Operating the Internet's Largest Measurement System

Geoff Huston

APNIC Labs

Japanese ISPs

Estimate of the major ISPs in Japan and their market share

Date: 25/07/2025

| Rank	ASN	AS Name	CC	Users (est.)	% of country	% of Internet	Samples
1	AS17676	GIGAINFRA SoftBank Corp.	JP	22,747,015	20.82	0.536	15,979,447
2	AS2516	KDDI KDDI CORPORATION	JP	20,129,488	18.42	0.475	14,140,672
3	AS4713	OCN NTT Communications Corporation	JP	12,563,744	11.5	0.296	8,825,847
4	AS9605	DOCOMO NTT DOCOMO, INC.	JP	7,293,352	6.67	0.172	5,123,474
5	AS9824	JTCL-JP-AS JCOM Co., Ltd.	JP	4,655,683	4.26	0.11	3,270,550
6	AS17511	OPTAGE OPTAGE Inc.	JP	4,619,281	4.23	0.109	3,244,978
7	AS2527	SO-NET Sony Network Communications Inc.	JP	4,096,250	3.75	0.097	2,877,556
8	AS2518	BIGLOBE BIGLOBE Inc.	JP	3,822,147	3.5	0.09	2,685,003
9	AS18126	CTCX Chubu Telecommunications Company, Inc.	JP	2,648,489	2.42	0.063	1,860,525
10	AS9617	ZAQ JCOM Co., Ltd.	JP	1,677,246	1.53	0.04	1,178,241

Use of IPv6 in Japan

Use of IPv6 for Japan (JP)
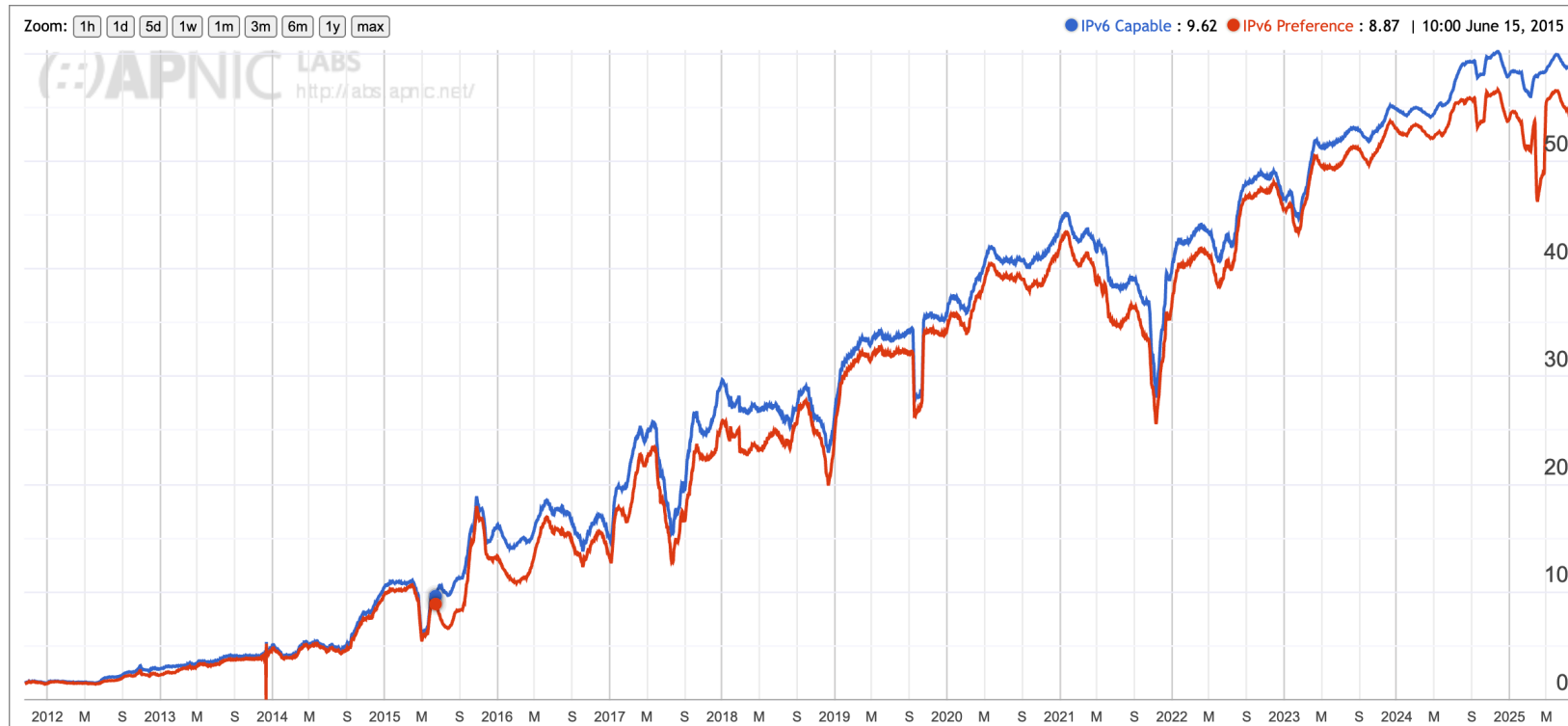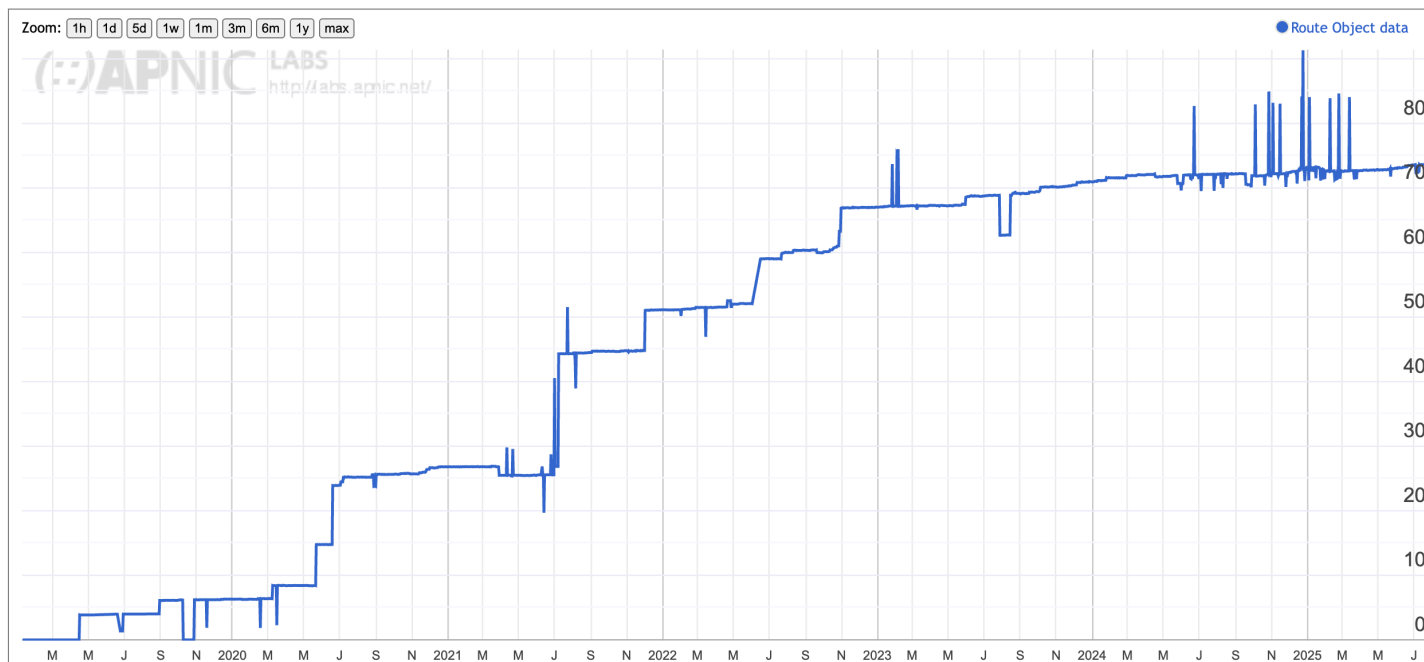
Use of DNSSEC in Japan

Use of DNSSEC Validation for Japan (JP)
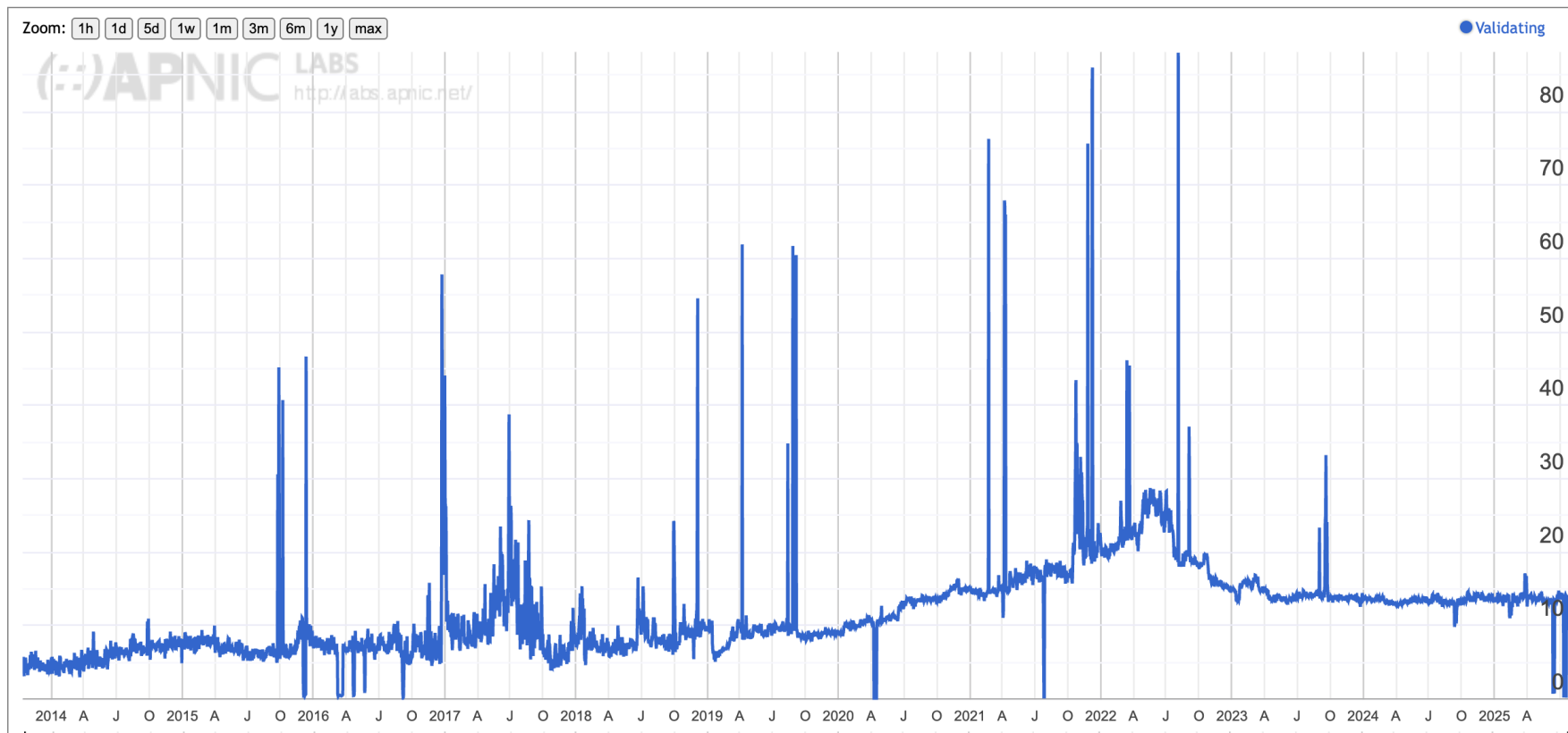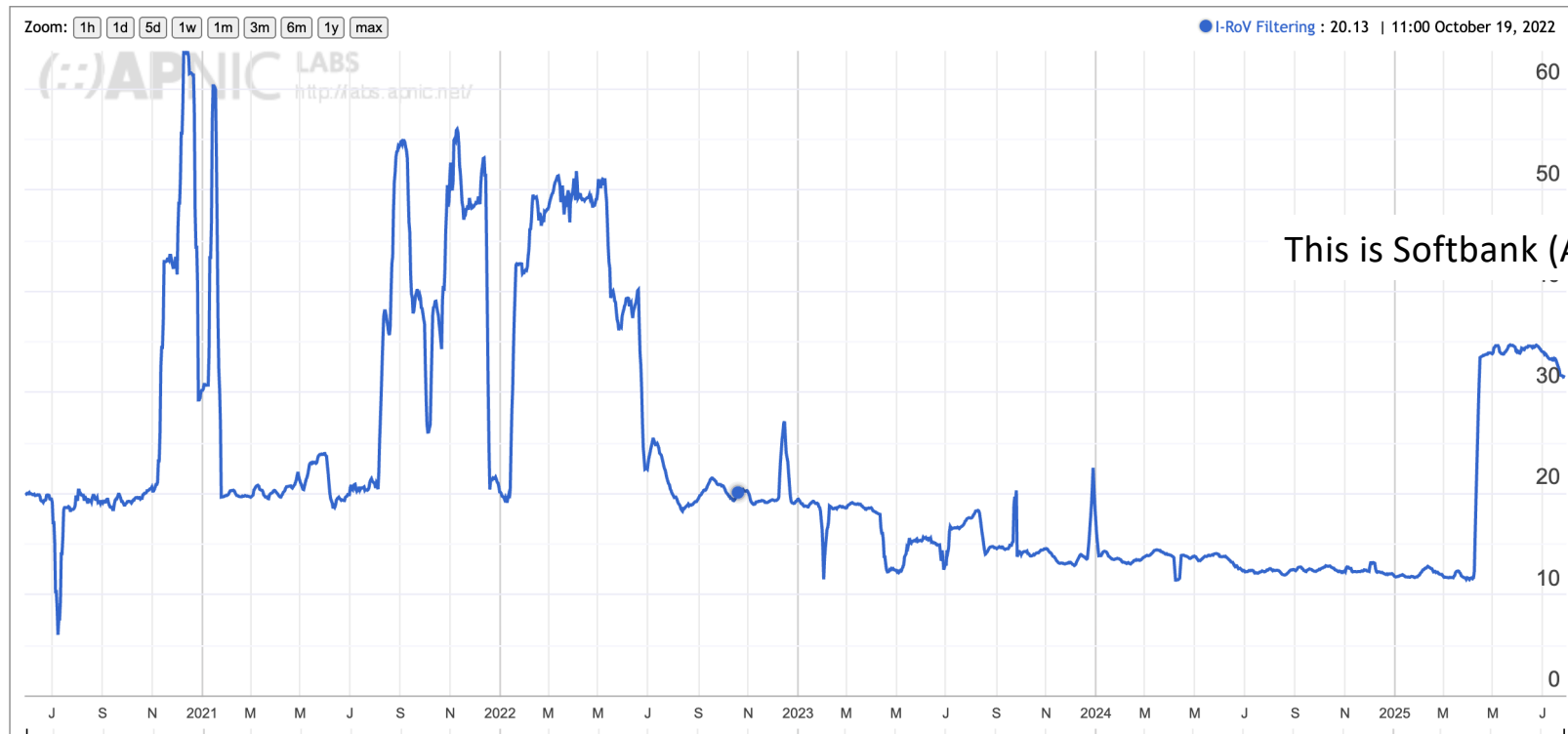
Use of RPKI in Japan

Use of Route Object Validation for Japan (JP)

Display: **Addresses** (Advertised ROA-Valid Advertised Addresses), **IPv4, Percent** (of Total)

Use of ROV-Drop in Japan

Use of RPKI Validation for Japan (JP)

This is Softbank (AS17676)

So much to measure…

so little time!

How and what

- The basic questions are to figure out **what** measurement approach to use:
    - whole of network metrics vs sample measurements
    - system behaviour metrics vs user experience metrics vs component metrics
    - snapshot metrics vs time series measurements

How and what

- The basic questions are to figure out **what** measurement approach to use:
    - whole of network metrics vs sample measurements
    - system behaviour metrics vs user experience metrics vs component metrics
    - snapshot metrics vs time series measurements

- And then figure out **how** to perform the measurement:
    - Passive vs active
    - Dedicated probes vs enrolment
    - Deliberate and Intentional vs Opportunistic

APNIC's path into measurement

2010:

IPv4 exhaustion is just around the corner - so how "ready" are we to operate an IPv6 Internet?

"Measurable" IPv6 Questions

- How much traffic uses IPv6?
- How many connections use IPv6?
- How many routes are IPv6 routes?
- How many service providers offer IPv6?
- How many domain names have AAAA RRs?
- How many domain NS's use AAAA's?
- How many DNS queries are for AAAA RRs?
- How many DNS queries are made over IPv6?
- How many end devices have IPv6?
- How many end devices use IPv6?
- …

Close, but

- None of these specific measurement questions really embrace the larger question of IPv6 "readiness" for the Internet as a whole
    - They are all aimed at measuring IPv6 within particular aspects of the network's infrastructure, but they don't encompass **all** of the infrastructure of the network at once

What's the question?

- To make an IPv6 connection everything else (routing, forwarding, DNS, transport) has to work with IPv6

- So can we measure:

    How many connected devices on today's Internet are capable of making IPv6 connections?

- What if we use scripting on a web server to test the capabilities of clients via a scripted set of related web object fetches?
    - That way we can test a very large number of clients for IPv6

Scale of Measurement

- We really need to use a massively popular web service to conduct this experiment
  - But "massively popular web services" worry constantly about service resiliency and privacy of their data regarding users
  - They tend to be extremely suspicious of adding script elements to their service that performs third party dual stack tests with their clients (and I can't blame them!)

Scale of Measurement

- We really need to use a massively ~~popular~~ web service to conduct this experiment
  - But "massively popular ~~web services~~" worry constantly about service resiliency and ~~risk to~~ their data regarding users
  - They tend to be extremely suspicious of adding script elements to their ~~server that~~ performs third party dual stack tests with their clients (and I can't blame them!)

We need to rethink this approach...

How to conduct measurements at scale

Be Google

How to conduct measurements at scale

Or get Google to place your measurement code on millions of end user's systems, all of the time

How to conduct measurements at scale

How?

Online Ads

Ads use Scripts

- Each time an ad is loaded the ad server loads creative content and scripts on to the client's browser

- The script can include action items to fetch 'network assets'
  - Typically used to load alternate images, sequences
  - It's not a generalized network stack, subject to constraints such as limited to certain object loads, reduced run-time library

- There are on-Load, on-Hover and on-Click actions

- We want to eliminate all interactions with the user, so we use on-Load scripting

This can work

- We can instrument the target host via an ad script
  - we can constrain the ad script to talk ONLY to our server(s)
  - And if we instrument the servers, we can infer the target host properties
- Ads try to deliver to new users all of the time
  - We want to measure new sample points all of the time to avoid implicit repeat bias in the measurement set
- Ads are biased towards 'clicks'
  - We are not interested in clicks
  - We just want impressions
  - Impressions are far cheaper than clicks!

Advertising placement logic

- Fresh Eyeballs means a constant flow of unique endpoints
  - We have good evidence the advertising channel is able to sustain a constant supply of unique endpoints

- Pay by click, or pay by impression
  - If you select a preference for impressions, then the channel tries hard to present your ad to as many unique endpoints as possible

- Time/Location/Context tuned
  - Can select for time of day, physical location or keyword contexts (for search-related ads)
  - But if you don't select, then placement is generalized

Advertising placement logic

- Set a 'CPM' bid in the ad
  - Clicks Per Millepressions: bid rate to pay per thousand impressions

- Uneven distribution of ads throughout the day
  - But we can compensate for this by running 24 x 1-hour campaigns per day

- Use multiple campaigns each with a constrained locale
  - That way we can 'encourage' the ad system to give the ad a broad placement

- Outcome: ~35M placements per day, on a mostly even placement model across each 24H window

Advertising placement logic

Completed Measurement per second

Results per Second

Legend:
- Total (purple)
- ap — Asia (Singapore)
- am — America (Dallas)
- eu — Europe (Frankfurt)
- in — Asia (Mumbai)
- la — S America (Sao Paulo)

X-axis: 10- 0h, 10- 4h, 10- 8h, 10-12h, 10-16h, 10-20h, 11- 0h

26 hours
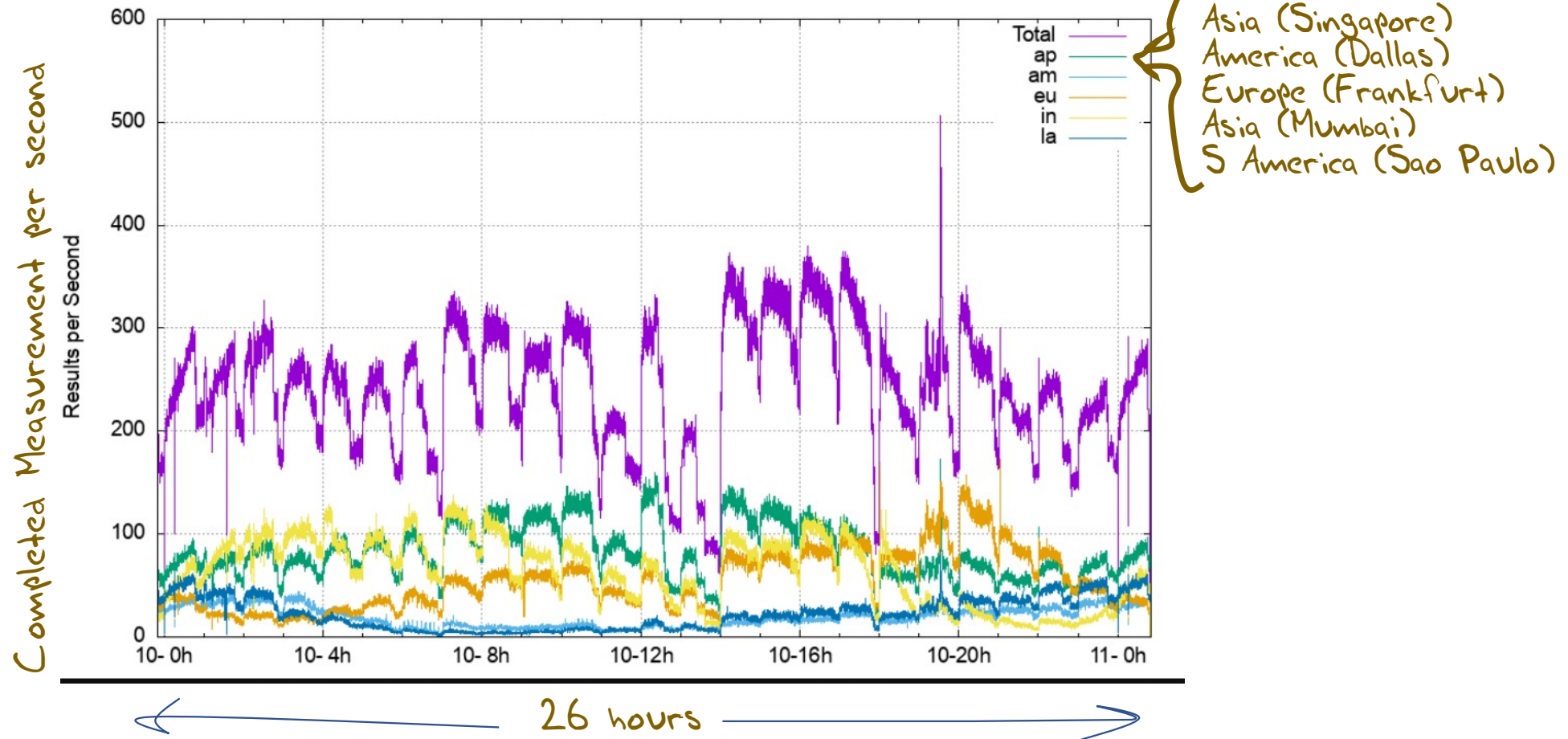
What can be scripted in an Ad

Not much:
- http.FetchImg()
    - i.e. attempt to retrieve a URL

But that's enough!
- It's EXACTLY what users do!
- A URL consists of a DNS question and an HTML question
- What if we point both the DNS and the HTML to use servers that we run?
- As long as each Ad execution uses unique DNS names, then we can push the user query back to our servers and avoid the use of caching
- We can't instrument the client, but we CAN (and do) instrument the server

Measuring IPv6 via Ads
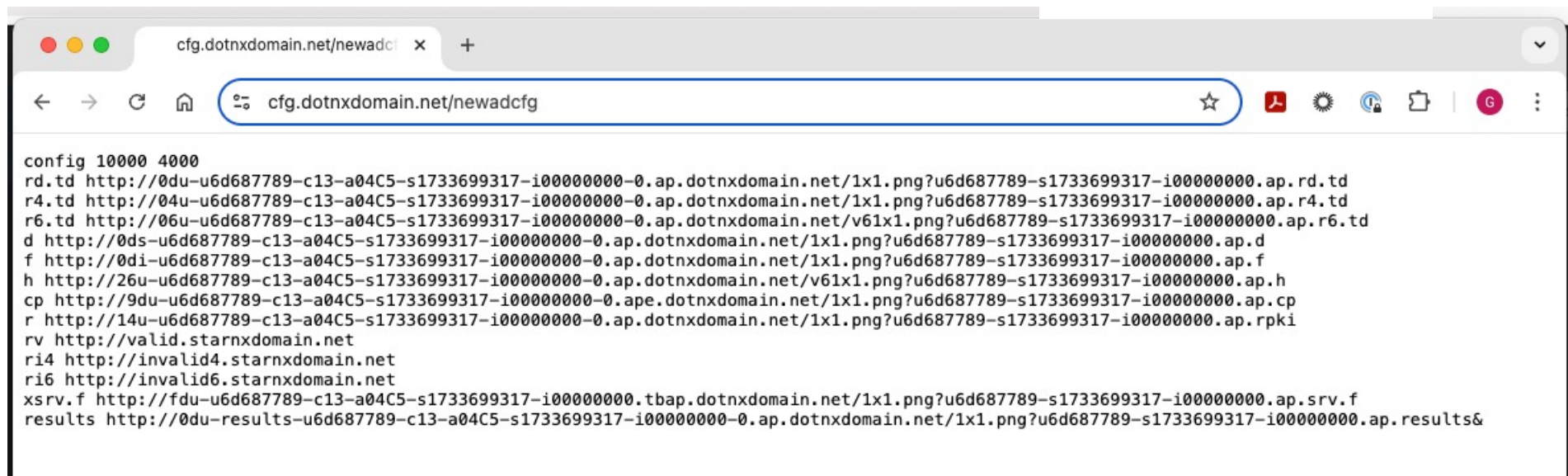
Use HTML5 code that is executed on ad impression
- Client retrieves set of "tests" from an ad-controller
  - That way we can alter the test set without re-filing the ad campaign
- Client is given 10 URLs to load, including:
  - Dual Stack object
  - V4-only object
  - V6-only object
  - Result reporting URL (10 second timer)
  - All DNS is dual stack
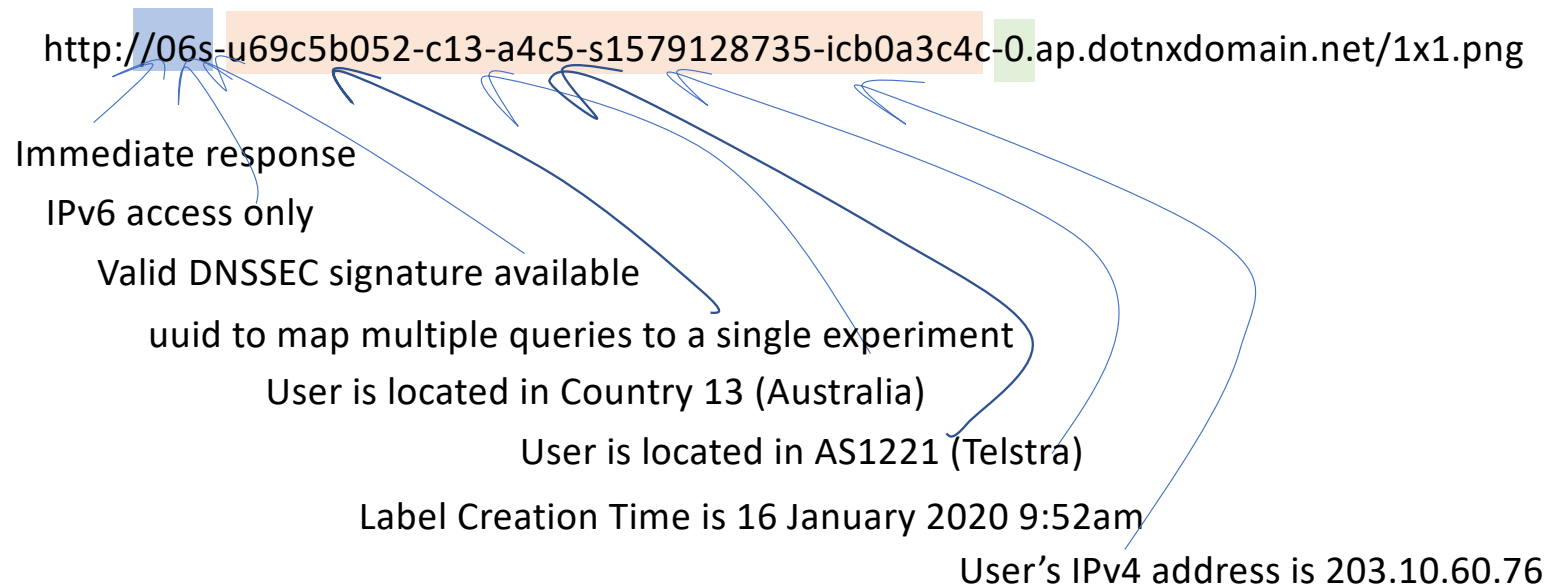 - All URLs use a unique DNS label

For Example:


```
config 10000 4000
rd.td http://0du-u6d687789-c13-a04C5-s1733699317-i00000000-0.ap.dotnxdomain.net/1x1.png?u6d687789-s1733699317-i00000000.ap.rd.td
r4.td http://04u-u6d687789-c13-a04C5-s1733699317-i00000000-0.ap.dotnxdomain.net/1x1.png?u6d687789-s1733699317-i00000000.ap.r4.td
r6.td http://06u-u6d687789-c13-a04C5-s1733699317-i00000000-0.ap.dotnxdomain.net/v61x1.png?u6d687789-s1733699317-i00000000.ap.r6.td
d http://0ds-u6d687789-c13-a04C5-s1733699317-i00000000-0.ap.dotnxdomain.net/1x1.png?u6d687789-s1733699317-i00000000.ap.d
f http://0di-u6d687789-c13-a04C5-s1733699317-i00000000-0.ap.dotnxdomain.net/1x1.png?u6d687789-s1733699317-i00000000.ap.f
h http://26u-u6d687789-c13-a04C5-s1733699317-i00000000-0.ap.dotnxdomain.net/v61x1.png?u6d687789-s1733699317-i00000000.ap.h
cp http://9du-u6d687789-c13-a04C5-s1733699317-i00000000-0.ape.dotnxdomain.net/1x1.png?u6d687789-s1733699317-i00000000.ap.cp
r http://14u-u6d687789-c13-a04C5-s1733699317-i00000000-0.ap.dotnxdomain.net/1x1.png?u6d687789-s1733699317-i00000000.ap.rpki
rv http://valid.starnxdomain.net
ri4 http://invalid4.starnxdomain.net
ri6 http://invalid6.starnxdomain.net
xsrv.f http://fdu-u6d687789-c13-a04C5-s1733699317-i00000000.tbap.dotnxdomain.net/1x1.png?u6d687789-s1733699317-i00000000.ap.srv.f
results http://0du-results-u6d687789-c13-a04C5-s1733699317-i00000000-0.ap.dotnxdomain.net/1x1.png?u6d687789-s1733699317-i00000000.ap.results&
```

DNS Label Encoding

Think of a DNS name as a micro-coded instruction set directed to programmable DNS and HTTP servers ...

http://06s-u69c5b052-c13-a4c5-s1579128735-icb0a3c4c-0.ap.dotnxdomain.net/1x1.png

Immediate response

IPv6 access only

Valid DNSSEC signature available

uuid to map multiple queries to a single experiment

User is located in Country 13 (Australia)

User is located in AS1221 (Telstra)

Label Creation Time is 16 January 2020 9:52am

User's IPv4 address is 203.10.60.76

Experiment Server config

- There are six server sets, identically configured in VMs in DCs (Frankfurt, Singapore, Hong Kong, Dallas, Sao Paulo, Mumbai)

- The experiment script directs the client to the "closest" server set (based on geolocation of the client IP address)

- Server set has dedicated DNS and web content server VMs

Collected Data

Per Server, Per Day:

- HTTP access log

  (successfully completed fetches)

- DNS query log

  (incoming DNS queries)

- Packet capture

  All packets (first 60 bytes)!

Data Analysis

For example – IPv6 measurement

- IPv6 "capable" means that the client successfully fetched the URL target that is only accessible using IPv6
- IPv6 "preferred" means that the client used IPv6 to fetch the dual stack URL target
- Aggregate data by origin AS and by geolocation CC
- "Normalise" the country data against estimates of national user populations (to compensate for aD placement bias at a national level)
- Generate IPv6 daily report and data to data set

V6 Time Series

Use of IPv6 for World (XA)

IPv6 Report

100 ➤

https://stats.labs.apnic.net/ipv6
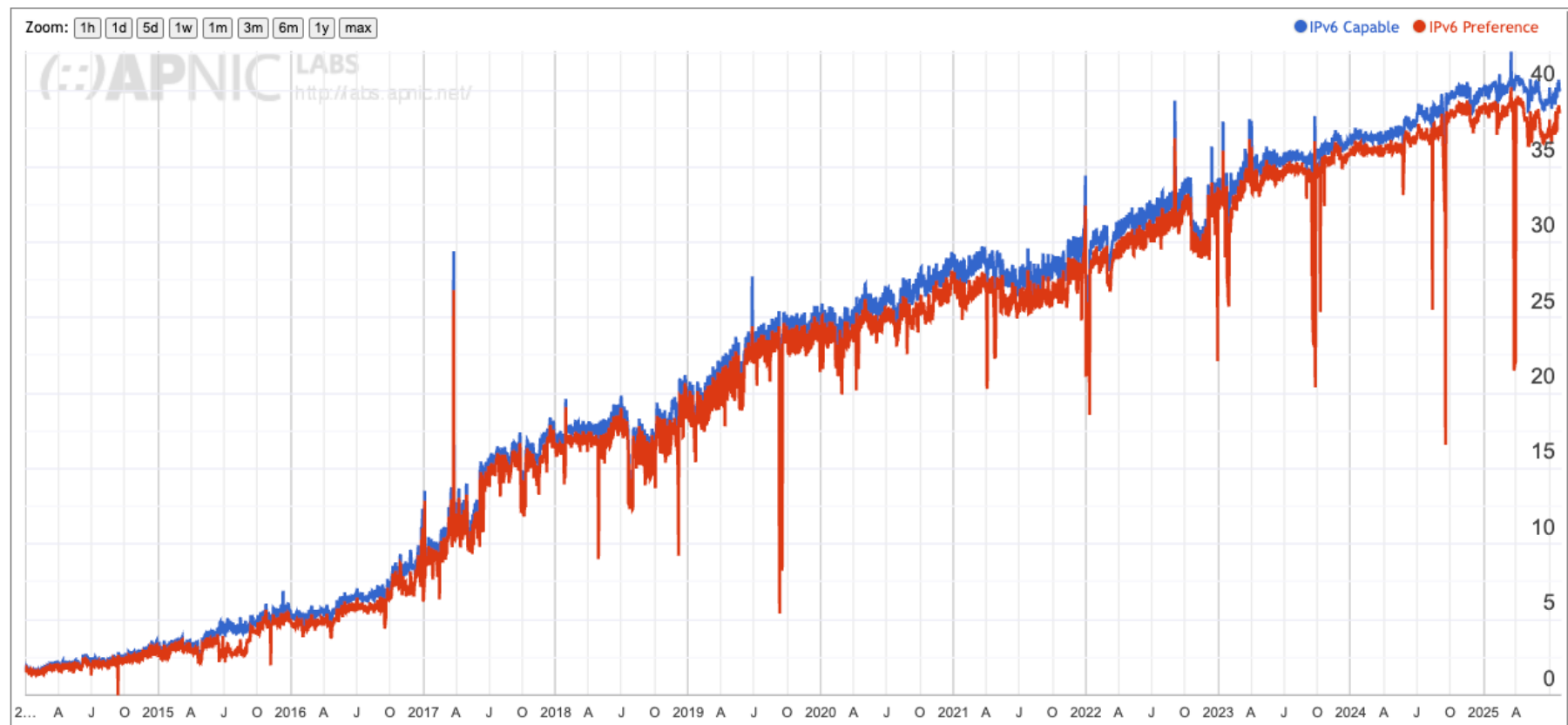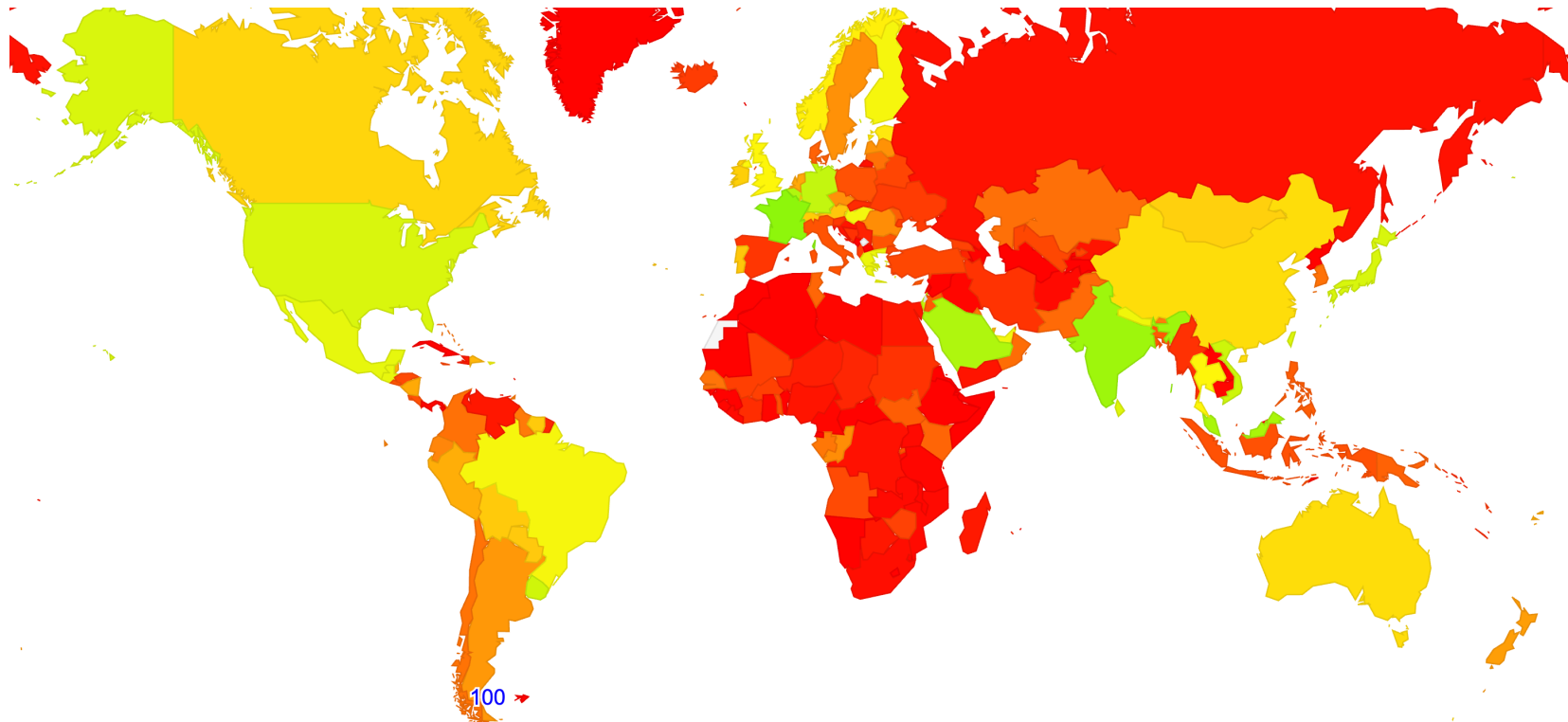
IPv6 Report

IPv6 Capable Rate by country (%)

CC	Country	IPv6 Capable	IPv6 Preferred	Samples
IN	India, Southern Asia, Asia	79.81%	78.47%	148,742,179
MY	Malaysia, South-Eastern Asia, Asia	72.08%	68.38%	8,162,536
FR	France, Western Europe, Europe	70.39%	69.90%	16,054,034
BE	Belgium, Western Europe, Europe	68.33%	67.58%	2,541,184
DE	Germany, Western Europe, Europe	66.98%	66.28%	13,860,132
SA	Saudi Arabia, Western Asia, Asia	65.71%	64.40%	7,641,062
VN	Vietnam, South-Eastern Asia, Asia	64.23%	62.94%	9,891,922
IL	Israel, Western Asia, Asia	61.41%	54.37%	3,859,507
TW	Taiwan, Eastern Asia, Asia	60.94%	52.11%	4,127,683
UY	Uruguay, South America, Americas	59.32%	58.83%	621,842
JP	Japan, Eastern Asia, Asia	59.21%	55.38%	21,675,976
NP	Nepal, Southern Asia, Asia	58.09%	57.54%	2,101,637
AX	Aland Islands, Northern Europe, Europe	58.02%	57.56%	8,932
GR	Greece, Southern Europe, Europe	56.75%	56.46%	2,289,524
LK	Sri Lanka, Southern Asia, Asia	56.46%	55.76%	1,298,790
FI	Finland, Northern Europe, Europe	55.23%	54.54%	1,524,989
GT	Guatemala, Central America, Americas	55.10%	54.33%	628,593
HU	Hungary, Eastern Europe, Europe	54.57%	53.98%	2,638,417
US	United States of America, Northern America, Americas	54.33%	53.29%	92,238,748
AE	United Arab Emirates, Western Asia, Asia	54.16%	53.16%	1,598,869

https://stats.labs.apnic.net/ipv6

Per-Country Time Series - India

Use of IPv6 for India (IN)

https://stats.labs.apnic.net/ipv6/IN

Per-Country Time Series - India

ASN	AS Name	IPv6 Capable	IPv6 Preferred	Samples
AS55836	RELIANCEJIO-IN Reliance Jio Infocomm Limited	95.31%	93.74%	70,668,475
AS45609	BHARTI-MOBILITY-AS-AP Bharti Airtel Ltd. AS for GPRS Service	91.25%	89.97%	36,257,071
AS24560	AIRTELBROADBAND-AS-AP Bharti Airtel Ltd., Telemedia Services	65.31%	63.36%	8,388,823
AS38266	VIL-AS-AP Vodafone Idea Ltd	89.34%	88.34%	6,559,337
AS45271	ICLNET-AS-AP Idea Cellular Limited	87.88%	86.19%	4,469,821
AS9829	BSNL-NIB National Internet Backbone	4.24%	4.03%	3,193,236
AS24309	CABLELITE-AS-AP Atria Convergence Technologies Pvt. Ltd. Broadband Internet Service Provider INDIA	38.04%	37.67%	1,077,452
AS133982	EXCITEL-AS-IN Excitel Broadband Private Limited	0.38%	0.09%	968,656
AS45916	GTPL-AS-AP Gujarat Telelink Pvt Ltd	37.21%	34.54%	858,588
AS138754	KVBPL-AS-IN Kerala Vision Broad Band Private Limited	17.93%	17.67%	792,974
AS133661	NETPLUS-AS Netplus Broadband Services Private Limited	50.35%	47.17%	782,841
AS17488	HATHWAY-NET-AP Hathway IP Over Cable Internet	0.43%	0.22%	719,382
AS24186	RAILTEL-AS-IN RailTel Corporation of India Ltd	8.18%	7.76%	548,135
AS17665	ONEBROADBAND ONEOTT INTERTAINMENT LIMITED	3.30%	2.95%	541,747
AS55577	CABLELITE-AS-AP Atria Convergence Technologies Ltd.	26.72%	26.35%	495,761

https://stats.labs.apnic.net/ipv6/IN

Per-Network Time Series

IPv6 Per-Country Deployment for AS55836: RELIANCEJIO-IN Reliance Jio Infocomm Limited, India (IN)
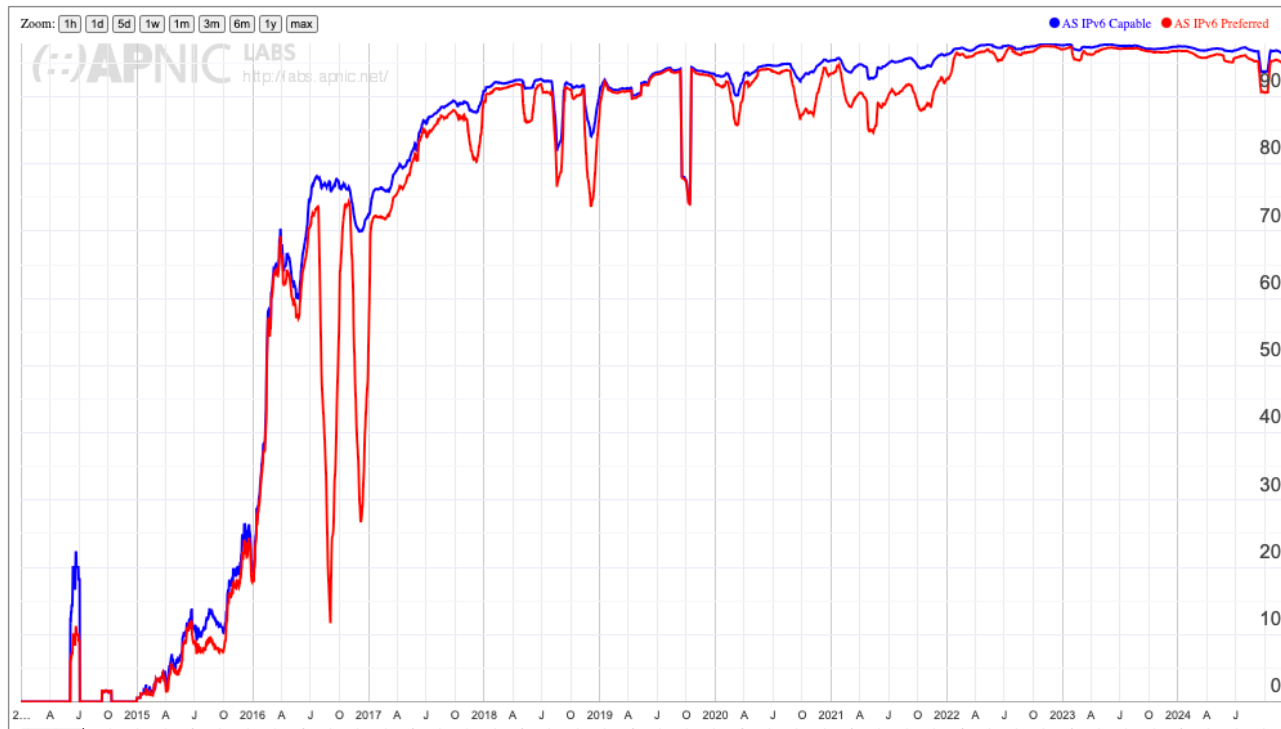
https://stats.labs.apnic.net/ipv6/AS55836

What about DNSSEC Use?

Can we use the same platform to measure the proportion of users who sit behind DNS resolvers that perform DNSSEC validation?

What about DNSSEC Use?

- Can we use the same platform to measure the proportion of users who sit behind DNS resolvers that perform DNSSEC validation?

DNSSEC-signed DNS name

Invalidly-signed DNSSEC-signed DNS name

DNSSEC Test

- A client is sitting behind DNSSEC validating resolvers if:
  - It fetches the validly-signed DNS URL
  - It does not fetch the invalidly-signed DNS URL
  - It queries for the address using EDNS0 DNSSEC OK field
  - It queries for the zone DNSKEY record for both DNS names *

- A client "partially" validates if the validation failure causes the client to use an alternative non-validating resolver and resolve the name

* This last one is a bit of a challenge as we want to see these queries at the authoritative server and not have them masked by caching – so we use a LDNS-based auth server to create a dynamic DNS server that constructs a DNSSEC signed delegated zone on the fly

DNSSEC Results

Use of DNSSEC Validation for World (XA)

https://stats.labs.apnic.net/dnssec/XA
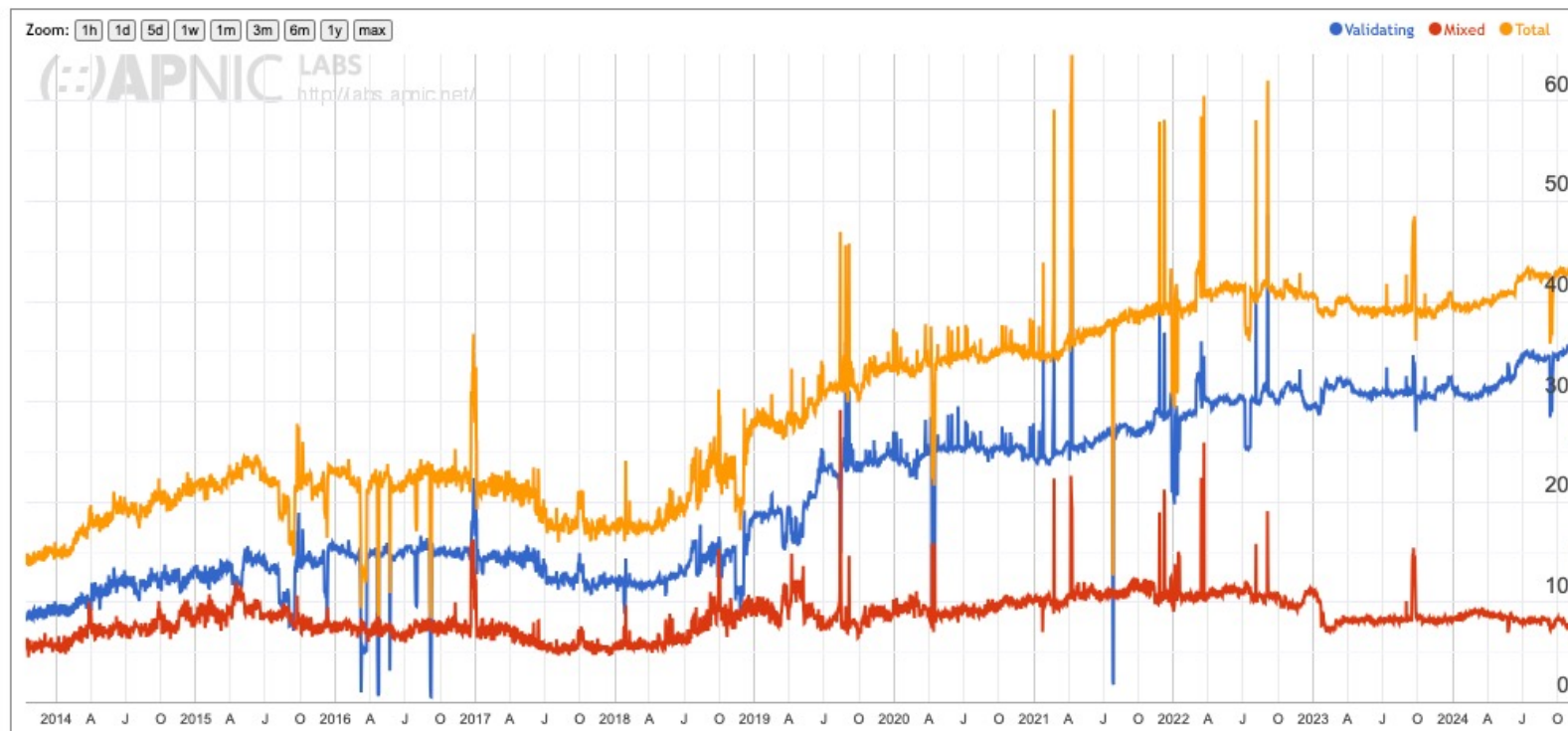
DNSSEC Results

DNSSEC Validation Rate by country (%)

Click here for a zoomable map
☐ Remember current choice for 7 days

https://stats.labs.apnic.net/dnssec

0   100

DNSSEC Validation in India
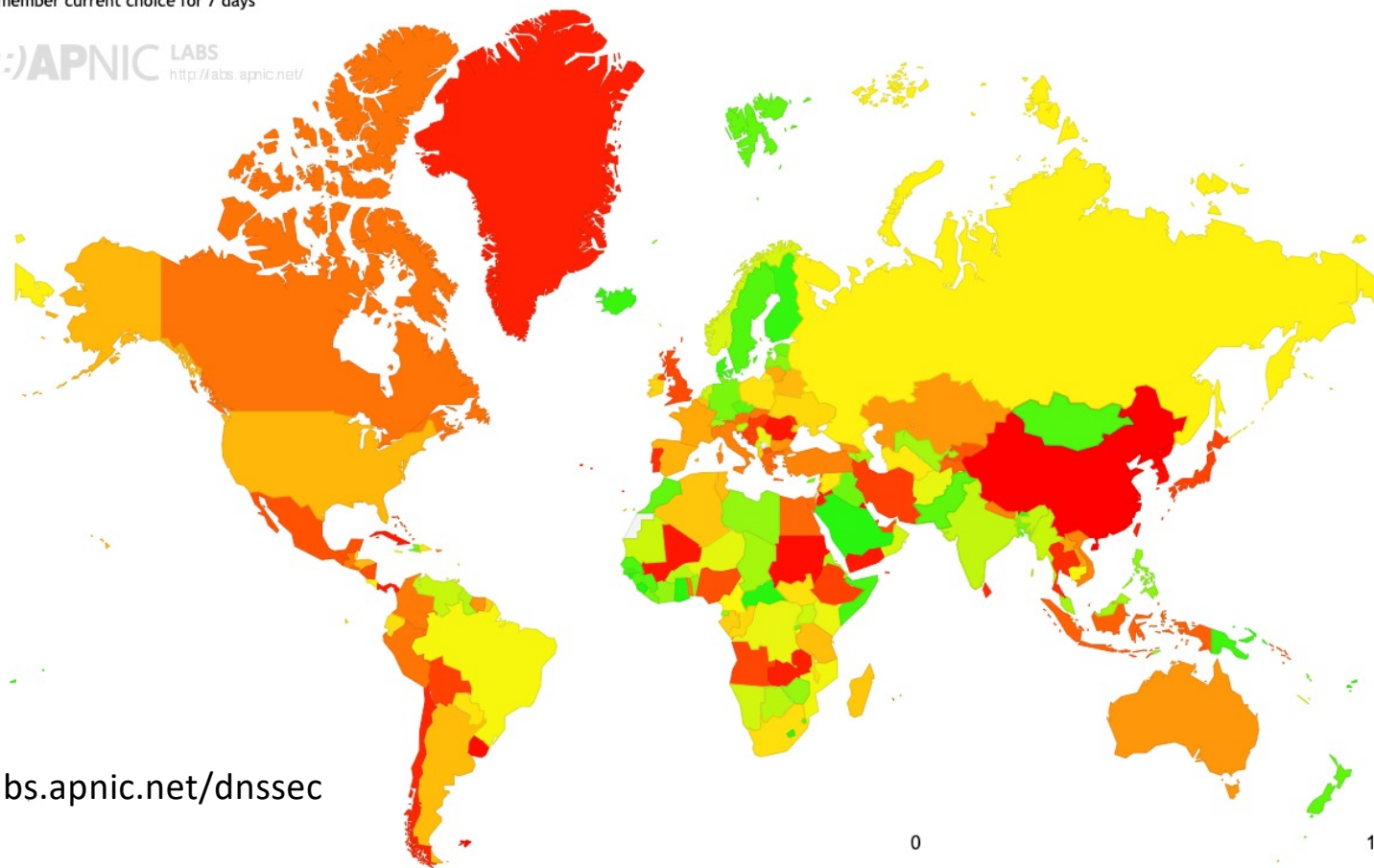
ASN	AS Name	DNSSEC Validates	Partial Validation	Samples
AS55836	RELIANCEJIO-IN Reliance Jio Infocomm Limited	99.75%	0.19%	1,988,476
AS45609	BHARTI-MOBILITY-AS-AP Bharti Airtel Ltd. AS for GPRS Service	5.32%	2.27%	955,922
AS24560	AIRTELBROADBAND-AS-AP Bharti Airtel Ltd., Telemedia Services	2.68%	1.69%	204,627
AS38266	VIL-AS-AP Vodafone Idea Ltd	80.48%	2.43%	164,999
AS45271	ICLNET-AS-AP Idea Cellular Limited	59.47%	3.93%	119,917
AS9829	BSNL-NIB National Internet Backbone	13.51%	1.92%	69,455
AS24309	CABLELITE-AS-AP Atria Convergence Technologies Pvt. Ltd. Broadband Internet Service Provider INDIA	94.37%	3.43%	26,785
AS133982	EXCITEL-AS-IN Excitel Broadband Private Limited	89.86%	10.00%	23,671
AS45916	GTPL-AS-AP Gujarat Telelink Pvt Ltd	22.30%	41.44%	22,358
AS133661	NETPLUS-AS Netplus Broadband Services Private Limited	17.56%	80.72%	19,356
AS17488	HATHWAY-NET-AP Hathway IP Over Cable Internet	26.39%	27.86%	16,139
AS24186	RAILTEL-AS-IN RailTel Corporation of India Ltd	61.97%	34.06%	15,657
AS138754	KVBPL-AS-IN Kerala Vision Broad Band Private Limited	99.05%	0.80%	14,535

https://stats.labs.apnic.net/dnssec/IN

Other server side measurement techniques

We treat the DNS name (and the full URL) as a set of server instructions and use a combination of dynamic DNS, NGINX modules and 2-step packet processing to generate specific server-side behaviours that we want to measure

Other server-side measurement techniques - Glueless DNS

"Glueless" DNS delegation to provide explicit confirmation that a resolver has received a response

- The client is forced to resolve the name of the zone name servers before proceeding with the original resolution task
- If the name of the name servers is dynamically generated and unique then DNS caching won't help
- We've used this technique to measure:
    - IDN support
    - qname minimisation
    - DNS fragmentation management
    - DNS dual stack behaviour
    - Recursive Resolvers' server selection

Other server side measurement techniques - Repeats

Explicitly directed repeat fetches to trigger content directives for HTTP/3

- Chrome relies on receiving an Alt-Svc: content directive before it will switch over to use HTTP for fetches from this server
- Which means it will only use HTTP/3 on the second (or subsequent) fetch
- To create this behaviour we have to allow the measurement script to schedule this fetch multiple times, with a small idle interval between fetches

Other server side measurement techniques – SERVFAIL DNS

SERVFAIL responses to force the client resolver to cycle through all configured recursive resolvers

- This technique uses a LDNS path that responds with a SERVFAIL response for all DNS queries for this name set
- This is intended to cause the local resolver to cycle through all locally configured recursive resolvers to find a resolver that will respond to the query
- We used this is exposing the set of resolvers that a user may use to resolve a name

Other server side measurement techniques – IPv6 Packet Mangling

- IPv6 packet manipulation to insert crafted IPv6 packets into an established TCP stream
  - To manipulate an IPv6 packet to manually control fragmentation and other forms of Extension Headers we use a "front end" unit to pick up incoming packets and pass them to a conventional back end server
  - The return packet is modified to add the appropriate Extension Header and/or Fragment before passing back to the end client

Measurement Projects

- IPv6 Performance (connection reliability and relative speed)
- IPv6 Fragmentation
- IPv6 Extension Header loss Rates (HBH and DST)
- DNS: Use of ECDSA and EDDI DNSSEC signing algorithms
- DNS: Fragmentation Drop (and TCP support)
- DNS resolver use profile (use of open DNS resolvers)
- DNS KSK roll probes (RFC8509)
- Support for QUIC use (HTTP/3)
- Support for Route Origination Validation
- Zombies and tracking

https://stats.labs.apnic.net

Server Side Measurement

- This approach complements client side measurements (CAIDA's ARK, RIPE NCC's Atlas) and network-level internal measurements by using a large scale server side measurement platform

- In this form of server-side measurement the client does what clients always do - fetch URLs

- We can test particular client behaviours and network behaviours by deliberately altering the server-side behaviour and triggering the behaviour in a measured behaviour

- The benefit of this approach is that rather than measuring the effect and inferring the cause, in this approach we trigger a cause and then correlate the observed outcomes against the known cause.

Thanks!

Measurement Reports at APNIC Labs:
https://stats.labs.apnic.net