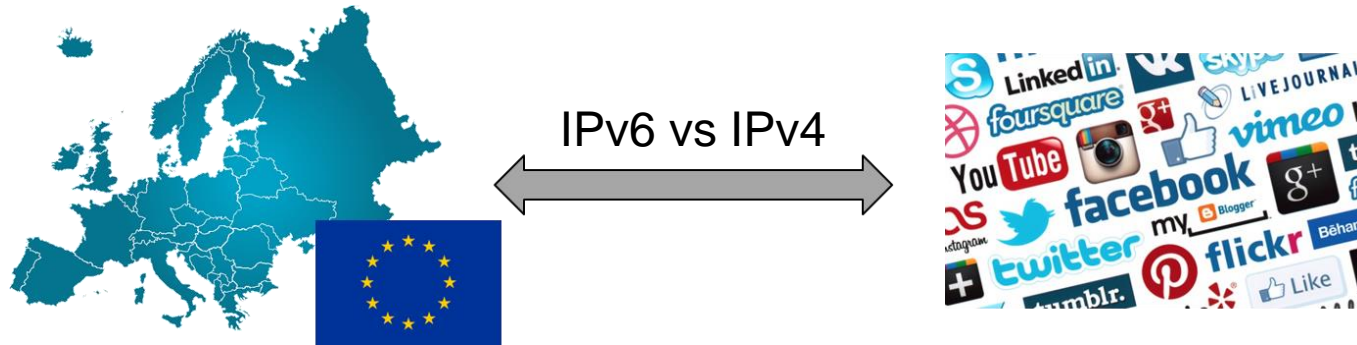(d) AS hops, Sept. 2019

(e) RTTs, May 2019
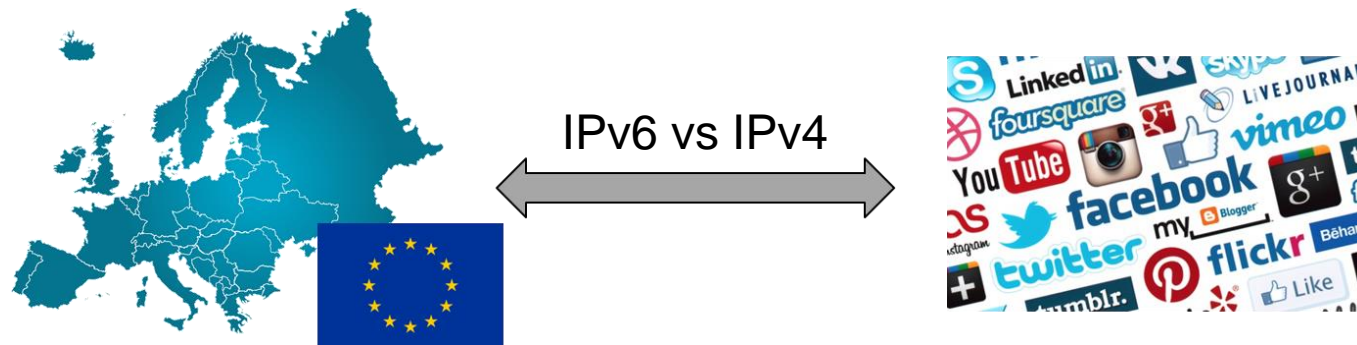
(f) RTTs, Sept. 2019

Conclusions

Summary and conclusions

IPv6 vs IPv4

- First report on using IPv6 for experiments on PlanetLab Europe

Summary and conclusions

IPv6 vs IPv4

- First report on using IPv6 for experiments on PlanetLab Europe

- Hypothesis-based methodology and the results from applying this on datasets collected using traceroutes from PlanetLab Europe nodes

Summary and conclusions

IPv6 vs IPv4

- First report on using IPv6 for experiments on PlanetLab Europe

- Hypothesis-based methodology and the results from applying this on datasets collected using traceroutes from PlanetLab Europe nodes

- Findings shows (among other things) that
  - IPv6 paths currently faster than the corresponding IPv4 paths, and
  - pairings for which this is the case is quickly increasing across a wide range of domain popularities and domain categories
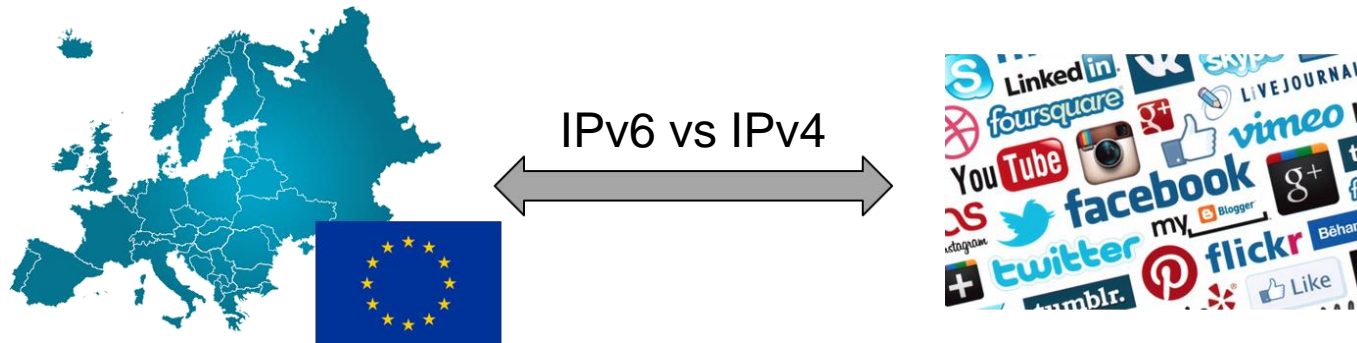
Summary and conclusions

IPv6 vs IPv4

- First report on using IPv6 for experiments on PlanetLab Europe

- Hypothesis-based methodology and the results from applying this on datasets collected using traceroutes from PlanetLab Europe nodes

- Findings shows (among other things) that
  - IPv6 paths currently faster than the corresponding IPv4 paths, and
  - pairings for which this is the case is quickly increasing across a wide range of domain popularities and domain categories

- Findings suggest that there is incentive to use IPv6 …
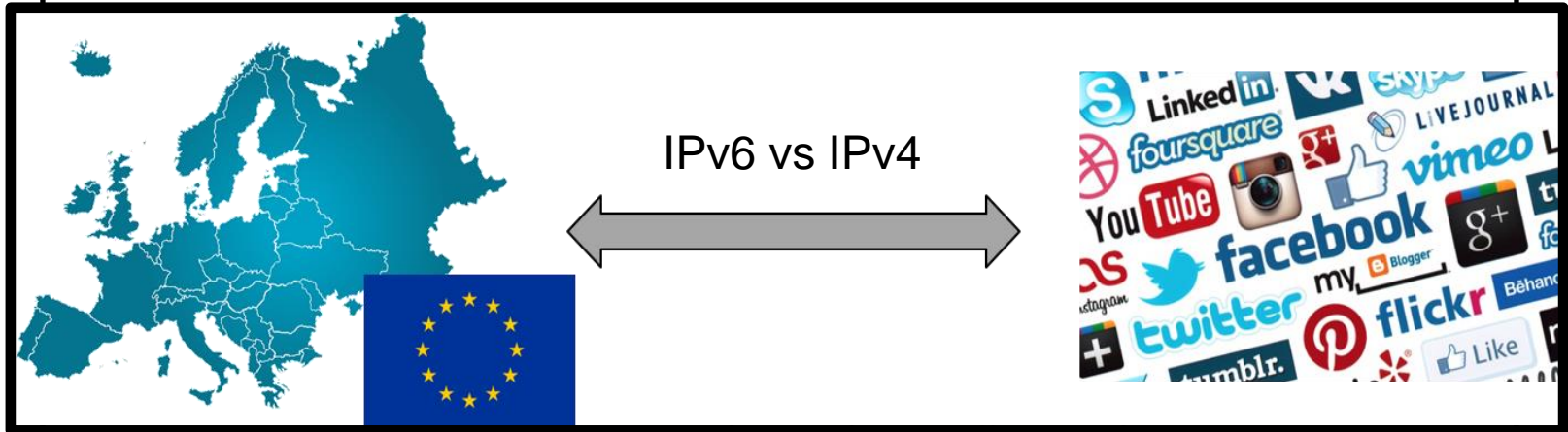
  … which may impact the rate of further IPv6 deployment!

Paper online!

Hypothesis-based Comparison of IPv6 and IPv4 Path Distances

David Hasselquist[1], Christian Wahl[1,2], Otto Bergdal[1], and Niklas Carlsson[1]

[1]Linköping University, Sweden
[2]Technische Universität München, Germany

IPv6 vs IPv4

PlanetLab, highlights the lack of IP support among PlanetLab nodes
and limitations of state-of-the-art traceroute tools used for IPv6 mea-

LINKÖPING UNIVERSITY

Niklas Carlsson (niklas.carlsson@liu.se)