

# Measuring DNSSEC Use

Geoff Huston &  
George Michaelson  
research@apnic.net

## Some Questions...

- ⇒ Who is using DNSSEC validation?
- ⇒ What is the DNSSEC performance overhead for users and servers?
- ⇒ What happens when the DNSSEC signature is not valid?

# And a Measurement Technique

Three URLs:

the good (DNSSEC signed)

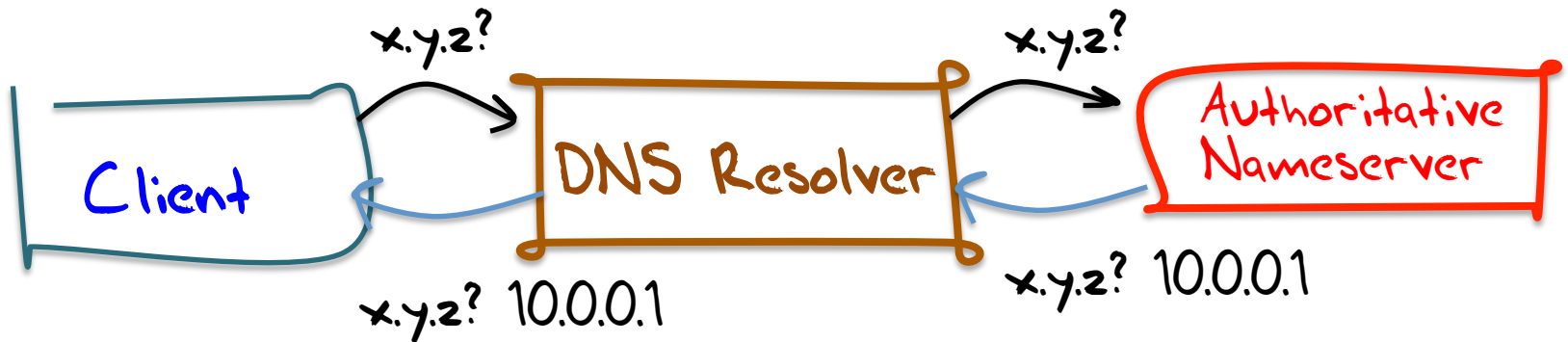
the bad (invalid DNSSEC signature)

the control (no DNSSEC at all)

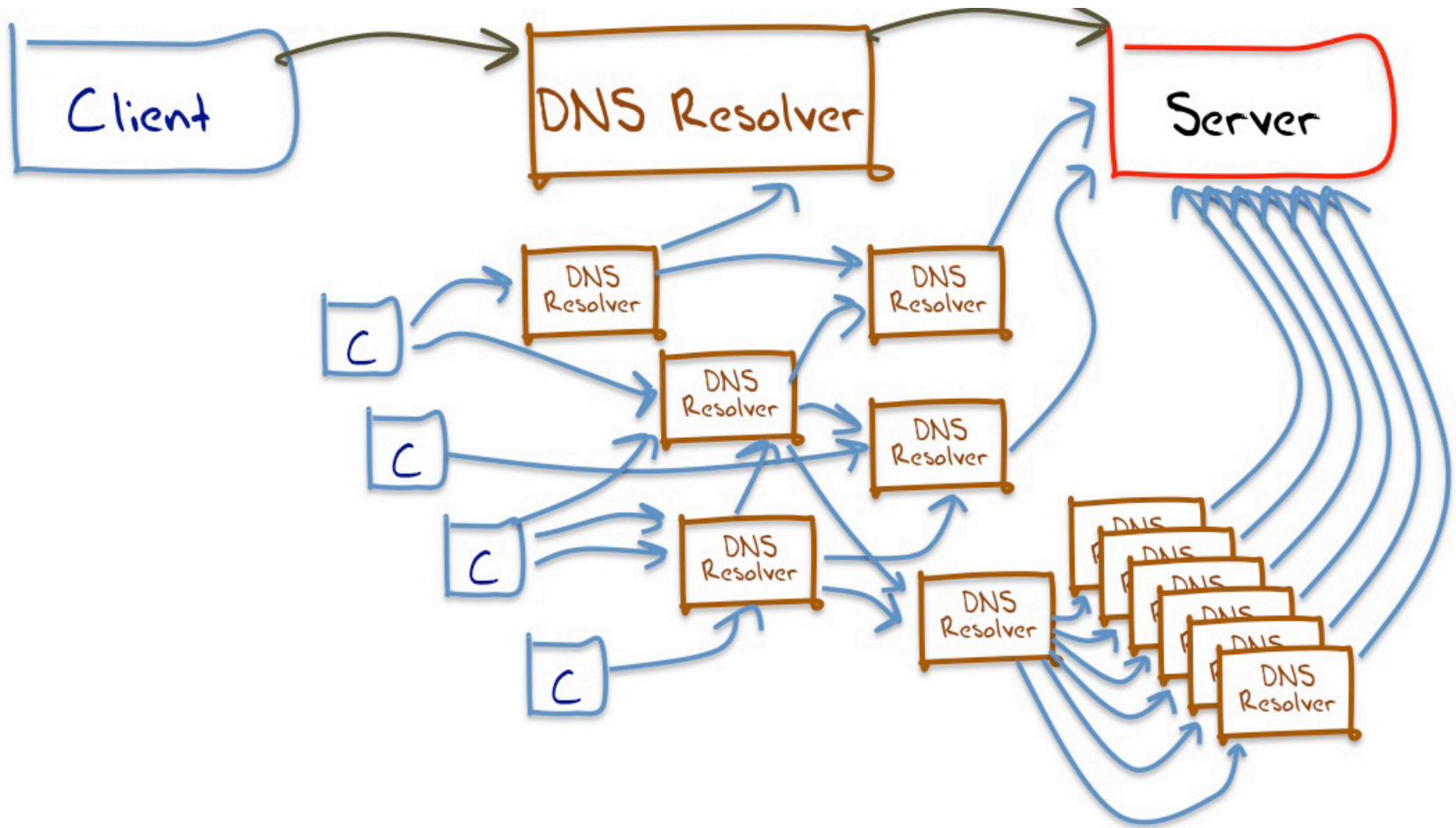
And an online ad system to deliver the test to a large pseudo-random set of clients

# Understanding Resolvers is "tricky"

What we would like to think happens in DNS resolution!

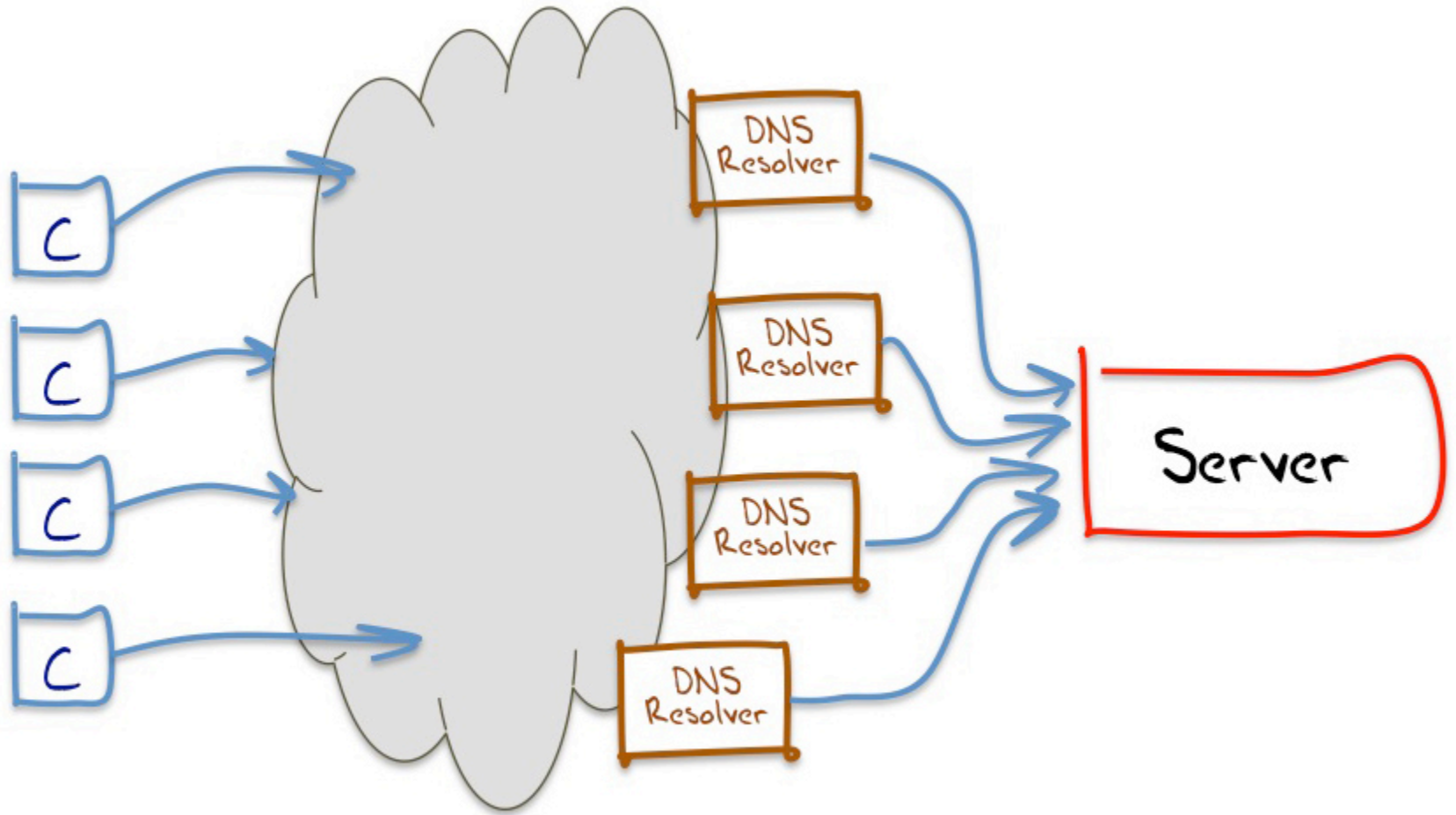


# Understanding Resolvers is "tricky"



A small sample of what appears to happen in DNS resolution

# Understanding Resolvers is "tricky"



The best model we can use for DNS resolution

# This means...

That it is hard to talk about “all resolvers”

- We don't know how many resolvers we can see from the perspective of an authoritative name server
- We can only talk about “visible resolvers”

And there is an added issue with DNSSEC:

- it can be hard to tell the difference between a visible resolver performing DNSSEC validation and a hidden validating resolver performing validation via a visible non-validating forwarder

So it's easier to talk about end clients, and whether we see end-clients use / don't use a DNS resolution service that performs DNSSEC validation

# Some Results

Web + DNS query log processing

9 – 26 May 2013

Completed Test Count: 2,498,497

- Appears to perform DNSSEC Validation: **8.3%**
- Appears to use a mix of resolvers: **4.3%**
- Did not have a clue, only fetched A, AAAA RRs: **87.4%**



# Some other results

- Used Google's Public DNS servers: **7.2%**
  - Exclusively Used Google's P-DNS: 5.3%
  - Used a mix of Google P-DNS + others: 1.9%
- Used other resolvers: **92.8%**

# Where is DNSSEC? - The Top 20

Rank	CC	Count	% D	% x	% A	Country
1	SE	5,212	77.92	3.38	18.70	Sweden
2	SI	1,000	75.85	4.90	36.25	Slovenia
3	LU	1,000	63.87	6.00	49.23	Luxembourg
4	RU	1,000	58.28	4.00	57.69	Russia
5	NO	1,000	57.01	16.00	46.70	Norway
6	FR	1,000	53.20	8.00	58.72	France
7	DE	1,000	50.26	8.00	61.41	Germany
8	CA	1,000	48.22	3.00	68.67	Canada
9	IE	8,079	27.04	2.00	68.96	Ireland
10	BB	1,312	27.04	2.00	24.00	Brazil
11	ID	54,816	27.04	2.00	55.00	Indonesia
12	UA	26,399	27.04	2.00	60.00	Ukraine
13	ZA	2,969	27.04	2.00	48.00	South Africa
14	TR	49,498	27.04	2.00	84.00	Turkey
15	US	140,234	27.04	2.00	11.00	United States of America
16	EG	36,061	27.04	2.00	01.00	Egypt
17	GH	973	27.04	2.00	29.00	Ghana
18	AZ	7,409	14.55	30.34	55.11	Azerbaijan
19	BR	179,424	14.43	6.13	79.44	Brazil
20	PS	2,893	14.00	36.85	49.15	Occupied Palestinian Territory

*% of clients who appear to use DNSSEC-validating resolvers*

*% of clients who use non-validating resolvers*

*% of clients who use a mix of DNSSEC-validating resolvers and non-validating resolvers*

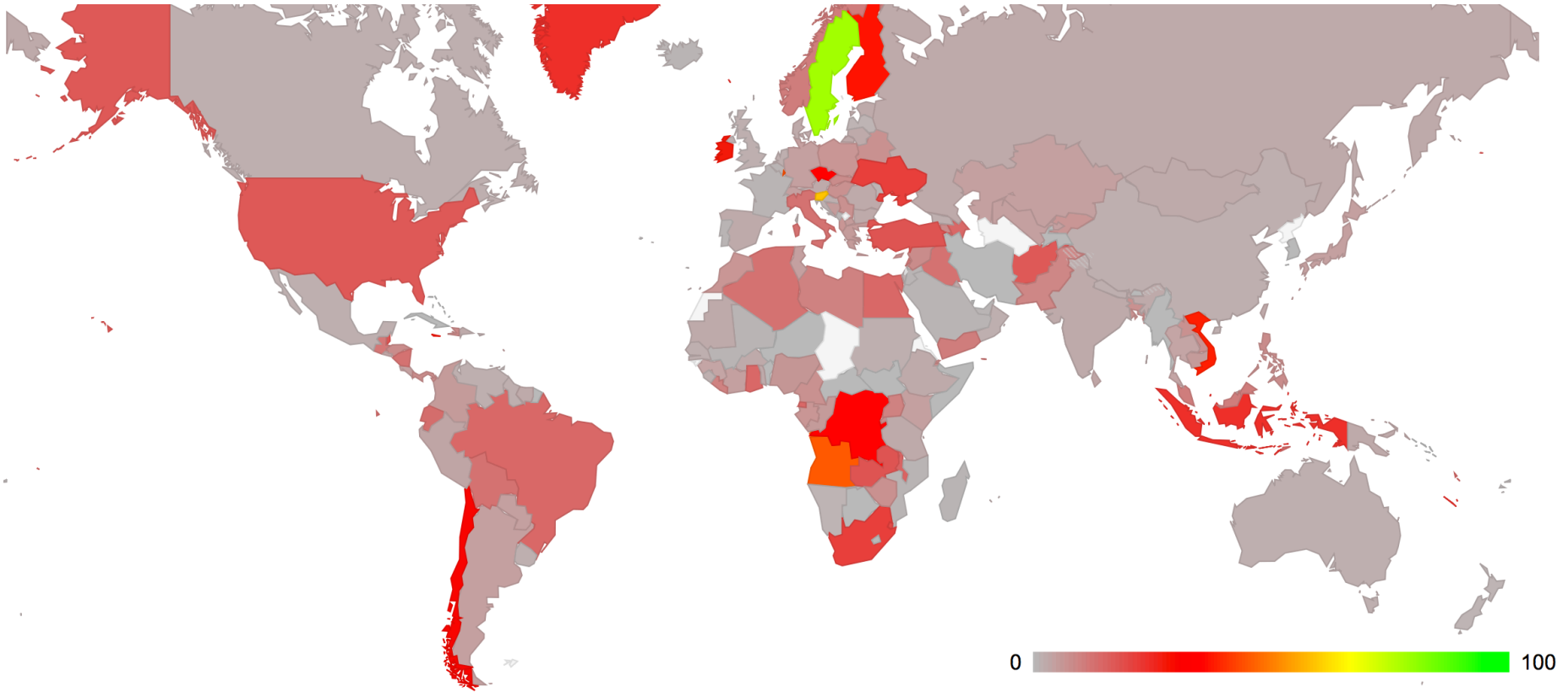
*When we geo-locate clients to countries, what proportion of these clients: perform DNSSEC validation? Retrieve some DNSSEC RRs? Do not retrieve any DNSSEC RRs?*

# Where is DNSSEC? - The Top 20

Rank	CC	Count	% D	% x	% A	Country
1	SE	5,349	77.92	3.38	18.70	Sweden
2	SI	4,758	58.85	4.90	36.25	Slovenia
3	LU	652	43.87	6.90	49.23	Luxembourg
4	VN	26,665	38.28	4.04	57.69	Vietnam
5	FI	2,456	37.01	16.29	46.70	Finland
6	CZ	30,827	33.20	8.08	58.72	Czech Republic
7	CL	46,151	30.26	8.34	61.41	Chile
8	JM	1,545	28.22	3.11	68.67	Jamaica
9	IE	8,079	27.94	3.11	68.96	Ireland
10	BB	1,312	24.24	1.52	74.24	Barbados
11	ID	54,816	23.87	8.58	67.55	Indonesia
12	UA	26,399	21.65	12.75	65.60	Ukraine
13	ZA	2,969	21.15	9.36	69.48	South Africa
14	TR	49,498	18.06	2.10	79.84	Turkey
15	US	140,234	17.32	3.57	79.11	United States of America
16	EG	36,061	14.68	10.32	75.01	Egypt
17	GH	973	14.59	8.12	77.29	Ghana
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*When we geo-locate clients to countries, what proportion of these clients perform DNSSEC validation? Retrieve some DNSSEC RRs? Do not retrieve any DNSSEC RRs?*

# The Map View



# Is Google's P-DNS a Factor?

Rank	CC	Count	% D	%AG	%SG	%NG	Country
1	SE	5,349	77.92	1.78	0.19	98.03	Sweden
2	SI	4,751	77.92	1.89	0.21	91.89	Slovenia
3	LU	651	77.92	1.40	0.00	98.60	Luxembourg
4	VN	26,666	66.66	66.66	2.22	1.09	Vietnam
5	FI	2,451	27.94	2.64	0.33	97.03	Finland
6	CZ	30,821	24.24	11.71	3.90	84.30	Czechia
7	CL	46,151	21.65	3.62	0.40	95.92	Chile
8	JM	1,541	21.15	91.74	0.60	7.57	Jamaica
9	IE	8,079	27.94	12.18	0.00	86.89	Ireland
10	BB	1,312	24.24	12.18	0.00	82.82	Barbados
11	ID	54,816	23.87	6.01	0.00	91.01	Indonesia
12	UA	26,399	21.65	1.01	0.00	91.01	Ukraine
13	ZA	2,969	21.15	1.01	0.00	47.47	South Africa
14	TR	49,498	18.06	9.41	0.00	41.41	Turkey
15	US	140,234	17.32	0.98	0.00	98.98	United States of America
16	EG	36,061	14.68	66.26	9.66	9.84	Egypt
17	GH	973	14.59	59.86	14.08	26.06	Ghana
18	AZ	7,409	14.55	71.24	26.72	2.04	Azerbaijan
19	BR	179,424	14.43	50.31	7.08	42.61	Brazil
20	PS	2,893	14.00	40.49	59.51	0.00	Occupied Palestinian Terr.

*% of validating clients who exclusively use Google's P-DNS*

*% of clients who do not use Google's P-DNS service*

*% of clients who use a mix of Google's P-DNS and other resolvers*

*Of those clients who perform DNSSEC validation, what resolvers are they using: All Google P-DNS, Some Google P-DNS? No Google P-DNS?*

# Is Google's P-DNS a Factor?

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9	IE	8,079	27.94	->	12.18	0.93	86.89	Ireland
10	BB	1,312	24.24	->	7.86	0.31	91.82	Barbados
11	ID	54,816	23.87	->	<b>68.36</b>	<b>12.63</b>	<b>19.01</b>	<b>Indonesia</b>
12	UA	26,399	21.65	->	19.84	2.15	78.01	Ukraine
13	ZA	2,969	21.15	->	5.73	0.80	93.47	South Africa
14	TR	49,498	18.06	->	<b>93.25</b>	<b>3.33</b>	<b>3.41</b>	<b>Turkey</b>
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19	BR	179,424	14.43	->	<b>50.31</b>	<b>7.08</b>	<b>42.61</b>	<b>Brazil</b>
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*Of those clients who perform DNSSEC validation, what resolvers are they using: All Google P-DNS, Some Google P-DNS? No Google P-DNS?*

# DNSSEC by Networks - the Top 25

Rank	AS	Count	% D	%x	%A	%G	AS Name
1	AS11111	1,000	98.73	0.14	1.13	0.71	Com Hem, SE
2	AS11112	1,000	97.77	2.13	0.00	0.49	Colomb
3	AS11113	1,000	97.71	1.14	1.14	2.34	Telefon
4	AS11114	1,000	96.76	0.14	2.40	1.24	T-2
5	AS11115	1,000	96.74	0.14	2.41	1.07	Kabel
6	AS11116	1,000	96.72	0.14	2.41	0.53	Teleko
7	AS11117	1,000	96.44	1.14	2.47	99.86	Linkem
8	AS11118	1,000	96.05	0.14	3.26	1.07	Elisa
9	AS5466	2,093	77.50	5.82	50.81	2.21	Eircom
10	AS6849	4,596	42.99	3.82	42.99	1.25	UKRTELECOM, UA
11	AS3301	1,445	42.99	3.82	42.99	1.25	TeliaSonera, SE
12	AS5610	6,889	36.36	5.18	36.36	1.25	Telecom nica Czech Rep., CZ
13	AS7922	24,129	36.36	5.18	36.36	1.25	Telecom ble, US
14	AS22047	15,274	36.36	5.18	36.36	1.25	Telecom ANCHA, CL
15	AS1257	795	36.36	5.18	36.36	1.25	Telecom Abadi, ID
16	AS38511	1,221	36.36	5.18	36.36	1.25	Telecom P
17	AS2519	523	36.36	5.18	36.36	1.25	Telecom P
18	AS1759	562	51.78	26.51	21.71	2.06	TeliaSonera, FI
19	AS2819	734	48.37	15.53	36.10	20.85	GTSCZ GTS Czech, CZ
20	AS45899	14,306	45.93	3.16	50.91	97.76	VNPT, VN
21	AS27738	950	45.79	40.11	14.11	4.60	Ecuadortelecom, EC
22	AS12301	6,885	42.96	3.59	53.45	5.71	Invitel Tavkozlesi HU
23	AS4230	1,327	37.91	17.48	44.61	59.44	EMBRATEL-EMPRESA, BR
24	AS34170	1,169	36.36	55.18	8.47	72.00	AZTELEKOM Azerbaijan Tele, AZ
25	AS7552	3,708	35.92	5.02	59.06	96.47	Vietel, VN

*% of clients who appear to use DNSSEC-validating resolvers*

*% of validating clients who exclusively use Google's P-DNS*

*% of clients who use a mix of DNSSEC-validating resolvers and non-validating resolvers*

*% of clients who use non-validating resolvers*

# DNSSEC by Networks - the Top 25

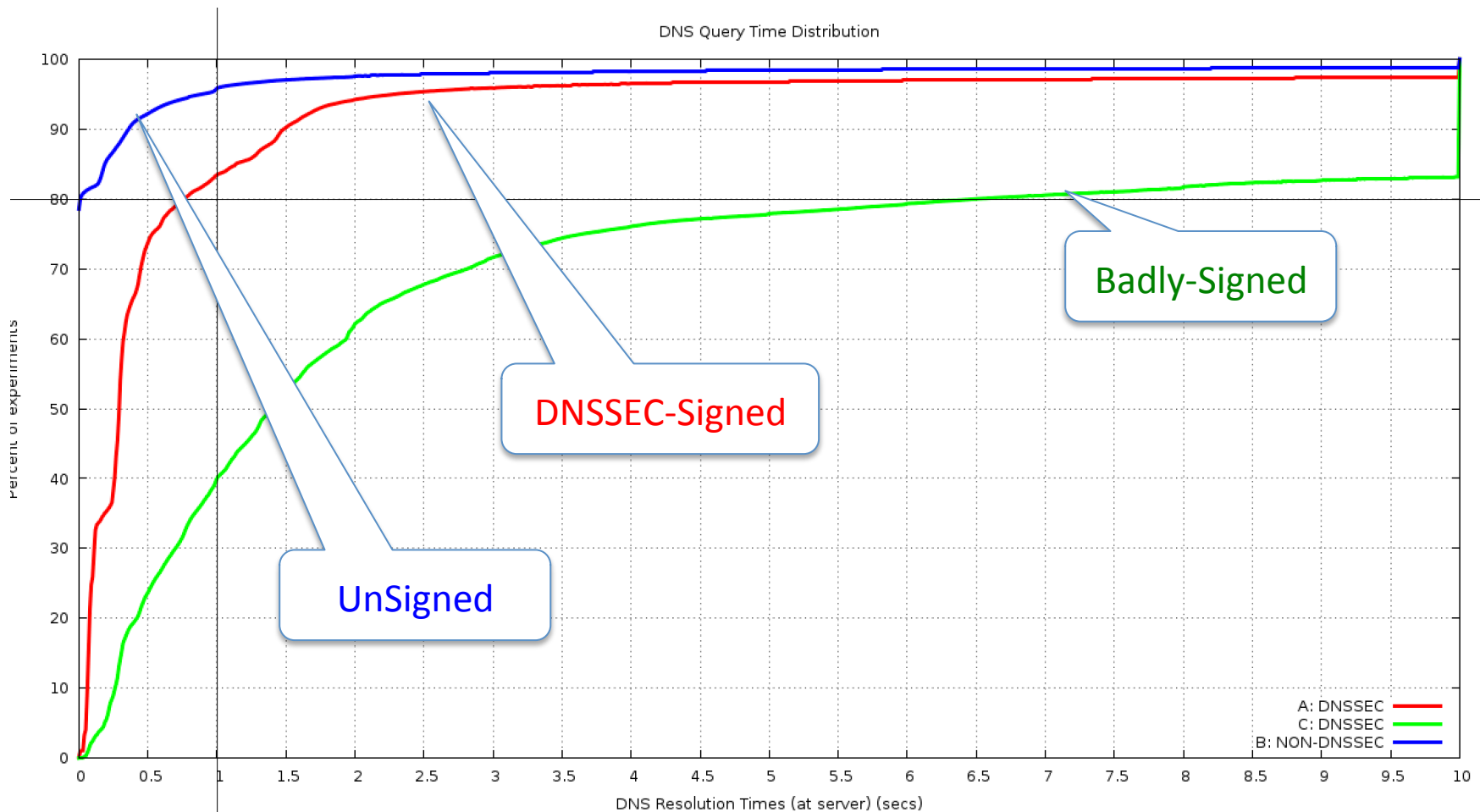
Rank	AS	Count	% D	%x	%A	%G	AS Name
1	AS39651	710	98.73	0.14	1.13	0.71	Com Hem, SE
2	AS27831	627	97.77	2.23	0.00	0.49	Colombia Movil,CO
3	AS12912	1,486	97.71	1.14	1.14	2.34	ERA Polska Telefonnia, PL
4	AS34779	834	96.76	0.84	2.40	1.24	T-2 Slovenia, SI
5	AS29562	582	96.74	0.86	2.41	1.07	Kabel BW GmbH, DE
6	AS5603	1,372	96.72	0.87	2.41	0.53	Telekom Slovenije, SI
7	AS198471	730	96.44	1.10	2.47	99.86	Linkem spa, IT
8	AS719	583	96.05	0.69	3.26	1.07	Elisa Oyj, EU
9	AS5466	2,093	94.70	1.53	3.77	1.21	Eircom, IE
10	AS6849	4,596	92.43	2.15	5.42	3.55	UKRTELECOM, UA
11	AS3301	1,445	91.56	1.45	6.99	1.44	TeliaSonera, SE
12	AS5610	6,889	90.58	2.48	6.94	4.97	TO2 Telefonica Czech Rep., CZ
13	AS7922	24,129	89.57	2.07	8.36	1.09	Comcast Cable, US
14	AS22047	15,274	88.61	9.68	1.71	1.12	VTR BANDA ANCHA, CL
15	AS1257	795	86.29	1.38	12.33	1.60	TELE2, SE
16	AS38511	1,221	79.36	4.18	16.46	10.84	PT Remala Abadi, ID
17	AS2519	523	57.36	3.82	38.81	0.67	VECTANT, JP
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23	AS4230	1,327	37.91	17.48	44.61	59.44	EMBRATEL-EMPRESA, BR
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# DNS Performance

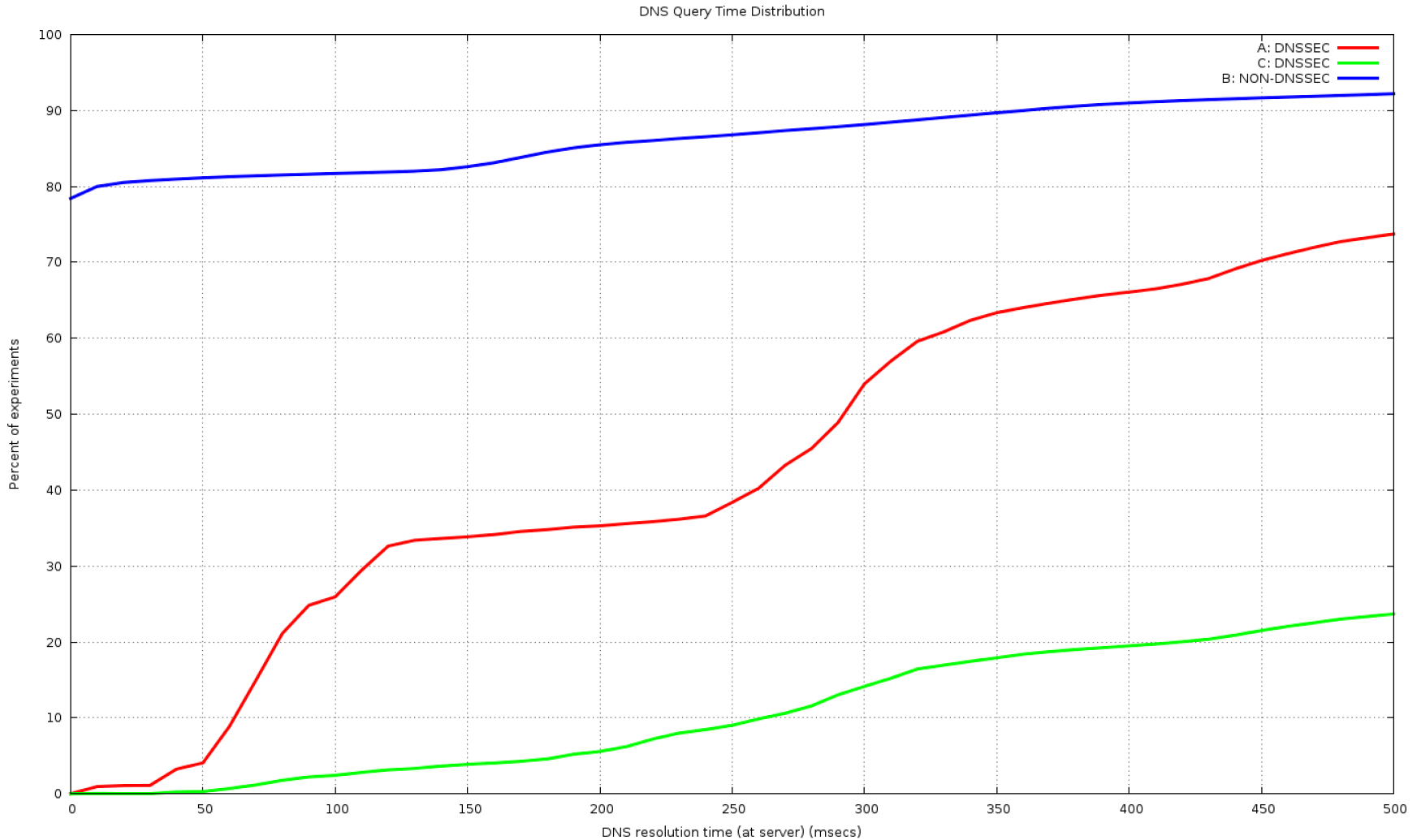
How can we measure the time taken to resolve each of the three domain name types (signed, unsigned, badly signed)?

# Cumulative Time Distribution



*If you perform DNSSEC validation, how long does it take to complete the DNS query process?*

# The first $\frac{1}{2}$ second



*If you perform DNSSEC validation, how long does it take to complete the DNS query process?*

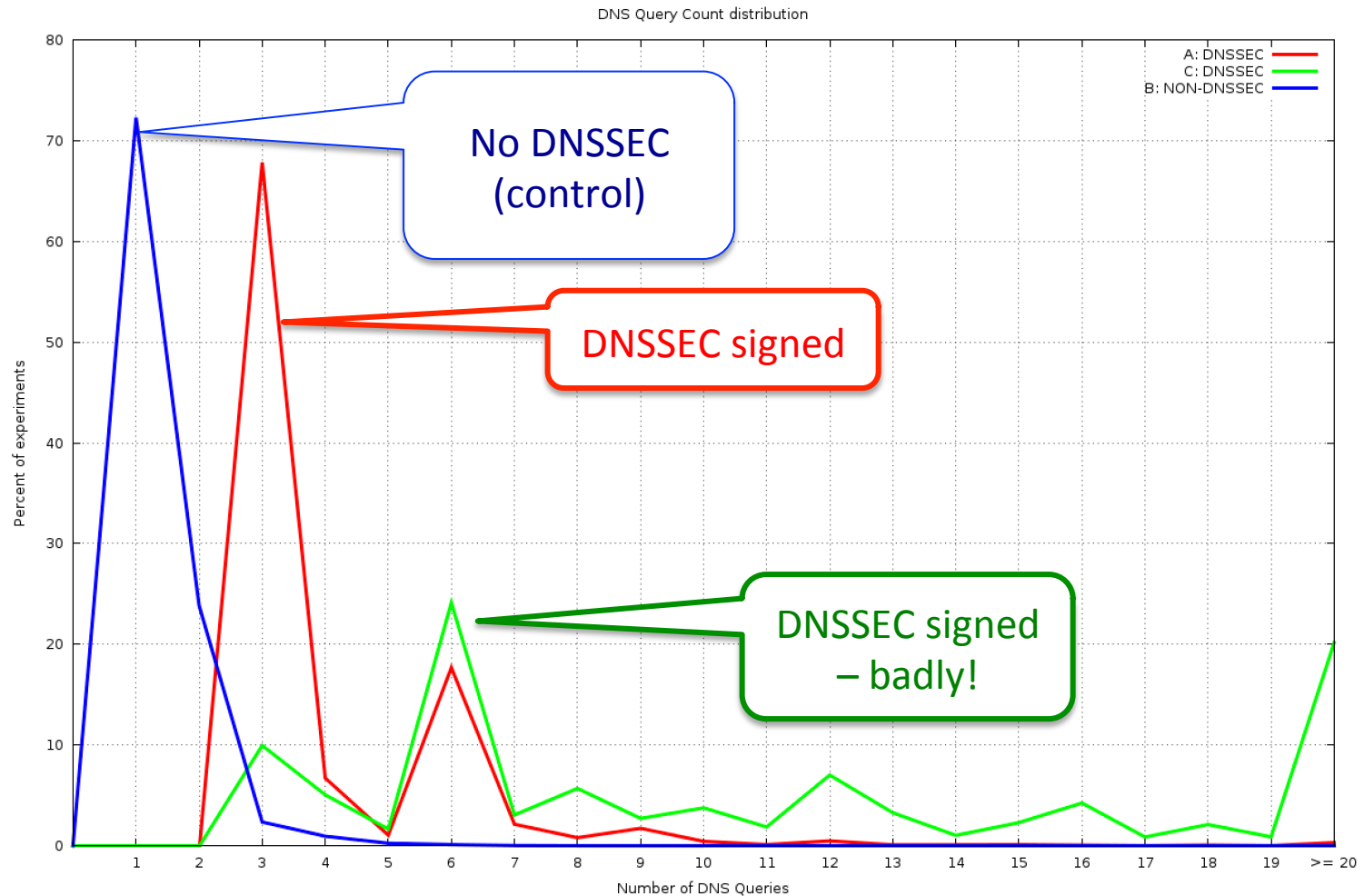
# What can we say?

- DNSSEC takes longer
  - Additional queries for DS and DNSKEY RRs
  - At a minimum that's 2 DNS query/answer intervals
    - Because it appears that most resolvers serialize and perform resolution then validation
- Badly-Signed DNSSEC takes even longer
  - Resolvers try hard to find a good validation path
  - And the SERVFAIL response causes clients to try subsequent resolvers in their list

At the other end...

Lets look at performance from the perspective of an Authoritative Name server who serves DNSSEC-signed domain names

# DNS Query count per Domain Name



*If you perform DNSSEC validation, how many queries are made for you at the Auth. Server?*

# DNSSEC Performance

At the Authoritative Name Server:

Serving DNSSEC-signed zones = More Queries!

- The Authoritative server will now see additional queries for the DNSKEY and DS RRs for a zone, in addition to the A (and AAAA) queries

**2,637,091** launched experiments

**4,222,352** unsigned name queries

**7,394,794** signed name queries

**12,213,677** badly-signed name queries

# What if everybody was doing it?

For the control name there are 1.6 queries per experiment

The total profile of queries for the control DNS name was:

3.4M A queries

0.4M AAAA queries

0.4M Other (NS, MX, ANY, SOA, CNAME, TXT, A6) queries

For the signed name, only 12.6% of clients use DNSSEC-aware resolvers, so the theory (2 additional queries per name) says we will see 4.8M queries

But we saw 7.4M queries for the signed DNS Name

- If 12.6% of clients' resolvers using DNSSEC generate an additional 3.1M queries for a signed domain name, what if every DNS resolver was DNSSEC aware?
- That would be 25M queries in the context of our experiment!

**A DNSSEC signed zone would see 6 times the query level of an unsigned zone if every resolver performed DNSSEC validation**



# Good vs Bad for Everyone

If 12.6% of clients performing some form of DNSSEC validation generate 12.2M queries for a badly-signed name, compared to the no-DNSSEC control level of 4.2M queries, what would be the query load if every resolver performed DNSSEC validation for the same badly signed domain?

- In our case that would be 63M queries!

**A badly-signed DNSSEC signed zone would see 15 times the query level of an unsigned zone if every resolver performed DNSSEC validation**

# Response Sizes

What about the relative traffic loads at the server?

In particular, what are the relative changes in the traffic profile for responses from the Authoritative Server?

# DNS Response Sizes

## Control (no DNSSEC)

Query: 124 octets

Response: 176 octets

## DNSSEC-Signed

Query: (A Record) 124 octets

Response: 951 Octets

Query: (DNSKEY Record) 80 octets

Response: 342 Octets

Query: (DS Record) 80 octets

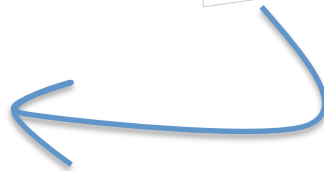
Response: 341 Octets

Total: Query: 284 octets

Total Response: 1634 octets

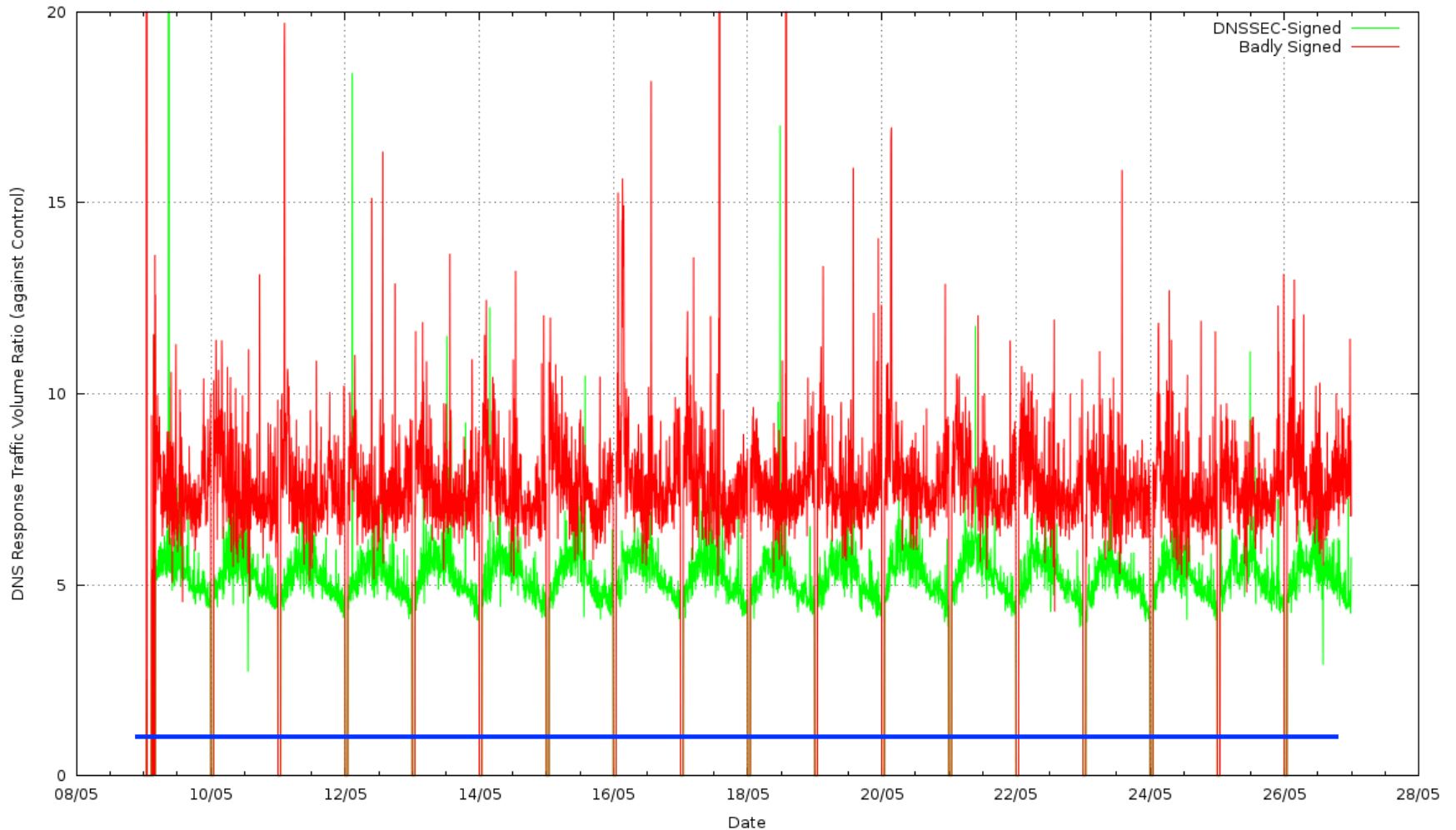
These are not constant sizes - the DNS packet sizes of responses relate to the particular name being resolved, the number of keys being used, and the key size

So these numbers are illustrative of what is going on, but particular cases will vary from these numbers



# Measurement - Response Traffic Volume

Relative Traffic Levels for DNSSEC Zones vs Unsigned Zone



# Interpreting Traffic Data

- The validly-signed domain name appears to generate ~5x the traffic volume in responses as compared to the unsigned domain name
- The badly-signed domain name appears to generate ~7.5x the traffic volume in responses
- What's contributing to this?
  1. Setting the DNSSEC OK bit in a query to the signed zone raises the response size from 176 to 951 octets
  2. Performing DNSSEC signature validation adds a minimum of a further 683 octets in the DS and DNSKEY responses

# What if you just sign your domain?

Lets start with the hypothetical question: How much more traffic will you be generating at the Authoritative Server if you sign your domain and NO resolvers perform DNSSEC validation?

**76% of clients use resolvers who pass our server queries with EDNS0 + DNSSEC OK flag set**

69% of queries for the unsigned zone

75% of queries for the signed zone

83% of queries for the badly-signed zone

(aside: why are these proportions different for each of these zones?)

If you just sign your zone and no resolvers are performing DNSSEC validation

Then from the May data, 69% of queries elicit a larger response then the total outbound traffic load is **4x** the traffic load of an unsigned zone

But we saw a rise of **5x** – why?

That's because 12.6 % of clients are also performing DNSSEC validation

# What if everybody was doing it?

If 12.6% of clients performing some form of DNSSEC validation for a signed zone generate around 5 times the traffic as compared to an unsigned zone, then what if every resolver performed DNSSEC validation?

**An authoritative server for a DNSSEC signed zone would've seen 13 times the traffic level of an unsigned zone if every resolver**

**A badly-signed DNSSEC zone would seen 31 times the traffic level of an unsigned zone**

# DNSSEC means you probably need more Server Foo

- Its probably a good idea to plan the serve the worst case: a badly signed zone
- In which case you may want to consider provisioning the authoritative name servers with processing capacity to handle **15x the query load**, and **30x the generated traffic load** that you would need to serve an unsigned zone



# It could be (a lot) better

“Real” performance of DNSSEC could be a lot better than what we have observed here

We have deliberately negated any form of resolver caching

- Every client receives a “unique” signed URL, and therefore every DNS resolver has to perform A, DS and DNSKEY fetches for the unique label
- The Ad placement technique constantly searches for “fresh eyeballs”, so caching is not as efficient as it could be
- Conventional DNS caching would dramatically change this picture
  - Our 16 day experiment generated 12,748,834 queries
  - A 7 day TTL would cut this to a roughly estimated 2M queries

# And it could be (a lot) worse

For the invalid DNSSEC case we deliberately limited the impact of invalidity on the server by using a single NS

- DNSSEC invalidity is not handled consistently by resolvers
- Some resolvers will perform an exhaustive check of all possible NS validation paths in the event of DNSSEC validation failure
  - See “Roll Over and Die” (<http://www.potaroo.net/ispcol/2010-02/rollover.html>)
- In this experiment we used a single NS record for the domains
- If we had chosen to use multiple nameservers, or used a deeper-signed label path, or both, on the invalid label, then the query load would’ve been (a lot) higher
- Resolver caching of invalidly signed data is also unclear – so a break in the DNSSEC validation material may also change the caching behaviour of resolvers, and increase load at the server

# So where are we?

User Measurement provides a rich feedback channel about how technology is being deployed - there is much more to learn here about the behaviour of the DNS

And much to think about in terms of security, robustness, scalability and performance of the DNS

Thanks!



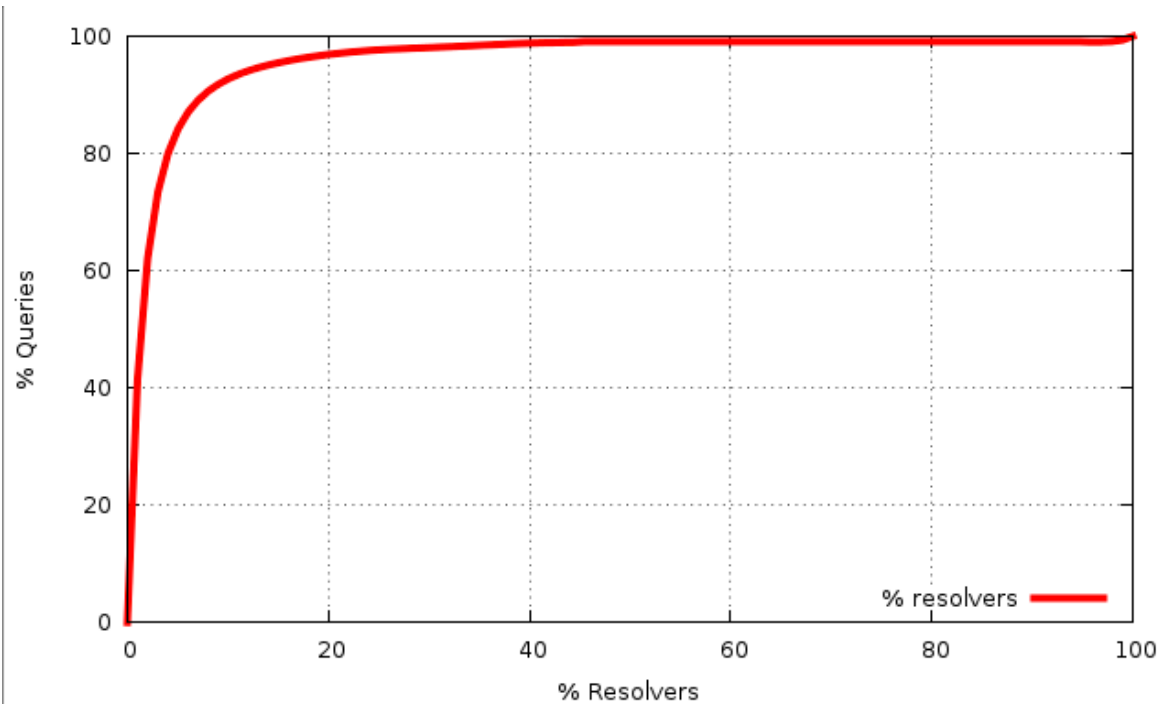
Questions?

# Some things to think about

- DNSSEC generates very large responses from very small queries
  - Which makes it a highly effective DDOS amplifier
  - Is relying on BCP38 going to work?
  - Do we need to think about DNS over TCP again?
  - But how many resolvers/firewalls/other middleware stuff support using TCP for DNS?
  - What's the impact on the authoritative server load and caching recursive resolver load when moving from UDP to TCP?

# Some things to think about

- 1% of visible resolvers provide the server with 58% of the seen queries
- A few resolvers handle a very significant proportion of the total query volume
- But there are an awful lot of small, old, and poorly maintained resolvers running old code out there too!



# Some things to think about

- Google's Public DNS is currently handling queries from 7.5% of the Internet's end client population
  - That's around 1 in 13 users
  - In this time of heightened awareness about corporate and state surveillance, and issues around online anonymity and privacy, how do we feel about this level of use of Google's Public DNS Service?

# Some things to think about

SERVFAIL is not just a “DNSSEC validation is busted” signal

- clients start walking through their resolver set asking the same query
- Which delays the client and loads the server
  - The moral argument: Failure should include a visible cost!
  - The expedient argument: nothing to see here, move along!

Maybe we need some richer signaling in the DNS for DNSSEC validation failure



# Some things to think about

Olde Code never seems to die out

We still see A6 queries!

So what about Key rollover and RFC5011 support?

How many resolvers don't support RFC5011 in their key management?

We don't know because we can't get resolvers to signal their capability

If we roll the TA, and if resolvers have hand-installed trust, and don't implement RFC5011 signalling

How many will say "broken DNSSEC" when the old sigs expire?

How many will re-query per NS high in the tree to the authoritative servers?

What percentage of of worldwide DNSSEC will do this?

# Some things to think about

Why do up to 80% of queries have EDNS0 and the DNSSEC OK flag set, yet only 1/10 of that (8.3% of clients) perform DNSSEC validation?

How come we see relatively more queries with the DNSSEC OK flag set for queries to domains in signed zones?

And relatively more when the zone is invalidly signed?