

IPv4 versus IPv6 - Who connects faster?

IFIP Networking 2015 Conference, Toulouse

Vaibhav Bajpai

v.bajpai@jacobs-university.de

Jürgen Schönwälder

j.schoenwaelder@jacobs-university.de

Computer Networks and Distributed Systems Group,
Jacobs University Bremen, Bremen, Germany

May 2015

Introduction

Motivation

Research Question

Research Contributions

Methodology

Metrics

Selection of Websites

Measurement Setup

Measurement Trial

Data Analysis

TCP Connect Times

Website Clusters

Comparing by CDN

Special Cases

Conclusion

References

Appendix

Comparing by Network Type

- ▶ Large IPv6 broadband rollouts¹ since World IPv6 Launch Day in 2012.
- ▶ Increased global adoption of IPv6 to 6% (as seen by Google, May 2015).

Recent research [1] (2014) has shown:

- ▶ 3.5% of top 10K ALEXA websites announce AAAA in DNS.
- ▶ 3.2% of top 10K ALEXA websites reachable over IPv6.

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

Introduction

Motivation

Research Question

Research Contributions

Methodology

Metrics

Selection of Websites

Measurement Setup

Measurement Trial

Data Analysis

TCP Connect Times

Website Clusters

Comparing by CDN

Special Cases

Conclusion

References

Appendix

Comparing by Network Type

Introduction

Motivation

Research Question

Research Contributions

Methodology

Metrics

Selection of Websites

Measurement Setup

Measurement Trial

Data Analysis

TCP Connect Times

Website Clusters

Comparing by CDN

Special Cases

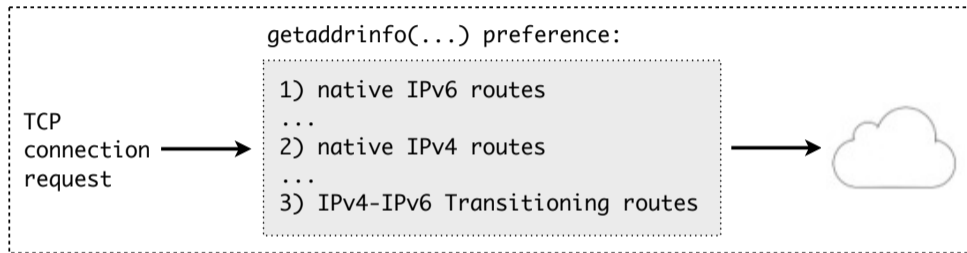
Conclusion

References

Appendix

Comparing by Network Type

Do users experience benefit (or an added penalty) when connecting to websites over IPv6?



- ▶ Returns a list of endpoints in an order that prioritizes an IPv6-upgrade path.
- ▶ The order is dictated by RFC 6724 [2] and `/etc/gai.conf`

Introduction

Motivation

Research Question

Research Contributions

Methodology

Metrics

Selection of Websites

Measurement Setup

Measurement Trial

Data Analysis

TCP Connect Times

Website Clusters

Comparing by CDN

Special Cases

Conclusion

References

Appendix

Comparing by Network Type

- ▶ Websites cluster around CDN deployments and show similar performance.
- ▶ CDN clusters are different over IPv4 and IPv6.
- ▶ CDN caches are largely absent over IPv6.
- ▶ TCP connect times to IPv6 CDN clusters have improved over time.
- ▶ IPv6 services from `www.bing.com` have stopped globally since 2013.
- ▶ Google CDN blacklists some resolvers over IPv6.

To the best of our knowledge, this is the first study to compare TCP connect times of top dual-stacked websites over IPv4 and IPv6.

Introduction

Motivation

Research Question

Research Contributions

Methodology

Metrics

Selection of Websites

Measurement Setup

Measurement Trial

Data Analysis

TCP Connect Times

Website Clusters

Comparing by CDN

Special Cases

Conclusion

References

Appendix

Comparing by Network Type

Methodology

Introduction

Motivation

Research Question

Research Contributions

Methodology

Metrics

Selection of Websites

Measurement Setup

Measurement Trial

Data Analysis

TCP Connect Times

Website Clusters

Comparing by CDN

Special Cases

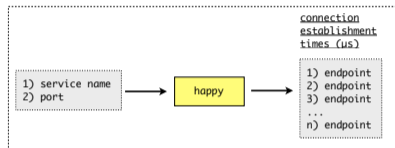
Conclusion

References

Appendix

Comparing by Network Type

- ▶ Uses `getaddrinfo(...)` to resolve service names.
- ▶ Uses non-blocking TCP `connect(...)` calls.
- ▶ DNS resolution time is not accounted.
- ▶ Can read multiple service names as arguments.
- ▶ Can read service names list from a file.
- ▶ File locking capability.
- ▶ Sets a delay between `connect(...)`; avoids SYN floods.
- ▶ Can produce both human-readable & CSV output.
- ▶ Cross-compiled for OpenWrt; Running on SamKnows.



happy.vaibhavbajpai.com.

```
% happy -q 1 -m www.google.com www.facebook.com  
HAPPY.0;1360681039;OK;www.google.com;80;173.194.69.105;8626  
HAPPY.0;1360681039;OK;www.google.com;80;2a00:1450:4008:c01::69;8884
```

Introduction

Motivation

Research Question

Research Contributions

Methodology

Metrics

Selection of Websites

Measurement Setup

Measurement Trial

Data Analysis

TCP Connect Times

Website Clusters

Comparing by CDN

Special Cases

Conclusion

References

Appendix

Comparing by Network Type

- ▶ Hurricane Electric (HE) maintains a top 100 dual-stacked service names list².
 - ▶ HE uses top 1M service names list from Alexa Top Sites (ATS)
 - ▶ HE does not follow CNAMEs.

- ▶ Amazon has made the ATS top 1M service names list public³.
 - ▶ Prepared a custom top 100 dual-stacked service names list.
 - ▶ Explicitly follow CNAMEs.
 - ▶ Prepend a www to each service name and cross-check any AAAA response.

²<http://bgp.he.net/ipv6-progress-report.cgi>

³<http://s3.amazonaws.com/alexa-static/top-1m.csv.zip>

Introduction

Motivation

Research Question

Research Contributions

Methodology

Metrics

Selection of Websites

Measurement Setup

Measurement Trial

Data Analysis

TCP Connect Times

Website Clusters

Comparing by CDN

Special Cases

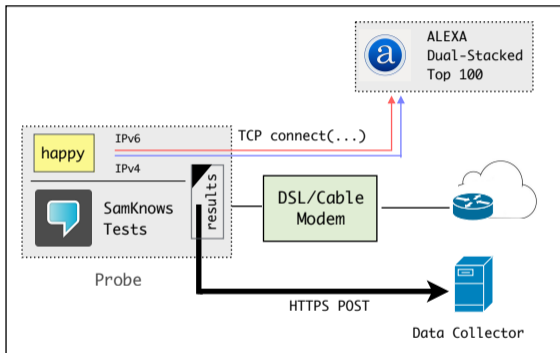
Conclusion

References

Appendix

Comparing by Network Type

- ▶ Frequency: Every hour.
- ▶ Duration: Feb 2013 - Present



Introduction

Motivation

Research Question

Research Contributions

Methodology

Metrics

Selection of Websites

Measurement Setup

Measurement Trial

Data Analysis

TCP Connect Times

Website Clusters

Comparing by CDN

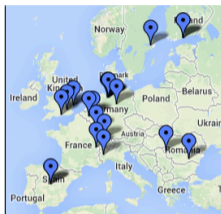
Special Cases

Conclusion

References

Appendix

Comparing by Network Type



TYPE	IPv4 AS	IPv6 AS	LOCATION	PROVIDER	ID
RESIDENTIAL	AS31334	AS31334	BREMEN	KABELDEUTSCHLAND	#02
RESIDENTIAL	AS3320	AS3320	BREMEN	DEUTSCHE TELEKOM	#04
RESIDENTIAL	AS50989	AS1257	STOCKHOLM	SITAB	#11
RESIDENTIAL	AS4685	AS4718	FUKUOKA	ASAHI NET	#12
RESIDENTIAL	AS12715	AS12715	MADRID	JAZZ TELECOM	#13
RESIDENTIAL	AS9031	AS9031	ALLEUR	EDPNET	#17
RESIDENTIAL	AS3320	AS3320	BREMEN	DEUTSCHE TELEKOM	#19
RESIDENTIAL	AS2518	AS2516	SHIZUOKA	BIGLOBE NEC	#20
RESEARCH	AS513	AS513	CERN	CERN	#16
NREN	AS680	AS680	BREMEN	DFN	#01
NREN	AS2614	AS2614	TIMISOARA	ROEDUNET	#08
NREN	AS2611	AS2611	LOUVAIN	BELNET	#15
NREN	AS680	AS680	BREMEN	DFN	#18
LAB	AS5607	AS5607	LONDON	BSKYB-BROADBAND	#05
LAB	AS3269	AS3269	TORINO	TELECOM ITALIA	#06
LAB	AS8903	AS8903	MADRID	BT ESPANA	#07
LAB	AS2856	AS5400	IPSWICH	BT UK	#10
IXP	AS18070	AS18070	NIIGATA	NDAC	#14
BUSINESS	AS24956	AS24956	BRAUNSCHWEIG	GAERTNER DATENSYSTEME	#03
BUSINESS	AS13030	AS13030	OLTEN	INIT SEVEN	#09

Introduction

Motivation

Research Question

Research Contributions

Methodology

Metrics

Selection of Websites

Measurement Setup

Measurement Trial

Data Analysis

TCP Connect Times

Website Clusters

Comparing by CDN

Special Cases

Conclusion

References

Appendix

Comparing by Network Type

*Data Analysis*⁴

Introduction

Motivation

Research Question

Research Contributions

Methodology

Metrics

Selection of Websites

Measurement Setup

Measurement Trial

Data Analysis

TCP Connect Times

Website Clusters

Comparing by CDN

Special Cases

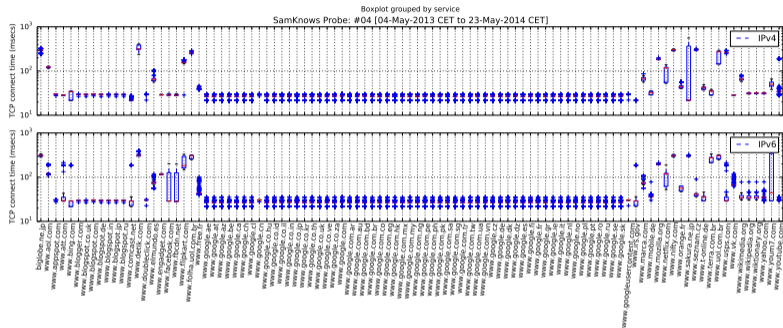
Conclusion

References

Appendix

Comparing by Network Type

⁴The results are derived from year-long measurements conducted between Feb 2013 – July 2014.



- ▶ Several websites⁵ show similar performance over IPv4/IPv6.
- ▶ Some disparate websites⁶ appear faster over IPv4.
- ▶ Some websites⁷ show substantially higher variance over IPv6.

⁵ www.google.*, www.blogspot.*

⁶ www.att.com, www.comcast.net, www.irs.gov (Akamai CDN)

⁷ www.facebook.com, www.fbcdn.net (Facebook CDN) and www.youm7.com (Cloudflare CDN)

Introduction

Motivation

Research Question

Research Contributions

Methodology

Metrics

Selection of Websites

Measurement Setup

Measurement Trial

Data Analysis

TCP Connect Times

Website Clusters

Comparing by CDN

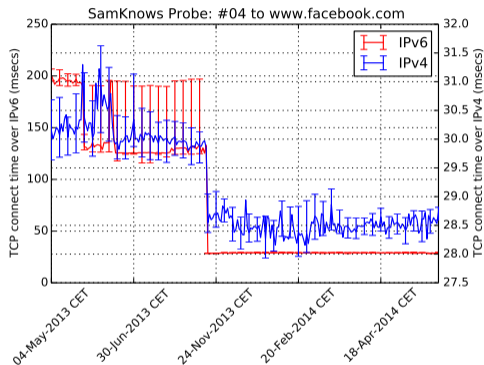
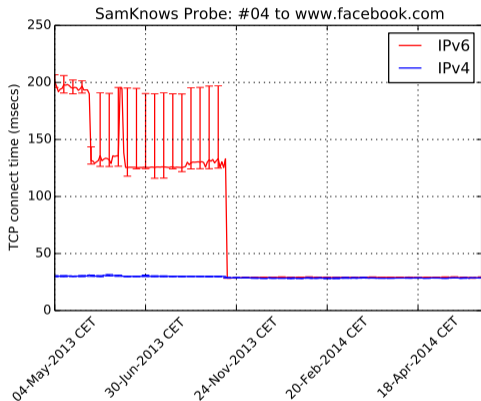
Special Cases

Conclusion

References

Appendix

Comparing by Network Type



- ▶ TCP connect times to Facebook CDN over IPv6 have improved over time.

Introduction

- Motivation
- Research Question
- Research Contributions

Methodology

- Metrics
- Selection of Websites
- Measurement Setup
- Measurement Trial

Data Analysis

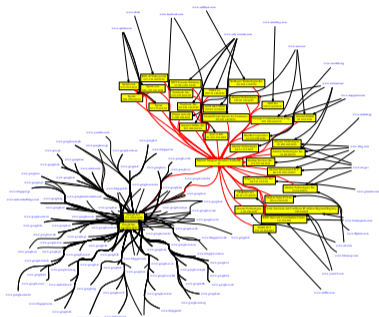
- TCP Connect Times
- Website Clusters
- Comparing by CDN
- Special Cases

Conclusion

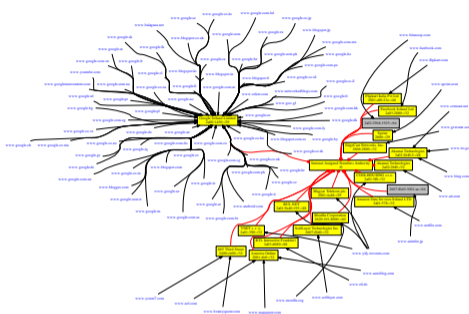
References

Appendix

- Comparing by Network Type



IPv4 WHOIS cloud



IPv6 WHOIS cloud

- ▶ Endpoints serving popular websites map to address blocks owned by Google/Akamai.
- ▶ WHOIS-based aggregated clusters are coarse-grained.

Introduction

Motivation

Research Question

Research Contributions

Methodology

Metrics

Selection of Websites

Measurement Setup

Measurement Trial

Data Analysis

TCP Connect Times

Website Clusters

Comparing by CDN

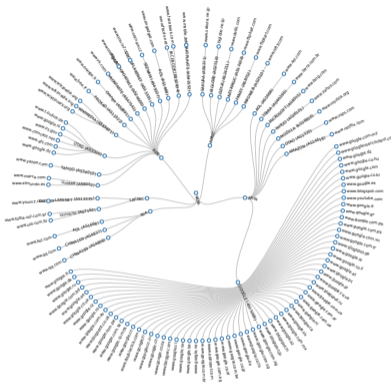
Special Cases

Conclusion

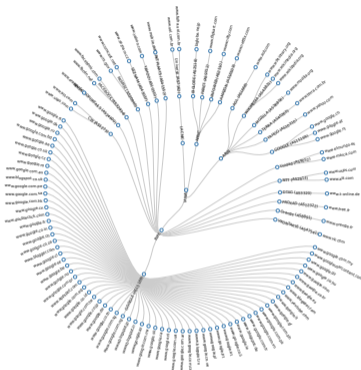
References

Appendix

Comparing by Network Type



IPv4 BGP cloud



IPv6 BGP cloud

- ▶ Akamai caches serve popular websites directly from within DTAG over IPv4.
- ▶ Akamai caches missing over IPv6 (served instead by Akamai CDN).

Introduction

Motivation

Research Question

Research Contributions

Methodology

Metrics

Selection of Websites

Measurement Setup

Measurement Trial

Data Analysis

TCP Connect Times

Website Clusters

Comparing by CDN

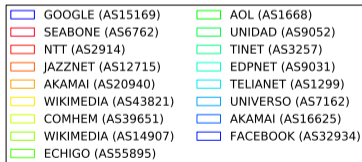
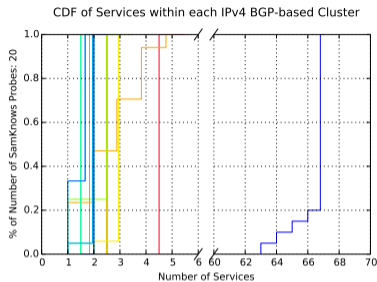
Special Cases

Conclusion

References

Appendix

Comparing by Network Type



IPv4 Cluster	#(↓)
GOOGLE (AS15169)	67
SEABONE (AS6762)	05
NTT (AS2914)	03
JAZZNET (AS12715)	03
AKAMAI (AS20940)	03
WIKIMEDIA (AS43821)	03
COMHEM (AS39651)	03
WIKIMEDIA (AS14907)	03
ECHIGO (AS55895)	02
AOL (AS1668)	02
UNIDAD (AS9052)	02
TINET (AS3257)	02
EDPNET (AS9031)	02
TELIANET (AS1299)	02
UNIVERSO (AS7162)	02
AKAMAI (AS16625)	02
FACEBOOK (AS32934)	02

- ▶ CDN caches serve popular websites over IPv4 from within service provider's network.

Introduction

Motivation

Research Question

Research Contributions

Methodology

Metrics

Selection of Websites

Measurement Setup

Measurement Trial

Data Analysis

TCP Connect Times

Website Clusters

Comparing by CDN

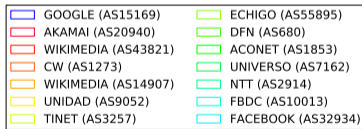
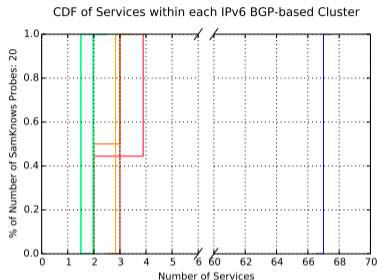
Special Cases

Conclusion

References

Appendix

Comparing by Network Type



IPv6 Cluster	#(↓)
GOOGLE (AS15169)	67
AKAMAI (AS20940)	04
WIKIMEDIA (AS43821)	03
CW (AS1273)	03
WIKIMEDIA (AS14907)	03
UNIDAD (AS9052)	02
TINET (AS3257)	02
ECHIGO (AS55895)	02
DFN (AS680)	02
ACONET (AS1853)	02
UNIVERSO (AS7162)	02
NTT (AS2914)	02
FBDC (AS10013)	02
FACEBOOK (AS32934)	02

- ▶ CDN caches over IPv6 are largely absent.

Introduction

- Motivation
- Research Question
- Research Contributions

Methodology

- Metrics
- Selection of Websites
- Measurement Setup
- Measurement Trial

Data Analysis

- TCP Connect Times
- Website Clusters
- Comparing by CDN
- Special Cases

Conclusion

References

Appendix

- Comparing by Network Type

- ▶ Several websites show similar performance over IPv4/IPv6.
...because they cluster around a CDN.
- ▶ Some websites show higher variance over IPv6
...because TCP connect times over IPv6 have improved over time.
- ▶ Some websites appear faster over IPv4
...because they are served by CDN caches over IPv4.
...CDN caches over IPv6 are largely absent.

Introduction

Motivation

Research Question

Research Contributions

Methodology

Metrics

Selection of Websites

Measurement Setup

Measurement Trial

Data Analysis

TCP Connect Times

Website Clusters

Comparing by CDN

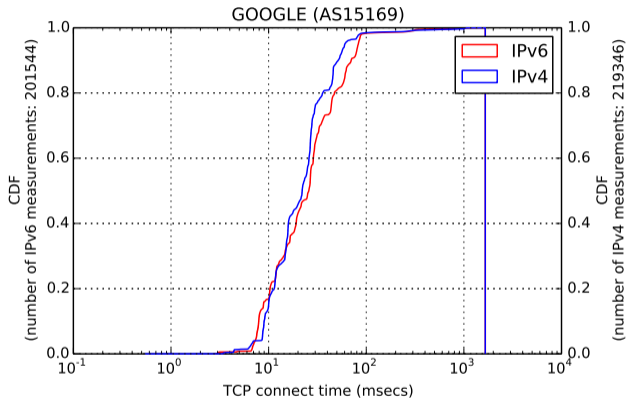
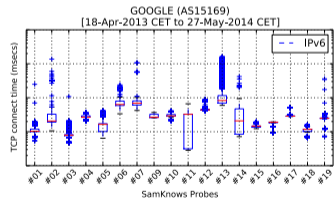
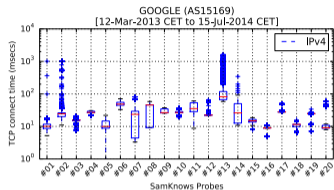
Special Cases

Conclusion

References

Appendix

Comparing by Network Type



- ▶ Who connects faster? - IPv6 appears comparable to IPv4.

Introduction

- Motivation
- Research Question
- Research Contributions

Methodology

- Metrics
- Selection of Websites
- Measurement Setup
- Measurement Trial

Data Analysis

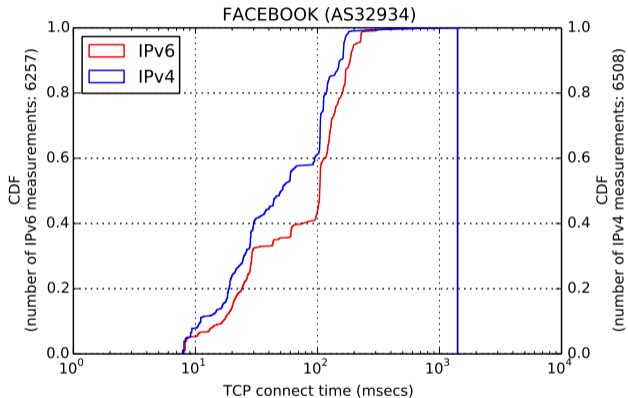
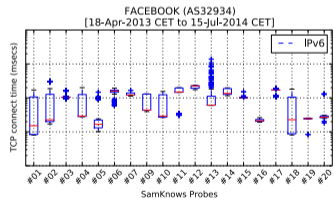
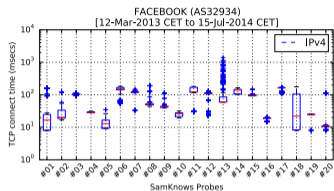
- TCP Connect Times
- Website Clusters
- Comparing by CDN
- Special Cases

Conclusion

References

Appendix

- Comparing by Network Type



► Who connects faster? - IPv6 slower to IPv4.

Introduction

- Motivation
- Research Question
- Research Contributions

Methodology

- Metrics
- Selection of Websites
- Measurement Setup
- Measurement Trial

Data Analysis

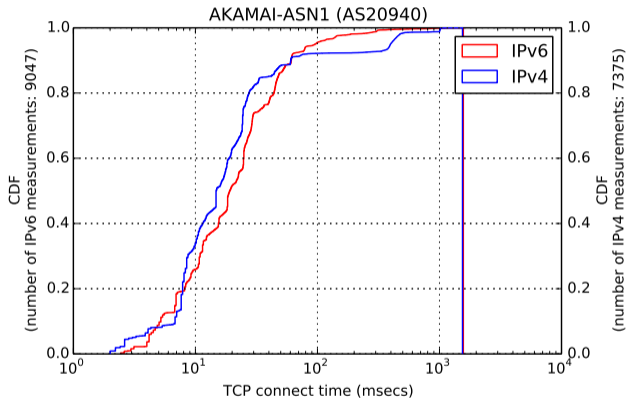
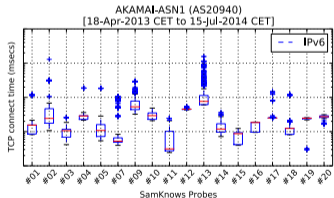
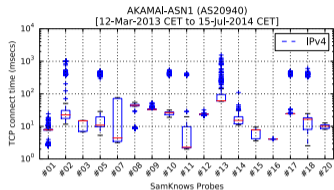
- TCP Connect Times
- Website Clusters
- Comparing by CDN
- Special Cases

Conclusion

References

Appendix

- Comparing by Network Type



► Who connects faster? - IPv6 slower to IPv4.

Introduction

- Motivation
- Research Question
- Research Contributions

Methodology

- Metrics
- Selection of Websites
- Measurement Setup
- Measurement Trial

Data Analysis

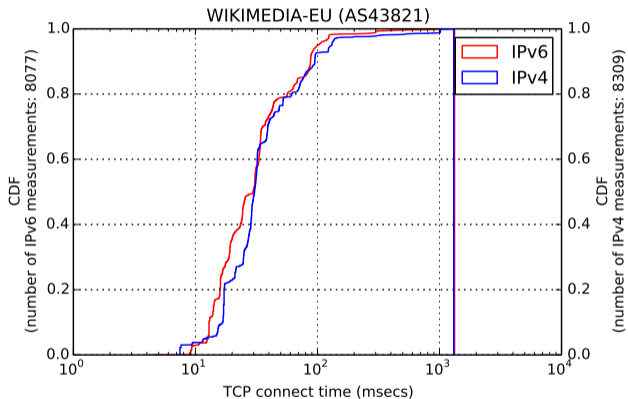
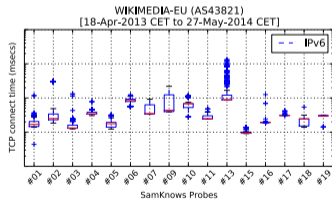
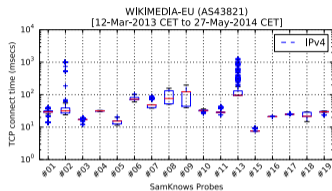
- TCP Connect Times
- Website Clusters
- Comparing by CDN
- Special Cases

Conclusion

References

Appendix

- Comparing by Network Type



- ▶ Who connects faster? - IPv6 faster to IPv4.

Introduction

- Motivation
- Research Question
- Research Contributions

Methodology

- Metrics
- Selection of Websites
- Measurement Setup
- Measurement Trial

Data Analysis

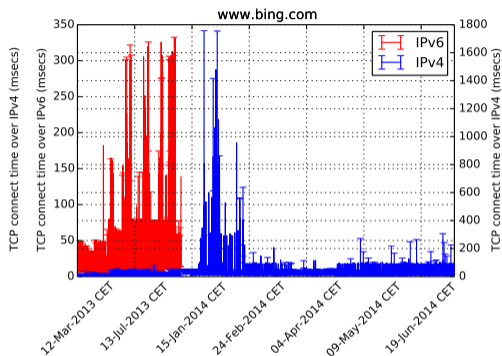
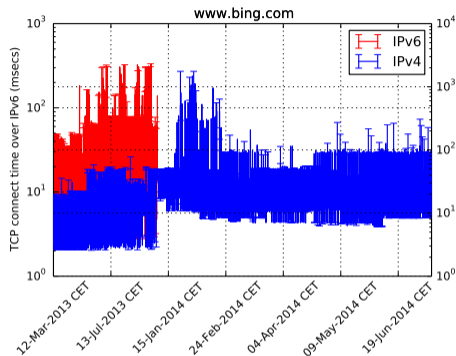
- TCP Connect Times
- Website Clusters
- Comparing by CDN
- Special Cases

Conclusion

References

Appendix

- Comparing by Network Type



- ▶ No IPv6 measurements to `www.bing.com` starting Sep 2013.
- ▶ Abrupt cut-off hinting towards a network policy decision.
- ▶ Upstream resolvers do not provide a AAAA entry for `www.bing.com`.

Introduction

- Motivation
- Research Question
- Research Contributions

Methodology

- Metrics
- Selection of Websites
- Measurement Setup
- Measurement Trial

Data Analysis

- TCP Connect Times
- Website Clusters
- Comparing by CDN
- Special Cases

Conclusion

References

Appendix

- Comparing by Network Type

Introduction

Motivation
Research Question
Research Contributions

Methodology

Metrics
Selection of Websites
Measurement Setup
Measurement Trial

Data Analysis

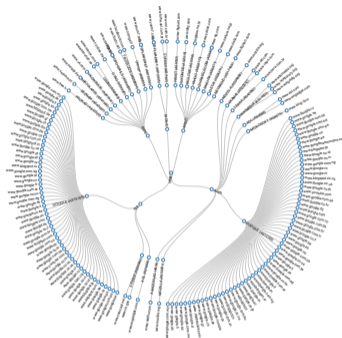
TCP Connect Times
Website Clusters
Comparing by CDN
Special Cases

Conclusion

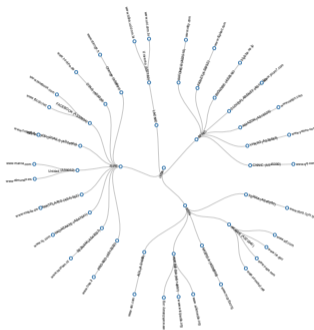
References

Appendix

Comparing by Network Type



IPv4 BGP cloud



IPv6 BGP cloud

- ▶ A Japanese probe running no IPv6 measurements to websites served by Google CDN.
- ▶ Google used to perform AAAA prefix whitelisting [3].
- ▶ Since World IPv6 Launch Day (2012), Google has changed this policy.



<http://googleipv6.vaibhavbajpai.com>

- ▶ The whitelist has been replaced by a blacklist.
- ▶ Eliminates the opt-in process; increases chances of reaching Google services over IPv6.

Introduction

- Motivation
- Research Question
- Research Contributions

Methodology

- Metrics
- Selection of Websites
- Measurement Setup
- Measurement Trial

Data Analysis

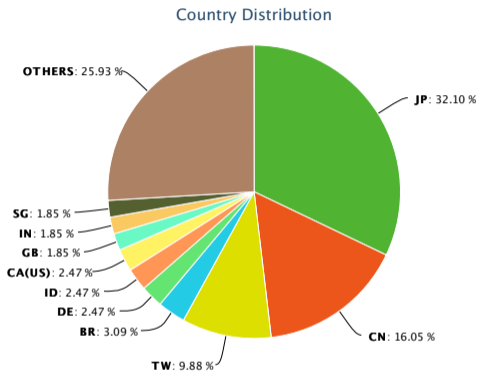
- TCP Connect Times
- Website Clusters
- Comparing by CDN
- Special Cases

Conclusion

References

Appendix

- Comparing by Network Type



Highcharts.com

- ▶ A large number of blacklisted resolvers originate from Japan.
- ▶ Around 58% of blacklisted resolvers in JP, CN, TW.

Introduction

Motivation
Research Question
Research Contributions

Methodology

Metrics
Selection of Websites
Measurement Setup
Measurement Trial

Data Analysis

TCP Connect Times
Website Clusters
Comparing by CDN
Special Cases

Conclusion

References

Appendix

Comparing by Network Type

Conclusion

- ▶ Websites cluster around CDN deployments and show similar performance.
- ▶ CDN clusters are different over IPv4 and IPv6.
- ▶ CDN caches are largely absent over IPv6.
- ▶ TCP connect times to IPv6 CDN clusters have improved over time.
- ▶ IPv6 services from `www.bing.com` have stopped globally since 2013.
- ▶ Google CDN blacklists some resolvers over IPv6.

The tool is publicly released:
<http://happy.vaibhavbajpai.com>



Introduction

Motivation

Research Question

Research Contributions

Methodology

Metrics

Selection of Websites

Measurement Setup

Measurement Trial

Data Analysis

TCP Connect Times

Website Clusters

Comparing by CDN

Special Cases

Conclusion

References

Appendix

Comparing by Network Type

- [1] J. Czyz, M. Allman, J. Zhang, S. Iekel-Johnson, E. Osterweil, and M. Bailey, "Measuring ipv6 adoption," in *Proceedings of the 2014 ACM Conference on SIGCOMM*, ser. SIGCOMM '14. New York, NY, USA: ACM, 2014, pp. 87--98. [Online]. Available: <http://doi.acm.org/10.1145/2619239.2626295>
- [2] D. Thaler, R. Draves, A. Matsumoto, and T. Chown, "Default Address Selection for Internet Protocol Version 6 (IPv6)," RFC 6724 (Proposed Standard), Internet Engineering Task Force, Sep. 2012. [Online]. Available: <http://www.ietf.org/rfc/rfc6724.txt>
- [3] J. Livingood, "Considerations for Transitioning Content to IPv6," RFC 6589 (Informational), Internet Engineering Task Force, Apr. 2012. [Online]. Available: <http://www.ietf.org/rfc/rfc6589.txt>

Introduction

Motivation

Research Question

Research Contributions

Methodology

Metrics

Selection of Websites

Measurement Setup

Measurement Trial

Data Analysis

TCP Connect Times

Website Clusters

Comparing by CDN

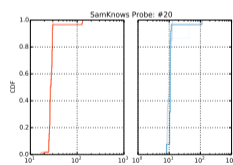
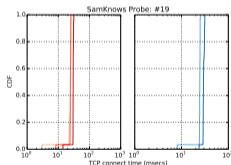
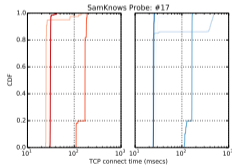
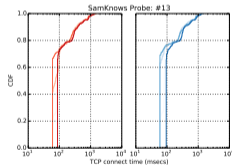
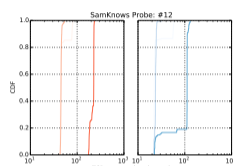
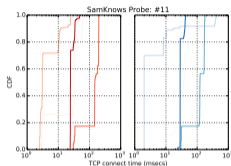
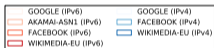
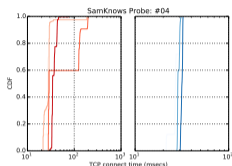
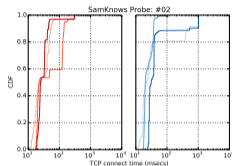
Special Cases

Conclusion

References

Appendix

Comparing by Network Type



Introduction

- Motivation
- Research Question
- Research Contributions

Methodology

- Metrics
- Selection of Websites
- Measurement Setup
- Measurement Trial

Data Analysis

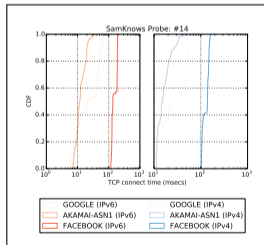
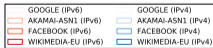
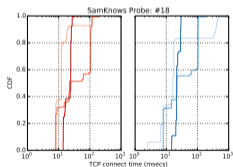
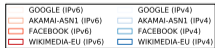
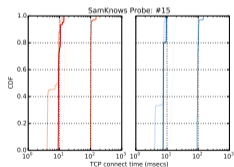
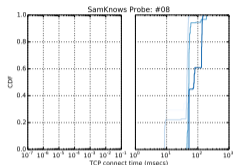
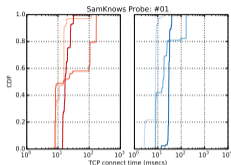
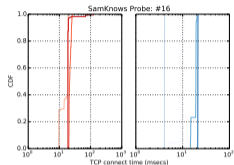
- TCP Connect Times
- Website Clusters
- Comparing by CDN
- Special Cases

Conclusion

References

Appendix

Comparing by Network Type



Introduction

- Motivation
- Research Question
- Research Contributions

Methodology

- Metrics
- Selection of Websites
- Measurement Setup
- Measurement Trial

Data Analysis

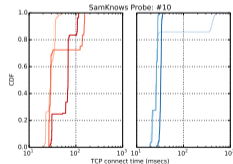
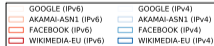
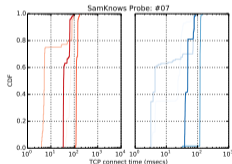
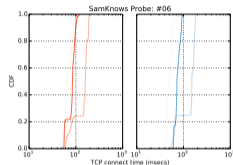
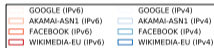
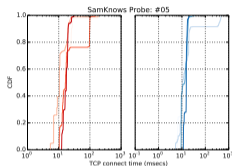
- TCP Connect Times
- Website Clusters
- Comparing by CDN
- Special Cases

Conclusion

References

Appendix

- Comparing by Network Type



Introduction

- Motivation
- Research Question
- Research Contributions

Methodology

- Metrics
- Selection of Websites
- Measurement Setup
- Measurement Trial

Data Analysis

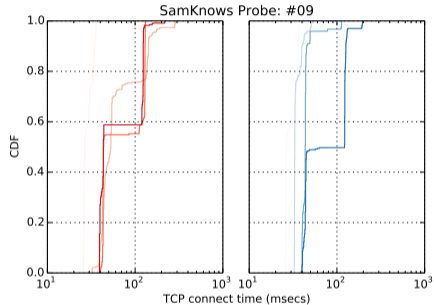
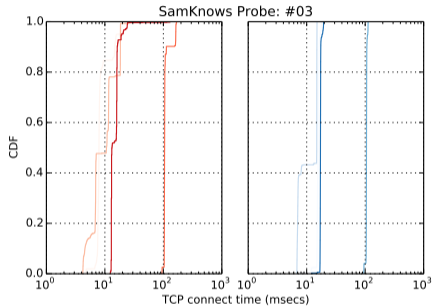
- TCP Connect Times
- Website Clusters
- Comparing by CDN
- Special Cases

Conclusion

References

Appendix

- Comparing by Network Type



Introduction

Motivation

Research Question

Research Contributions

Methodology

Metrics

Selection of Websites

Measurement Setup

Measurement Trial

Data Analysis

TCP Connect Times

Website Clusters

Comparing by CDN

Special Cases

Conclusion

References

Appendix

Comparing by Network Type