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The User Side of DNSSEC

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APNIC

What is DNSSEC? (the ultra-short version)

DNSSEC adds Digital Signatures to DNS

- All DNS “data” is signed by the Zone Admin’s private key
- All DNS “gaps” are signed by the Zone key
- All DNS responses include the signature over the response data

This is a counter to various forms of DNS cache poisoning attacks, DNS MITM attacks and some other forms of attack on the integrity of the DNS

- (Other DNS vulnerabilities exist, so DNSSEC is not a panacea!)

Let's look at USING DNSSEC…

Our Questions…

- What proportion of the Internet’s users will perform DNSSEC validation if they are presented with a signed domain?

- Where are these DNSSEC-validating users?

- What is the performance overhead of serving signed names?

The Experiment

Each user is presented with three URLs to load:

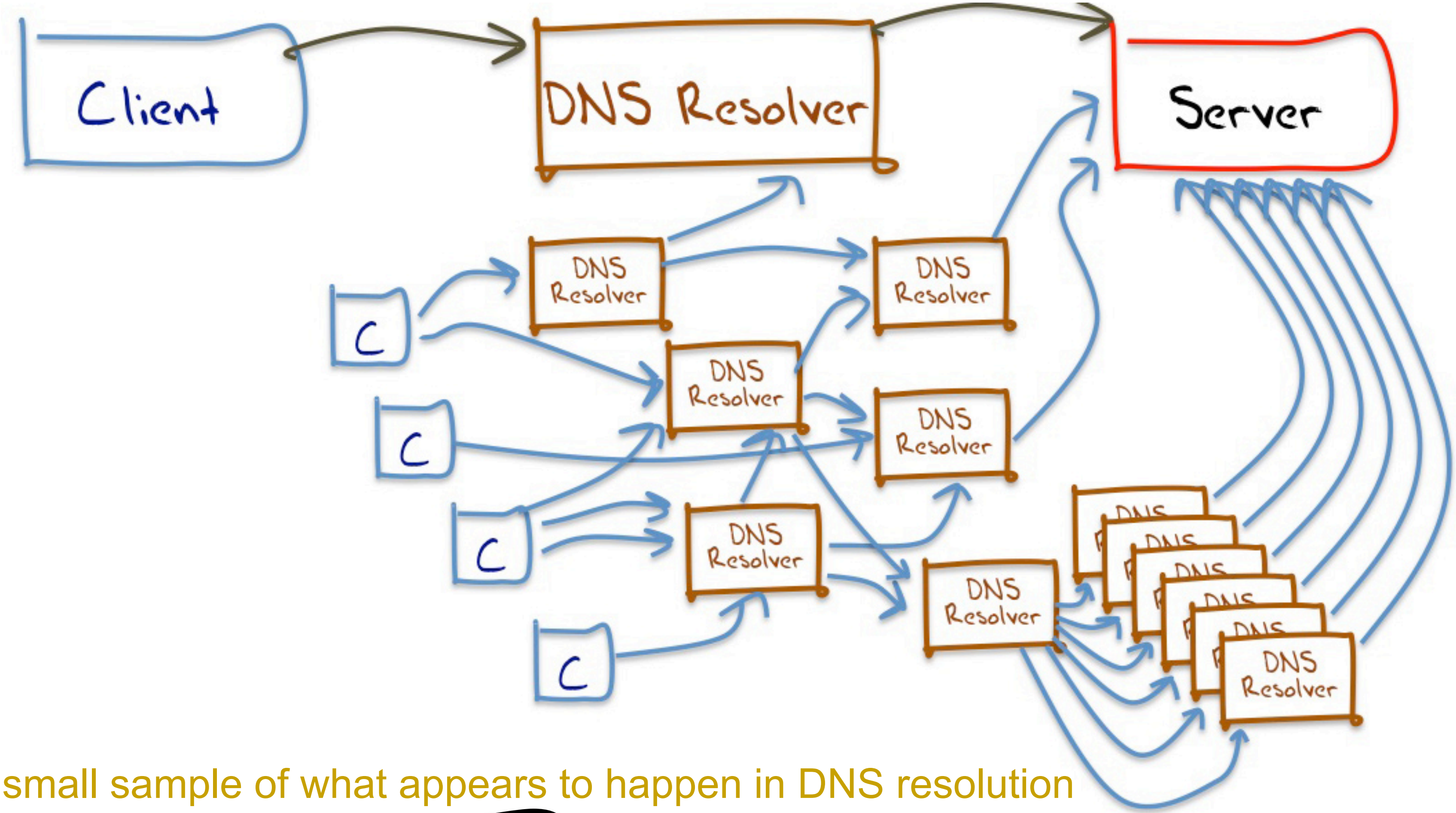
the good (DNSSEC signed)

the bad (invalid DNSSEC signature)

the control (no DNSSEC at all)

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

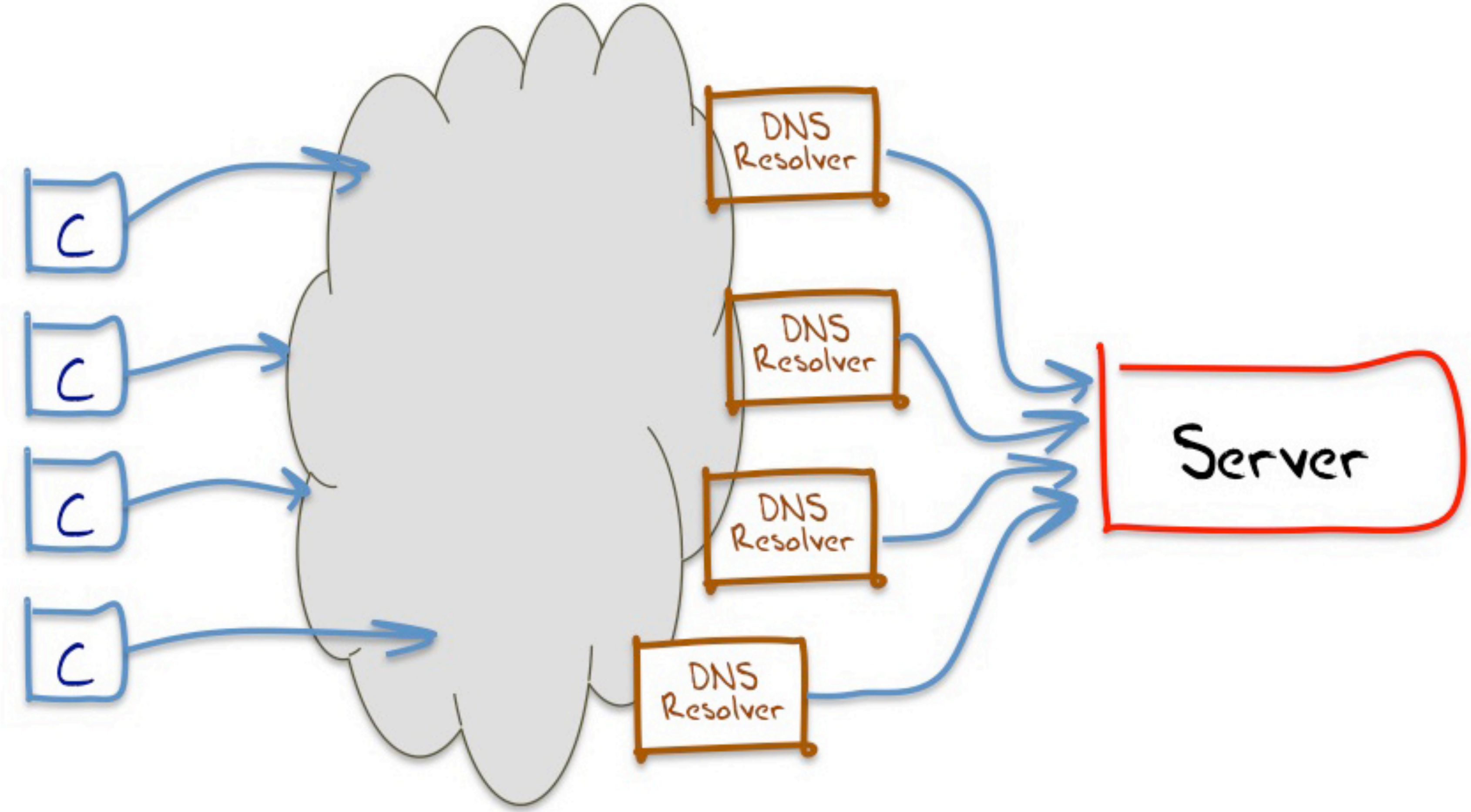
Understanding DNS Resolvers is "tricky"



A small sample of what appears to happen in DNS resolution

Understanding DNS 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 the ratio of the number of resolvers we cannot see compared to the resolvers we can see from the perspective of an authoritative name server

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

The Results

- Reported: 2,498,497 experiments that ran to “completion”

Web + DNS query log results for clients:

- Performed DNSSEC signature validation: **8.3%**
- Fetched DNSSEC RRs but then retrieved the object anyway: **4.3%**
- No DNSSEC; only fetched A RRs: **87.4%**

Who uses DNSSEC? – The Top 20

Rank	CC	Count	% D	% x	% A	Country
1	SE	5,349	77.92	3.38	18.70	Sweden
		4,	58.85	4.90	36.25	Slovenia
		52	43.87	.90	49	Luxembourg
		26,665	38.28	.04	5	Vietnam
		2,456	37.01	.29		
		30,827	33.20	.08		ublic
		46,151	30.26	8.34		
		1,545	28.22	3.11		
9	IE	8,079	27.9	3.11		
10	BB			2		
11	ID			8	67.55	Indonesia
12	UA			5	65.60	Ukraine
13	ZA			6	69.48	South Africa
14	TR			0	79.84	Turkey
15	US	1		7	79.11	United States of America
16	EG			2	75.01	Egypt
17	GH			2	77.29	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 a mix of DNSSEC-validating resolvers and non-validating resolvers

% of clients who use 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?

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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
18	AZ	7,409	14.55	30.34	55.11	Azerbaijan
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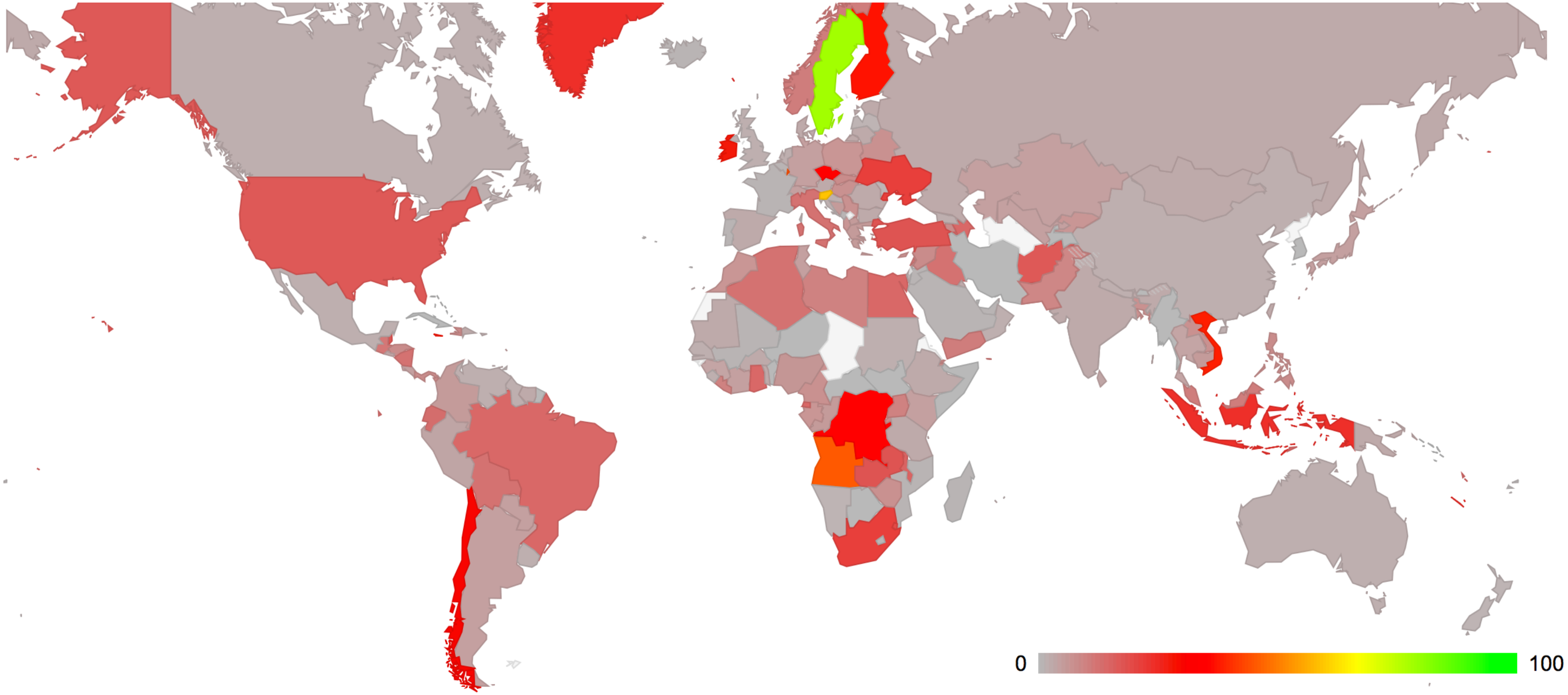
The Mapped view of DNSSEC Use



% of users who use DNSSEC-validating resolvers

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			->	7.89	0.21	91.89	Slovenia
3	LU				1.40	0.00	60	Luxembourg
4	VN			->	96.66	2.25	09	Vietnam
5	FI			->	2.64	0.		d
6	CZ			->	11.71	3.		Republic
7	CL			->	3.62	0.		
8	JM			->	91.	0.		a
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16	EG	36,061	14.68			9.88	3.84	Egypt
17	GH	973	14.59			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	Occ. Palestine

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

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

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

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

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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	AS39651	710	98.73	0.14	1.13	0.71	Com Hem, SE
2	AS27831	6[illegible]	97.77	2.23	0.00	0.49	Colombia Movil,CO
[illegible]	[illegible]	[illegible]	97.71	1.14	1.1	2.34	ERA Polska Telefonia, PL
[illegible]	[illegible]	[illegible]	96.76	.84	2.4	1.24	T-2 Slovenia, SI
[illegible]	[illegible]	[illegible]	96.74	.86	2.41	1.07	el BW GmbH, DE
[illegible]	[illegible]	[illegible]	96.72	.87	2.41	0.53	Te om Slovenije, SI
[illegible]	[illegible]	[illegible]	96.44	10	2.47	99.86	Link pa
[illegible]	[illegible]	[illegible]	96.05	69	3.26	1.07	Elisa
[illegible]	[illegible]	[illegible]	94.70	.53	3.77	1.21	Eircom,
[illegible]	[illegible]	[illegible]	92.43	.15	5.42	3.55	UKRTELECOM
[illegible]	[illegible]	[illegible]	91.56	.45	6.99	1.44	TeliaSonera
12	AS5610	6,889	90.58	.48	6.94	4.97	TO2 Telefo
13	AS7922	24	[illegible]	[illegible]	8.36	.09	Comcast Ca
14	AS22047	15	[illegible]	[illegible]	1.71	12	VTR BANDA
15	AS1257	[illegible]	[illegible]	[illegible]	12.33	60	TELE2, SE
16	AS38511	1	[illegible]	[illegible]	16.46	[illegible]	a Abadi, ID
17	AS2519	[illegible]	[illegible]	[illegible]	38.81	[illegible]	JP
18	AS1759	[illegible]	[illegible]	[illegible]	21.71	[illegible]	era, FI
19	AS2819	[illegible]	[illegible]	[illegible]	36.10	[illegible]	S Czech, CZ
20	AS45899	14	[illegible]	[illegible]	50.91	[illegible]	[illegible]
21	AS27738	[illegible]	[illegible]	[illegible]	14.11	[illegible]	elecom, EC
22	AS12301	6	[illegible]	[illegible]	53.45	[illegible]	Tavkozlesi HU
23	AS4230	1,327	37.91	17.48	44.61	[illegible]	-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

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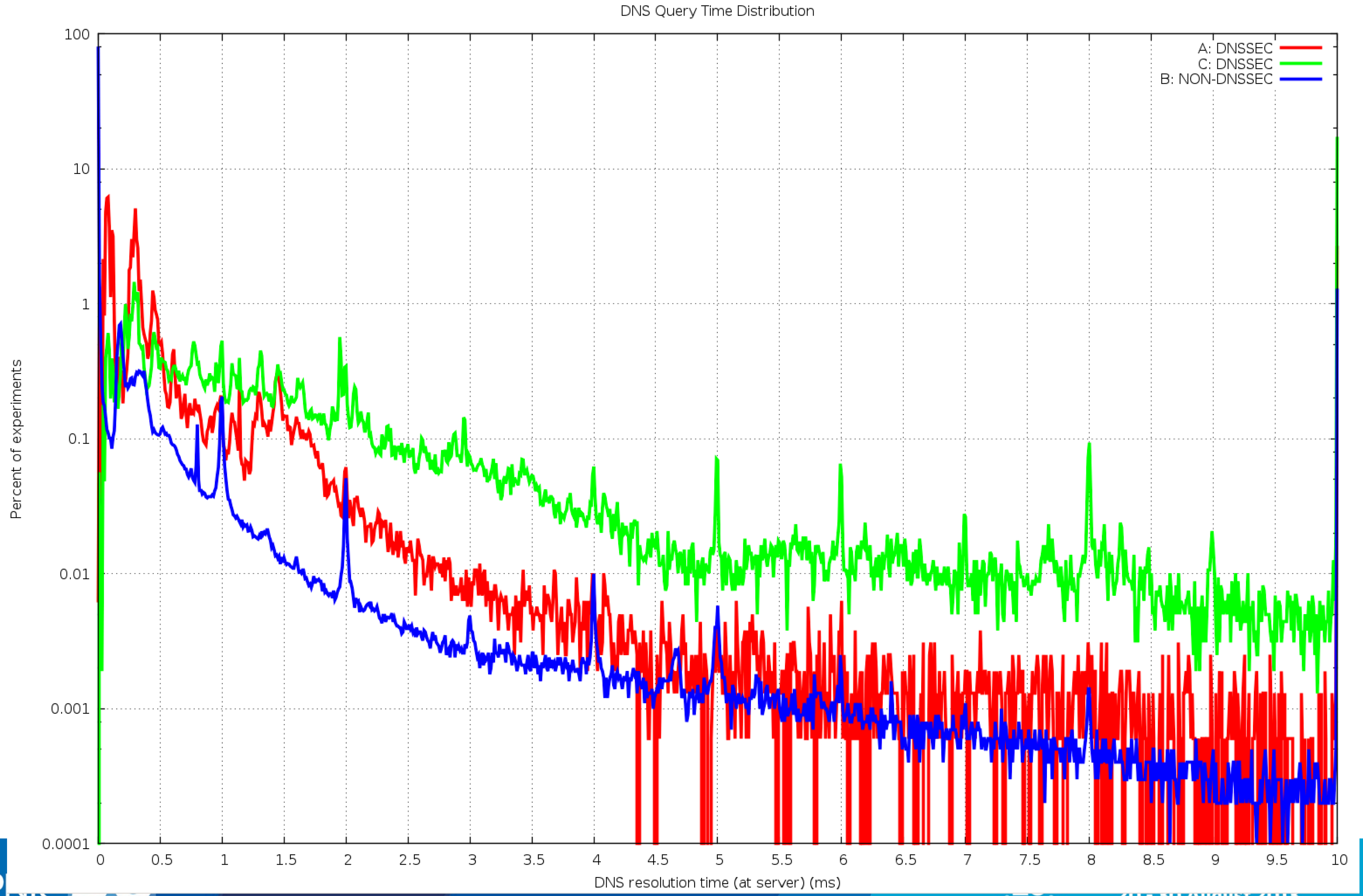
2	AS27831	627	97.77	2.23	0.00	0.49	Colombia Movil,CO
3	AS12912	1,486	97.71	1.14	1.14	2.34	ERA Polska Telefonia, PL
4	AS34779	834	96.76	0.84	2.40	1.24	T-2 Slovenia, SI
5	AS29562	582	96.74	0.86	2.41	1.07	Kabel BW GmbH, DE
6	AS5603	1,372	96.72	0.87	2.41	0.53	Telekom Slovenije, SI
7	AS198471	730	96.44	1.10	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
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

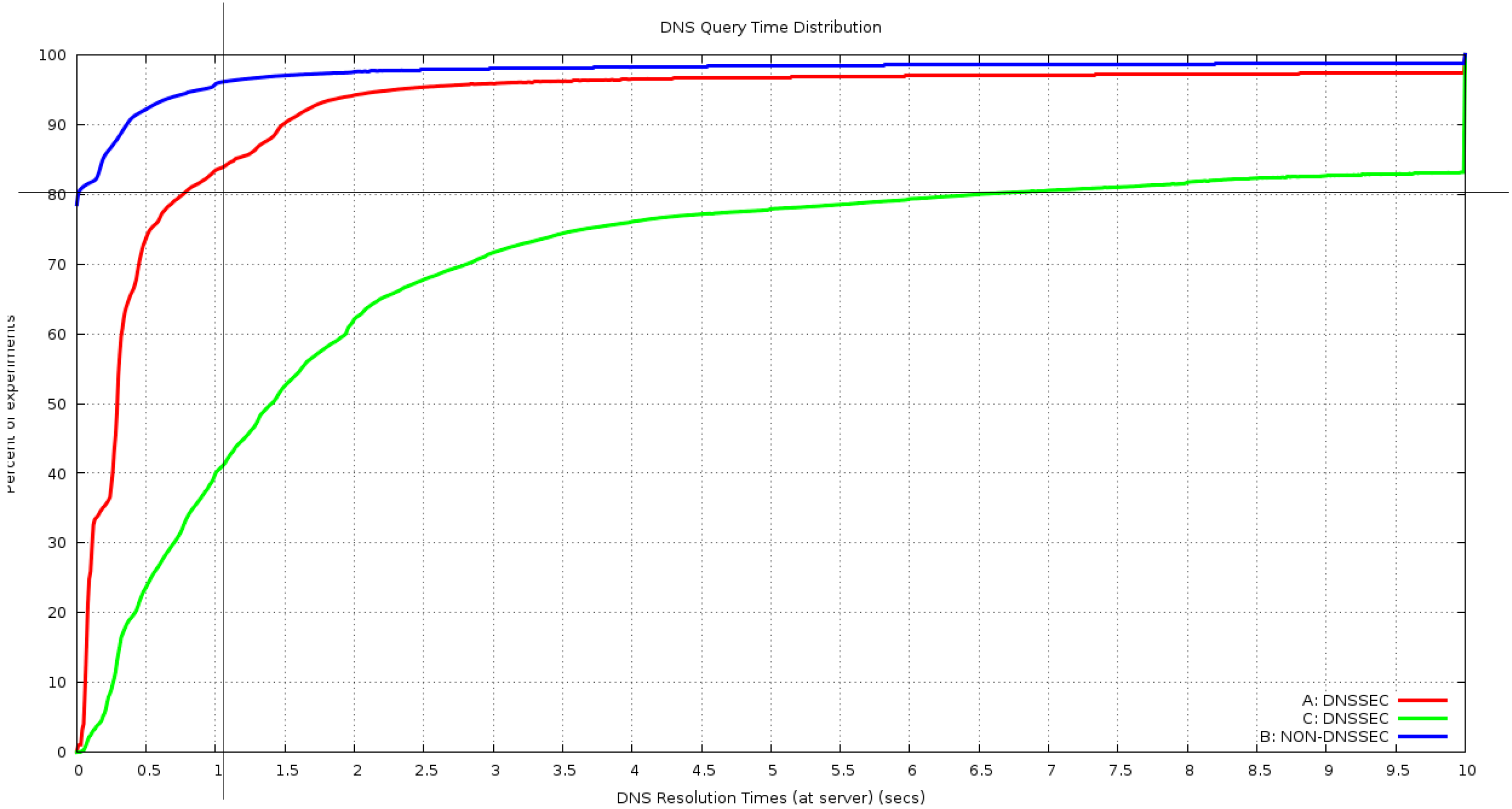
DNS Performance

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

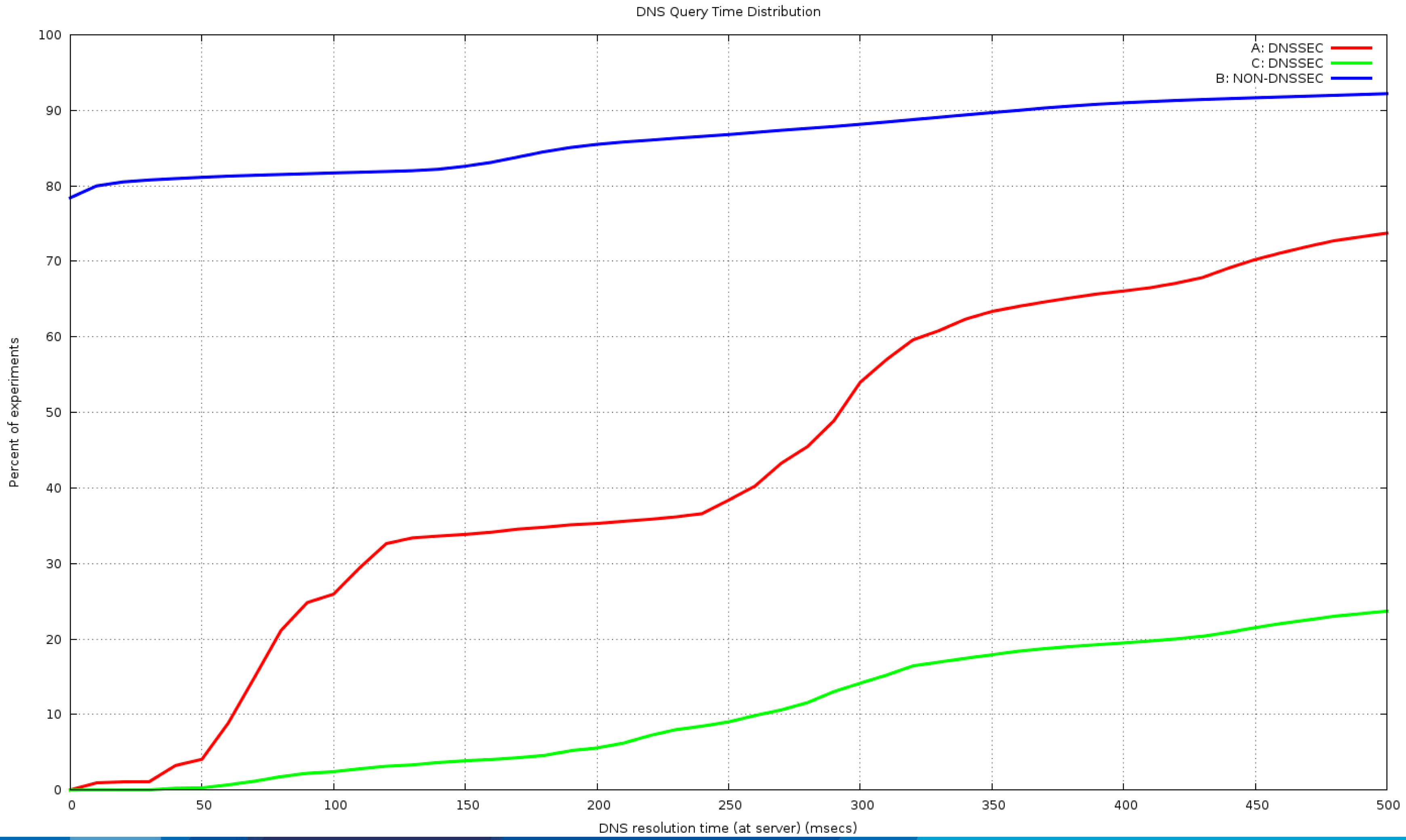
DNS Query Time



Cumulative Time Distribution



The first ½ second



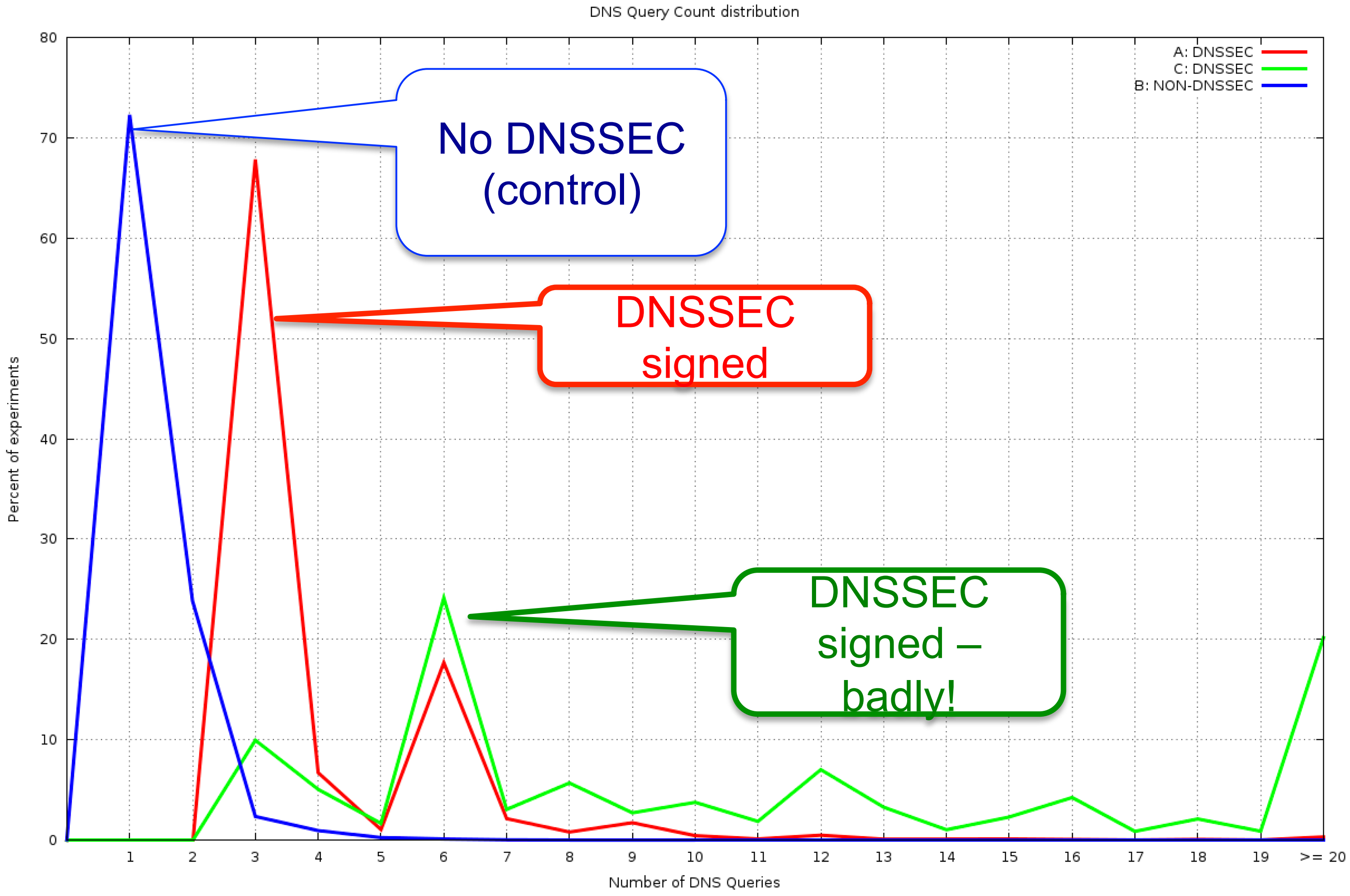
What can we say?

- DNS itself has its own performance issues
  - 20% of clients take 2 or more queries for a simple address query
  - 8% take longer than 500ms to complete the DNS query
- 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 serialise 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



No DNSSEC (control)

DNSSEC signed

DNSSEC signed – badly!

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

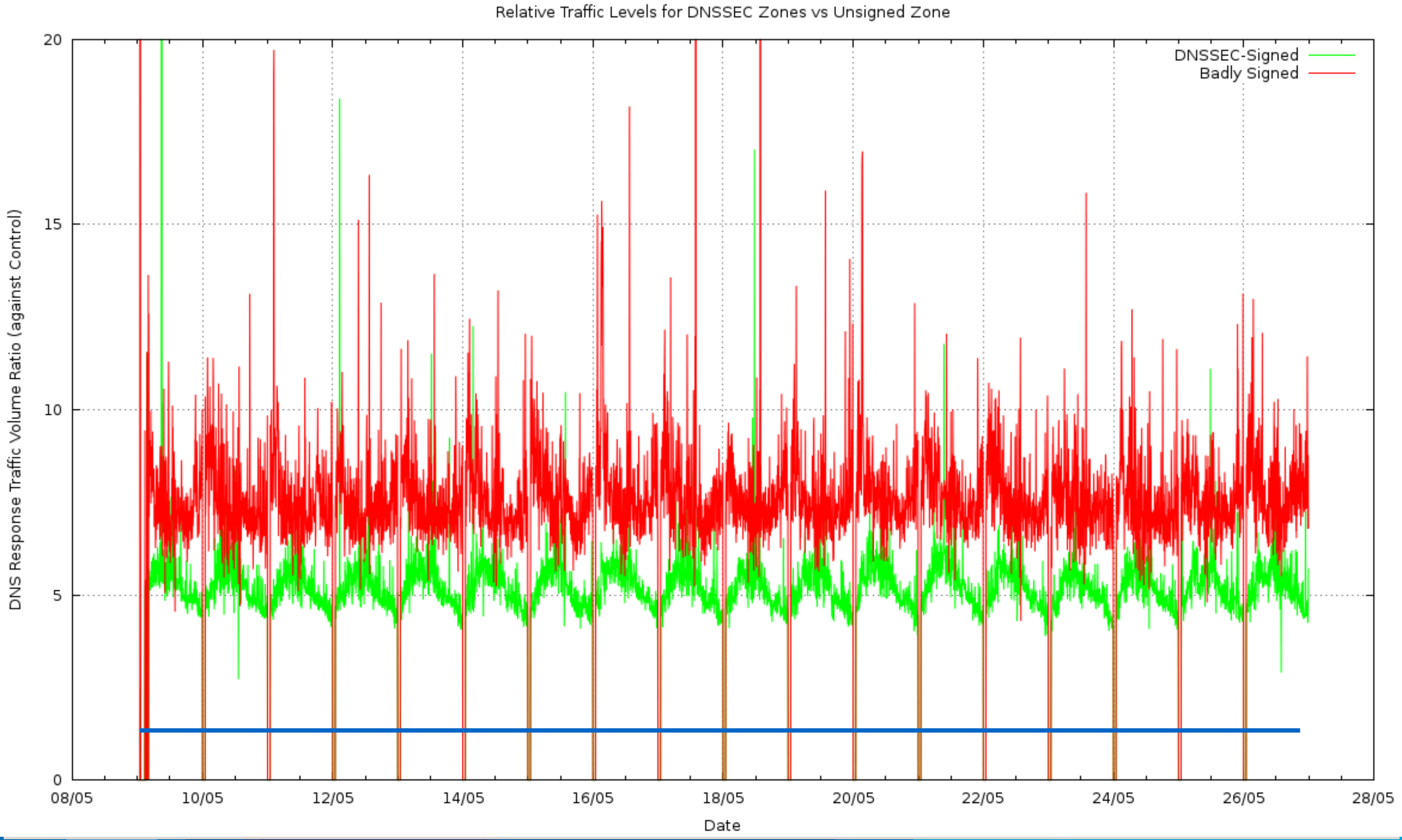
Query: (DS Record) 80 octets
Response: 341 Octets

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 resolver, 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



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 (80% of clients do this)
  2. Performing DNSSEC signature validation adds a minimum of a further 683 octets in DS and DNSKEY responses (12% of clients do this)

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 performed DNSSEC validation

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

DNSSEC means more Server capacity needed

- 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 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 (far) worse…

- For the invalid DNSSEC case we deliberately limited the impact of invalidity on the server
  - 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
  - In this experiment we used a single NS record for the invalidly signed 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

Something 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?
  - 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?

Thanks!

Questions?