Understanding the Impact of Network Infrastructure Changes using Large Scale Measurement Platforms

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This thesis would not have been possible without these amazing people!

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Introduction | Motivation

- Large-scale Internet Measurement Platform

  An infrastructure of dedicated hardware probes that periodically runs Internet measurement tests to satisfy specific use-case requirements.

- Use-cases

  Since '98: Topology Mapping (Mature)

  CAIDA Ark [1], DIMES [2], iPlane [3] *et al.*

  Since '08: Network Performance

  SamKnows [4], BISmark [5], RIPE Atlas [6, 4], PerfSONAR [4] *et al.*

  - Measure performance and reliability of *broadband* access networks
  - Facilitate *regulators* to make better policy decisions.

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- This dissertation *expands* the goal:

  Since '98: Topology Mapping

  Since '08: Network Performance

  - Measure performance and reliability of *broadband* access networks
  - Facilitate *regulators* to make better policy decisions.
  - Understand the impact of *network infrastructure changes*

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1. Measuring IPv6 Performance
2. Measuring Access Network Performance

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1. Survey on Internet Performance Measurement Platforms [COMST '15]

2. Measuring IPv6 Performance
   - Measuring TCP Connect Times [NETWORKING '15]
   - Measuring YouTube Performance [PAM '15]
   - Measuring Effects of Happy Eyeballs [ANRW '16]
   - Measuring Web Similarity [CNSM '16]

3. Measuring Access Network Performance
   - RIPE Atlas Vantage Point Selection [*]
   - Dissecting Last-mile Latency Characteristics [*]
   - Lessons Learned from using RIPE Atlas [CCR '15]

* entries are papers currently under review.

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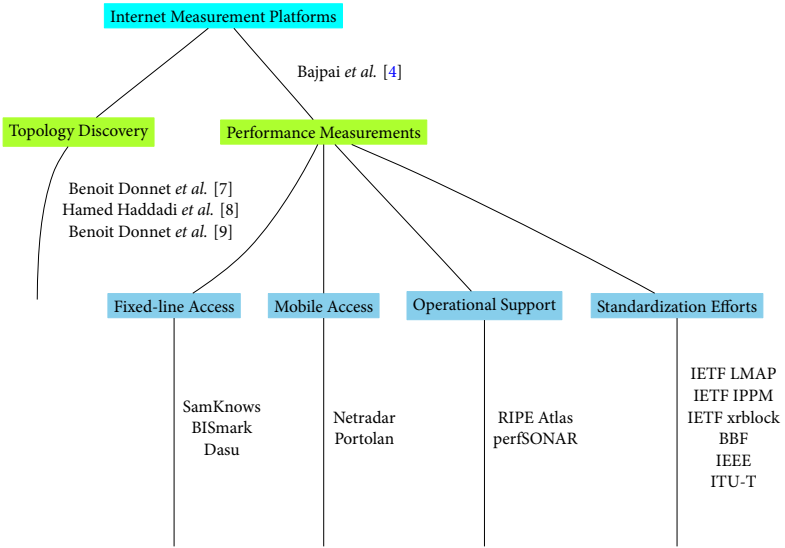
Part I



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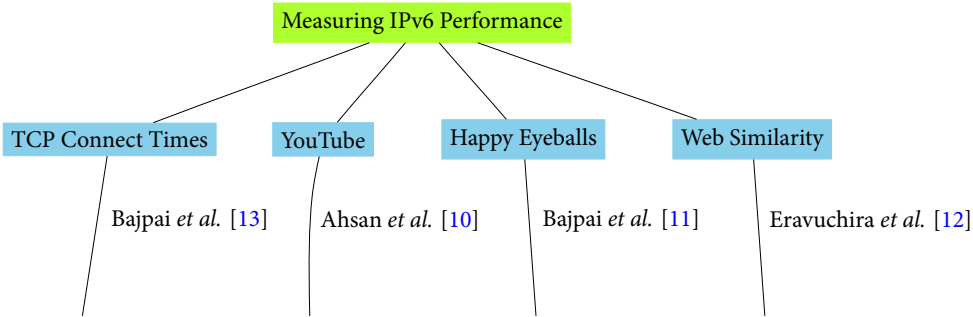
Part II | Overview



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Part II | Motivation

- Literature has *largely* focussed on measuring IPv6 adoption [14, 15, 16] ('10 –'14).
  - Addressing
  - Naming
  - Routing
  - Reachability
- Very little work [17] on measuring performance of service delivery over IPv6.
- Largely due to lack of available content over IPv6.
- A number of *significant* events occured during the span of this dissertation.
  - IANA IPv4 Address Exhaustion [18]
  - World IPv6 Day '11 [19]
  - World IPv6 Launch Day '12 [20]
  - RIR IPv4 Address Exhaustion [18]

APNIC	Apr'11
RIPE	Sep'12
LACNIC	Jun'14
ARIN	Sep'15

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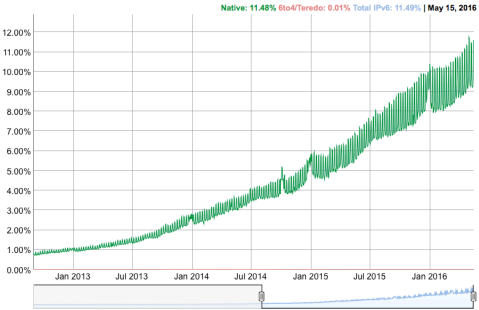
Part II | Motivation

- Large IPv6 broadband rollouts[1] [13].
- Global IPv6 adoption [21].

09/2012 0.85%
05/2016 11.48%

Belgium	40.49%
Switzerland	27.38%
United States	23.62%
Germany	21.41%



- This study *closes* the gap.
- It measures IPv6 performance of *operational* dual-stacked content delivery services.

[1] Comcast, Deutsche Telekom AG, AT&T, Verizon Wireless, T-Mobile USA

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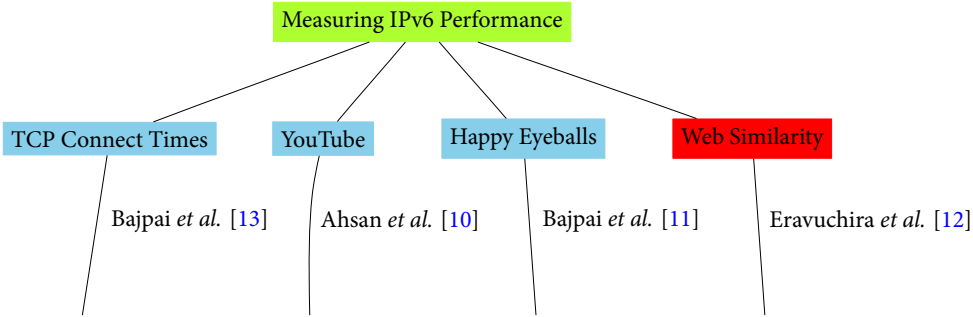

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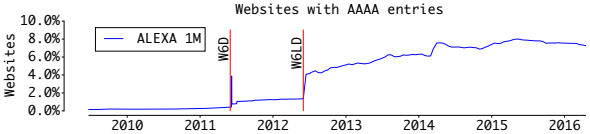
Web Similarity | Introduction

Recent work [13], [17], [15] has compared performance of dual-stacked websites over IPv4 and IPv6.

No study comparing web similarity over IPv4 / IPv6.



http://www.employees.org/~dwing/aaaa-stats

We want to know:

- *How similar are webpages accessed over IPv6 to their IPv4 counterparts?*
- *What factors contribute to the dissimilarity over IPv4 and IPv6?*

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Web Similarity | Introduction

We measure against ALEXA top 100 dual-stacked websites.

1. `simweb` : A tool for measuring web similarity over IPv4 and IPv6.
2. Websites (27%) have some fraction of webpage elements failing over IPv6.
3. Failure rates over IPv6 are largely due to DNS resolution error on images, js and CSS.
4. Both same-origin and cross-origin sources contribute to the failure rates over IPv6.

To the best of our knowledge, this is the first study to:

- *Measure webpage similarity over IPv4 and IPv6.*
- *Investigate IPv6 adoption that goes beyond the root page of a dual-stacked website.*

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We use 2 well-known webpage complexity metrics from literature [22, 23]:

1. Content Complexity
   The number & size of fetched webpage elements.

2. Service Complexity
   The number of same-origin & cross-origin sources.

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- We use the ALEXA top 100 dual-stacked websites as measurement targets [13].

1. www.google.com
2. www.facebook.com
3. www.youtube.com
4. www.yahoo.com
5. www.wikipedia.org
6. www.qq.com
7. www.blogspot.com
8. ...

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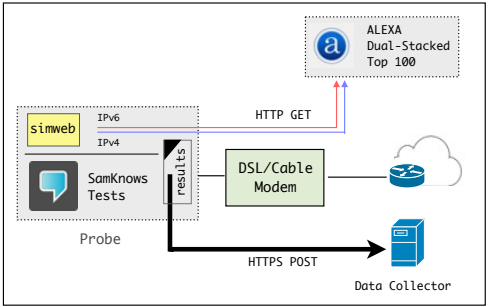
The `simweb` test:

- runs twice (once for each AF).
- repeats every hour.
- uses user-agent string: `Mozilla/4.0`



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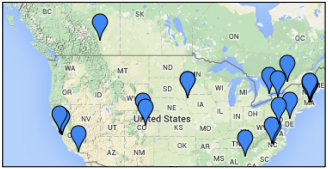

NETWORK TYPE	#
RESIDENTIAL	55
NREN / RESEARCH	11
BUSINESS / DATACENTER	09
OPERATOR LAB	04
IXP	01

RIR	#
RIPE	42
ARIN	29
APNIC	07
AFRINIC	01
LACNIC	01

We measure from 80 dual-stacked SamKnows probes.

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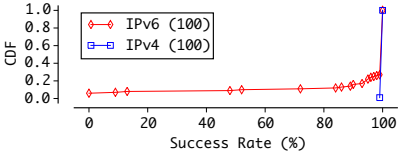
Can we fetch all webpage elements over IPv6?

- 27% of websites show some rate of failure over IPv6.
- 9% exhibit more than 50% failures over IPv6.
- 6% show complete failure (0% success) over IPv6.



#	Webpage	Success Rate (%) IPv6(↓)	Success Rate (%) IPv4	W6LD
01	www.bing.com	0	100	✓
02	www.detik.com	0	100	✓
03	www.engadget.com	0	100	✓
04	www.nifty.com	0	100	
05	www.qq.com	0	100	
06	www.sakura.ne.jp	0	100	
07	www.flipkart.com	09	99	✓
08	www.folha.uol.com.br	13	100	
09	www.aol.com	48	100	✓
10	www.comcast.net	52	100	✓
11	www.yahoo.com	72	100	✓
12	www.mozilla.org	84	100	✓
13	www.orange.fr	86	100	✓
14	www.seznam.cz	89	100	✓
15	www.mobile.de	90	100	✓
16	www.wikimedia.org	90	100	
17	www.t-online.de	93	100	✓
18	www.free.fr	95	100	
19	www.usps.com	95	100	
20	www.vk.com	95	100	✓
21	www.wikipedia.org	95	100	✓
22	www.wiktionary.org	95	100	
23	www.elmundo.es	96	100	✓
24	www.uol.com.br	96	100	✓
25	www.marca.com	97	100	✓
26	www.terra.com.br	98	100	✓
27	www.youm7.com	99	100	

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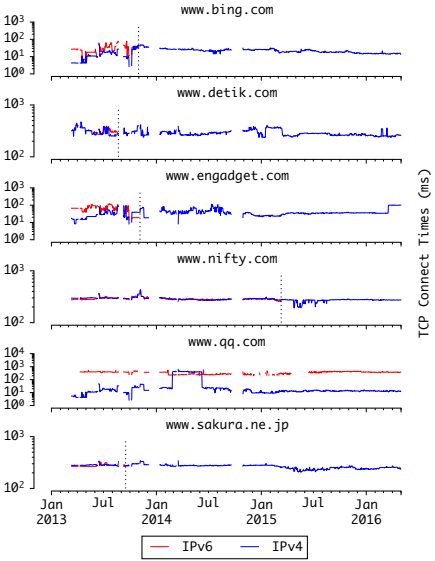
ALEXA top 100 dual-stacked websites:

- 6% show complete failure over IPv6.

#	Webpage	Success Rate (%) IPv6(↓)	Success Rate (%) IPv4	W6LD
01	www.bing.com	0	100	✓
02	www.detik.com	0	100	✓
03	www.engadget.com	0	100	✓
04	www.nifty.com	0	100	
05	www.qq.com	0	100	
06	www.sakura.ne.jp	0	100	

- Metrics that measure IPv6 adoption should account for *changes* in IPv6-readiness.



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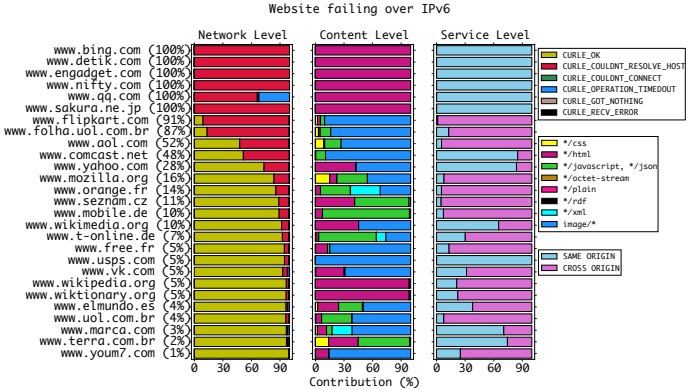
Where in the network does the failure occur?



- `CURLE_COULDNT_RESOLVE_HOST` is the major contributor to failure rates.
- AAAA entries missing for these webpage elements in the DNS.

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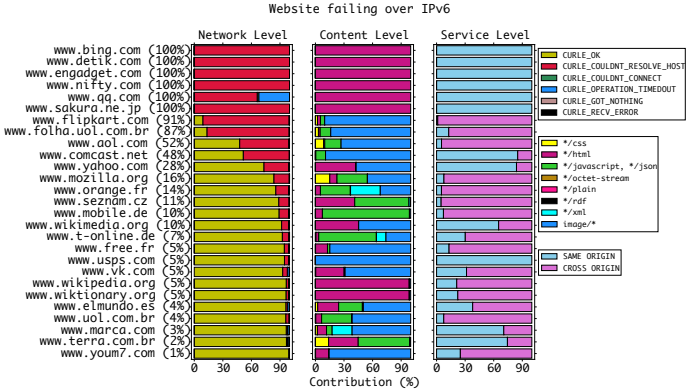
Which type of objects fail more than others?



- `image/*`, `*/javascript`, `*/json` and `*/css` content contribute to the majority of the failure over IPv6.

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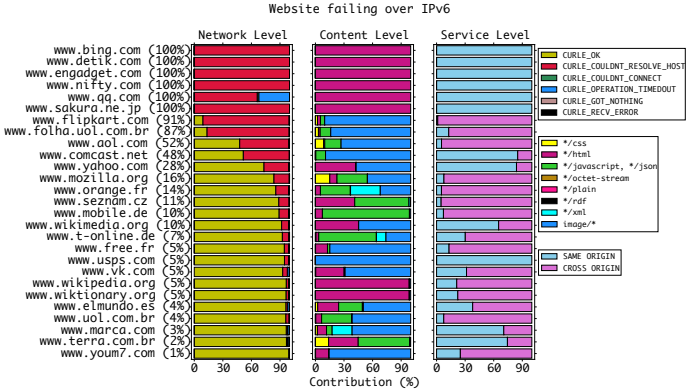
Where do the failing objects originate from?



- Both same and cross origin sources contribute to the failure of webpage elements over IPv6.

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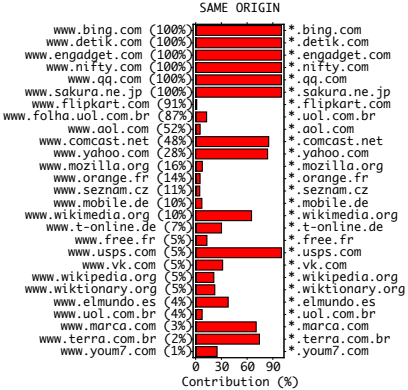
What is failure contribution of same-origin sources?



- 12% of websites have more than 50% webpage elements that belong to the same origin source and fail over IPv6.

#	Webpage	Same Origin (↓)
01	www.bing.com	100%
02	www.detik.com	100%
03	www.engadget.com	100%
04	www.nifty.com	100%
05	www.usps.com	100%
06	www.qq.com	100%
07	www.sakura.ne.jp	100%
08	www.comcast.net	85%
09	www.yahoo.com	83%
10	www.terra.com.br	74%
11	www.marca.com	70%
12	www.wikimedia.org	65%
13	www.elmundo.es	37%
14	www.vk.com	31%
15	www.t-online.de	30%
16	www.youm7.com	24%
17	www.wiktionary.org	22%
18	www.wikipedia.org	22%
19	www.free.fr	13%
20	www.folha.uol.com.br	12%
21	www.mozilla.org	7%
22	www.uol.com.br	7%
23	www.mobile.de	7%
24	www.aol.com	5%
25	www.orange.fr	5%
26	www.seznam.cz	4%
27	www.flipkart.com	1%

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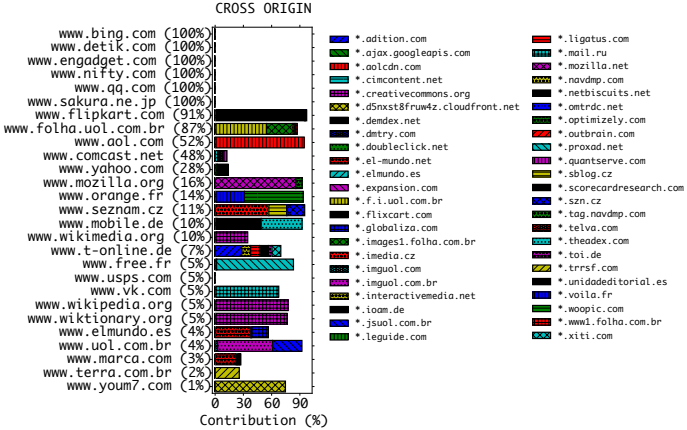
What is failure contribution of cross-origin sources?



- Some of the cross-origin sources contribute to the failure of multiple websites.

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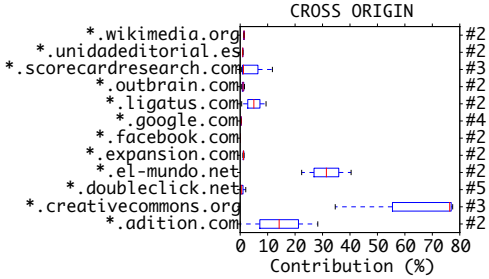
Which cross-origin sources span across multiple failing websites?



CROSS ORIGIN	MEDIAN
*.creativecommons.org	76.33%
*.el-mundo.net	31.41%
*.adition.com	14.20%
*.ligatus.com	4.98%
*.wikimedia.org	1.40%
*.expansion.com	1.21%
*.scorecardresearch.com	1.19%
*.outbrain.com	1.06%
*.unidadeditorial.es	0.94%
*.doubleclick.net	0.54%
*.google.com	0.31%
*.facebook.com	0.06%

- doubleclick.net spans 5 websites with a 0.54% median contribution to failure rates.
- creativecommons.org has 76% median contribution to the failure rate of 3 websites.

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- Metrics that measure IPv6 adoption should account for changes in IPv6-readiness.
- Limiting to root webpage can lead to overestimation of IPv6 adoption numbers.
- Unclear whether websites with failure rates can be deemed IPv6-ready.
- Few cross-origin sources once IPv6 enabled will help large number of websites at once.

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   - Lessons Learned from using RIPE Atlas [CCR '15]

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