Network Security 6: DNSSEC

TOP DEFINITION

Infosec

A profession that turns normal people into whiskey drinking, swearing, paranoid, disheartened curmudgeons with no hope for the future of computers or humanity.

Hi, I work in Infosec. Please pass the whiskey.
No, I won't fix your computer.

@joXn@weirder.earth @joXn · 14 Sep 2018

Keeping our workplace safe!

It has been −32768 days since the last integer overflow incident.

8 21

SwiftOnSecurity Retweeted

Not like the rapper @naztynaz_ · Mar 12

DID YALL KNOW IF YOU RECORD AUDIO AND TAKE NOTES USING ONENOTE, YOU CAN GO BACK TO A LINE IN YOUR NOTES AND HEAR WHAT THE PROFESSOR WAS SAYING AT THE TIME YOU TYPED THOSE NOTES. IT'S ALL SYNCED

I wish I knew this as a freshman

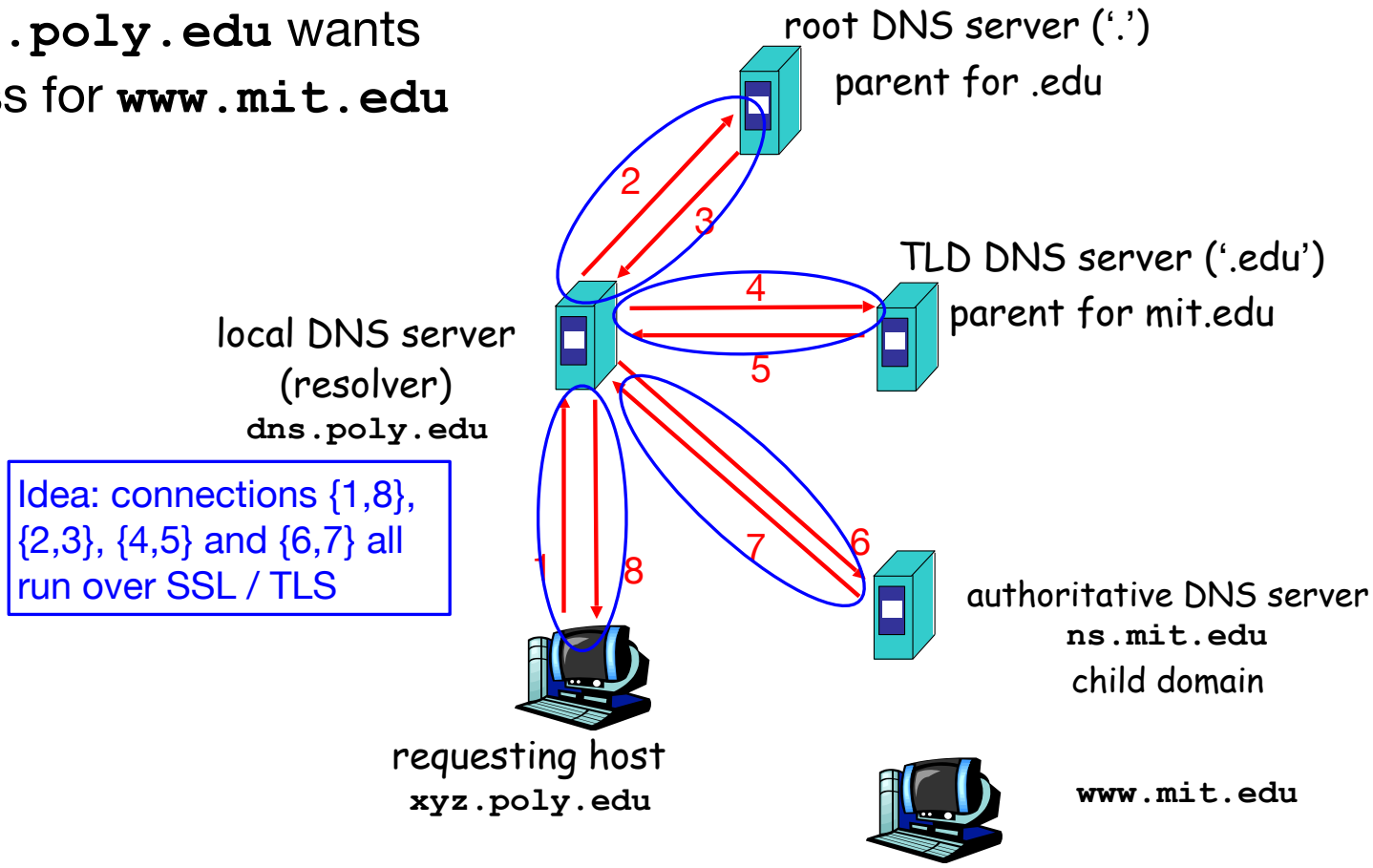
19 92 403

A Warning:
I'm Giving ***Unfiltered*** DNSSEC

- Why?
  - Because it is a well thought through cryptographic protocol designed to solve a real world data integrity problem
  - It is a real world PKI with some very unique trust properties:
    - A constrained ***path of trust*** along ***established business relationships***.
  - It is important to appreciate the real world of what it takes to build a secure system
  - I've worked with it for far too much for my own sanity...
  - And I'm a ***cruel bastard***

Hypothetical:
Securing DNS Using SSL/TLS

Host at **`xyz.poly.edu`** wants
IP address for **`www.mit.edu`**



But This Doesn't Work

- TLS provides ***channel*** integrity, but we need ***data*** integrity
- TLS in this scheme is not ***end to end***
  - In particular, the recursive resolver is a ***known adversary:***
    - "NXDOMAIN wildcarding": a "helpful" page when you give a typo
    - Malicious MitM of targeted schemes for profit
- TLS in this scheme is ***painfully slow***:
  - DNS lookups are 1 RTT, this is 3 RTTs!
- And ***confidentiality*** is of little benefit:
  - We use DNS to contact hosts:
    Keeping the DNS secret doesn't actually disguise who you talk to!

DNS security:
If the Attacker sees the traffic...

- All bets are off:
  - DNS offers NO protection against an on-path or in-path adversary
    - Attacker sees the request, sends the reply, and the reply is accepted!
- The recursive resolver is the most common in-path adversary!
  - It is implicitly trusted
  - Yet ***often abuses*** the trust
- And this scheme keeps the resolver as the in-path adversary

So Instead Let's Make DNS a PKI and records certificates

- **`www.berkeley.edu`** is already trusting the DNS authorities for **`berkeley.edu`**, **`.edu`**, and **`.`** (the root)
  - Since **`www.berkeley.edu`** is in bailiwick for all these servers and you end up having to contact all of them to get an answer.
- So let's start signing things:
  - . will sign .edu's key
  - .edu will sign Berkeley's key
  - Berkeley's key will sign the record
- DNSSEC: DNS Security Extensions
  - A heirarchical, distributed trust system to validate the mappings of names to values

Enter DNSSEC
(DNS Security Extensions)

- An extension to the DNS protocol to enable cryptographic authentication of DNS records
  - Designed to prove the value of an answer, ***or that there is no answer***!
  - A restricted path of trust
    - Unlike the HTTPS CA (Certificate Authority) system where your browser trusts every CA to speak for every site
- With backwards compatibility:
  - Authority servers don't need to support DNSSEC
    - But clients should know that the domain is not secured
  - Recursive and stub resolvers that don't support DNSSEC must not receive DNSSEC information

Reminder:
DNS Message Structure

- DNS messages:
  - A fixed header: Transaction ID, flags, etc...
  - 1 question: Asking for a name and type
  - 0-N answers: The set of answers
  - 0-N authority: ("glue records"): Information about the authority servers and/or ownership of the domain
  - 0-N additional: ("glue records"): Information about the authority server's IP addresses
    - Glue records are needed for the resolution process but aren't the answer to the question

Reminder:
DNS Resource Records and RRSETs

- DNS records (Resource Records) can be one of various types
  - Name TYPE TTL Value
- Groups of records of the same name and type form RRSETs:
  - E.g. all the nameservers for a given domain.
  - All the records in the RRSET have the same name, type, and TTL

The First New Type: OPT

- DNS contains some old limits:
  - Only 8 total flag bits, and messages are limited to 512B
- DNSSEC messages are much bigger
- DNSSEC needs two additional flags
  - DO: Want DNSSEC information
  - CD: Don't check DNSSEC information
- EDNS0 (Extension Mechanisms for DNS) adds the OPT resource record
  - Sent in the ***request*** and reply in the additional section
    - Uses CLASS field to specify how large a UDP reply can be handled
    - Uses TTL field to add 16 flag bits
      - Only flag bit currently used is DO
  - Used to signal to the authority that the client desires DNSSEC information

EDNS0 in action

- A query using **`dig +bufsize=1024`** uses EDNS0

```
nweaver% dig +norecurse +bufsize=1024 slashdot.org @a.root-servers.net

; <<>> DiG 9.8.3-P1 <<>> +bufsize=1024 slashdot.org @a.root-servers.net
;; global options: +cmd
;; Got answer:
;; ->>HEADER<<- opcode: QUERY, status: NOERROR, id: 13419
;; flags: qr; QUERY: 1, ANSWER: 0, AUTHORITY: 6, ADDITIONAL: 13

;; OPT PSEUDOSECTION:
; EDNS: version: 0, flags:; udp: 4096

;; QUESTION SECTION:
;slashdot.org.                  IN      A

;; AUTHORITY SECTION:
org.                    172800  IN      NS      a0.org.afilias-nst.info.
...
```

The second new type, a certificate: **RRSIG**

- A signature over an RRSET (not just a single answer): Multiple fields
  - Type: The DNS type which this is the RRSIG for
  - Algorithm: IANA assigned identifier telling the encryption algorithm
  - Labels: Number of segments in the DNS name
  - Original TTL: The TTL for the record delivered by the authority
  - Signature Expiration
  - Signature Inception
    - Both in seconds since January 1, 1970
  - Key tag: What key was used (roughly. Its a checksum on the key bits)
  - Signer's name
  - Signature

So an **RRSIG** in action (The **NS** entries for **isc.org.**)

- Type of the record its an RRSIG for
- Algorithm #5: RSA/SHA-1
- 2 labels in the name
- 7200s initial TTL

- Valid 2013-04-15-23:32:55 to 2013-05-15-23:32:53
- Key tag 50012
- Key belongs to isc.org.
- And lots of cryptogarbage...

```
nweaver% dig +dnssec NS isc.org @8.8.8.8
...

;; ANSWER SECTION:
isc.org.                4282    IN      NS      ns.isc.afilias-nst.info.
isc.org.                4282    IN      NS      sfba.sns-pb.isc.org.
isc.org.                4282    IN      NS      ord.sns-pb.isc.org.
isc.org.                4282    IN      NS      ams.sns-pb.isc.org.
isc.org.                4282    IN      RRSIG   NS 5 2 7200 20130515233253
20130415233253 50012 isc.org. HUXmb89gB4pVehWRcuSkJg020gw2d8QMhTrcu1ZD7nKomXHQFupXl5vT
iq5VUREGBQtnT7FEdPEJlCiJeogbAmqt3F1V5kBfdxZLe/EzYZgvSGWq sy/VHI5d+t6/
EiuCjM01UXCH1+L0YAqiHox5gsWMzRW2kvjZXhRHE2+U i1Q=
```

How Do We Know What Key To Use Part 1: `DNSKEY`

- The **`DNSKEY`** record stores key information
  - 16 bits of flags
  - Protocol identifier (always 3)
  - Algorithm identifier
  - And then the key itself
- The keys are split into multiple roles
  - The Key Signing Key (KSK) is used only to sign the **`DNSKEY`** RRSET
  - The Zone Signing Key (ZSK) is used to sign everything else
- The client has hardwired in one key for .
  - This is the root's KSK (Key Signing Key)

The **DNSKEY** for .

- The first is the root's ZSK
- The second is the root's KSK

- The RRSIG is signed using the KSK
  - Now the client can verify that the ZSK is correct

```
nweaver% dig +norecurse +dnssec DNSKEY . @a.root-servers.net
...
;; ANSWER SECTION:
.                       172800  IN      DNSKEY  256 3 8 AwEAAc5byZvwmHUlCQt7WSeAr3OZ2ao4x0Yj/
3UcbtFzQ0T67N7CpYmN qFmfvXxksS1/E+mtT0axFVDjiJjtklUsyqIm9ZlWGZKU3GZqI9Sfp1Bj
Qkhi+yLa4m4y4z2N28rxWXsWHCY740PREnmUtgXRdthwABYaB2WPum3y RGxNCP1/
.                       172800  IN      DNSKEY  257 3 8
AwEAAagAIKlVZrpC6Ia7gEzahOR+9W29euxhJhVVLOyQbSEW0O8gcCjF FVQUTf6v58fLjwBd0YI0EzrAcQqBGCzh/
RStIoO8g0NfnfL2MTJRkxoX bfDaUeVPQuYEhg37NZWAJQ9VnMVDxP/VHL496M/QZxkjf5/Efucp2gaD
X6RS6CXpoY68LsvPVjR0ZSwzz1apAzvN9dlzEheX7ICJBBtuA6G3LQpz
W5hOA2hzCTMjJPJ8LbqF6dsV6DoBQzgul0sGIcGOYl7OyQdXfZ57relS
Qageu+ipAdTTJ25AsRTAoub8ONGcLmqrAmRLKBP1dfwhYB4N7knNnulq QxA+Uk1ihz0=
.                       172800  IN      RRSIG   DNSKEY 8 0 172800 20130425235959 20130411000000
19036 . {Cryptographic Goop}
```

But how do we know what key to use part 2? `DS`

- The `DS` (Delegated Signer) record is relatively simple
  - The key tag
  - The algorithm identifier
  - The hash function used
  - The hash of the signer's name and the KSK
- The ***parent*** signs `DS` (Delegated Signer) records for the child's keys
  - So for the DS for .org is provided by the root
  - This is returned with the NS RRSET by the parent
    - And the RRSIG is signed by the parent, not the child

The DS for org.

- The two DS records are for the same key
  - Just with different hash functions, SHA-256 and SHA-1
- The RRSIG is signed using the ZSK not the KSK
  - And covers both DS records

```
nweaver% nweaver% dig +norecurse +dnssec www.isc.org @a.root-servers.net
...
;; AUTHORITY SECTION:
org.                    172800  IN      NS      d0.org.afilias-nst.org.
...
org.                    172800  IN      NS      a0.org.afilias-nst.info.
org.                    86400   IN      DS      21366 7 2
96EEB2FFD9B00CD4694E78278B5EFDAB0A80446567B69F634DA078F0 D90F01BA
org.                    86400   IN      DS      21366 7 1 E6C1716CFB6BDC84E84CE1AB5510DAC69173B5B2
org.                    86400   IN      RRSIG   DS 8 1 86400 20130423000000 20130415230000 20580 .
{Cryptographic Goop}
```

Putting It All Together To Lookup `www.isc.org`

? A www.isc.org

User's ISP's Recursive Resolver **? A www.isc.org**

Name	Type	Value	TTL	Valid
.	DNSKEY	{cryptogoop}	N/A	Yes

.
Authority Server
(the "root")

```
? A www.isc.org
Answers:
Authority:
org. NS a0.afilias-nst.info
org. IN DS 21366 7 2 {cryptogoop}
org. IN DS 21366 7 1 {cryptogoop}
org. IN RRSIG DS 8 1 86400 20130423000000
20130415230000 20580 . {cryptogoop}
Additional:
a0.afilias-nst.info A 199.19.56.1
```

Putting It All Together To Lookup `www.isc.org`

User's ISP's Recursive Resolver

? DNSKEY .

Name	Type	Value	TTL	Valid
org.	NS	a0.afilia-nst.info		No
a0.afilias-nst.info	A	199.19.56.1	86400	No
org.	DS	{cryptogoop}	86400	No
org.	DS	{cryptogoop}	86400	No
org.	RRSIG	DS {goop}	86400	No
.	DNSKEY	{cryptogoop}	N/A	Yes

. Authority Server (the "root")

```
? DNSKEY .
Answers:
. IN DNSKEY  257 3 8 {cryptogoop}
. IN DNSKEY 256 3 8 {cryptogoop}
. IN RRSIG DNSKEY 8 0 172800 20130425235959
20130411000000 19036 . {cryptogoop}
Authority:
Additional:
```

Putting It All Together To Lookup `www.isc.org`

. Authority Server (the "root")

User's ISP's Recursive Resolver

Name	Type	Value	TTL	Valid
org.	NS	a0.afilia-nst.info		No
a0.afilias-nst.info	A	199.19.56.1	86400	No
org.	DS	{cryptogoop}	86400	No
org.	DS	{cryptogoop}	86400	No
org.	RRSIG	DS {goop}	86400	No
.	DNSKEY	{cryptogoop}	172800	Yes
.	RRSIG	DNSKEY {goop}	172800	Yes
.	DNSKEY	{cryptogoop}	N/A	Yes

Putting It All Together To Lookup `www.isc.org`

User's ISP's Recursive Resolver **`? A www.isc.org`**

Name	Type	Value	TTL	Valid
org.	NS	a0.afilia-nst.info		No
a0.afilias-nst.info	A	199.19.56.1	86400	No
org.	DS	{cryptogoop}	86400	Yes
org.	DS	{cryptogoop}	86400	Yes
org.	RRSIG	DS {goop}	86400	Yes
.	DNSKEY	{cryptogoop}	172800	Yes
.	RRSIG	DNSKEY {goop}	172800	Yes
.	DNSKEY	{cryptogoop}	N/A	Yes

`org.` Authority Server

```
? A www.isc.org
Answers:
Authority:
isc.org. NS sfba.sns-pb.isc.org.
isc.org. DS {cryptogoop}
isc.org. RRSIG DS {cryptogoop}
Additional:
sfba.sns-pb.isc.org.      A 199.6.1.30
```

Putting It All Together To Lookup `www.isc.org`

User's ISP's
Recursive Resolver

Name	Type	Value	TTL	Valid
org.	NS	a0.afilia-nst.info		No
a0.afilias-nst.info	A	199.19.56.1	86400	No
org.	DS	{cryptogoop}	86400	Yes
org.	DS	{cryptogoop}	86400	Yes
org.	RRSIG	DS {goop}	86400	Yes
.	DNSKEY	{cryptogoop}	172800	Yes
.	RRSIG	DNSKEY {goop}	172800	Yes
isc.org.	DS	{cryptogoop}	86400	No
isc.org.	DS	{cryptogoop}	86400	No
isc.org.	RRSIG	DS {goop}	86400	No
isc.org.	NS	sfbay.sns-pb.isc.org	86400	No
sfbay.sns-pb.isc.org	A	149.20.64.3	86400	No
.	DNSKEY	{cryptogoop}	N/A	Yes

And so on...

- The process ends up requiring:
  - Ask the root for **`www.isc.org`** and the **`DNSKEY`** for **`.`**
  - Ask **`org`** for **`www.isc.org`** and the **`DNSKEY`** for **`org.`**
  - Ask **`isc.org`** for **`www.isc.org`** and the DNSKEY for **`isc.org`**
- Dig commands
  - `dig +dnssec +norecurse www.isc.org @a.root-servers.net`
  - `dig +dnssec +norecurse DNSKEY . @a.root-servers.net`
  - `dig +dnssec +norecurse www.isc.org @199.19.56.1`
  - `dig +dnssec +norecurse DNSKEY org. @199.19.56.1`
  - `dig +dnssec +norecurse www.isc.org @149.20.64.3`
  - `dig +dnssec +norecurse DNSKEY isc.org. @149.20.64.3`

So why such a baroque structure?

- Goal is end-to-end data ***integrity***
  - Even authorized intermediaries such as the recursive resolver don't need to be trusted
  - Don't benefit (much) from confidentiality since DNS is used to contact hosts
- Signature generation can be done all offline
  - Attacker must compromise the signature generation system, not just the authority nameserver
    - Allows other authority servers to be simply mirrors
- Validation can happen at either the recursive resolver or the client
  - The DNSKEYs cache very well
    - So most subsequent lookups will not need to do these lookups
- Constrained path of trust
  - For a given name, can enumerate the trusted entities

Another reason: Latency

- The DNS community is obsessed with latency
  - Thus the refusal to simply switch to TCP for all DNS traffic
- A recursive resolver may
  - Automatically fetch the **`DNSKEY`** record with a parallel request
  - While waiting for a child's response, validate the parent's **`DS`** record
    - Generally the validation should be the same time or faster so we can do this in parallel
  - Result: Only two signature validations of latency added even on uncached requests and no additional network latency
    - One for the **`DNSKEY`** to get the ZSK
    - One for the final RRSET
- A stub resolver looking up foo.example.com:
  - In parallel fetch **`DS`** and **`DNSKEY`** for foo.example.com, example.com, .com, and the DNSKEY for .

Two additional complications

- ***NOERROR***:
  - The name exists but there is no record of that given type for that name
  - For DNSSEC, prove that there is no ds record
    - Says the subdomain doesn't sign with DNSSEC
- ***NXDOMAIN***:
  - The name does not exist
- **`NSEC`** (Provable denial of existence), a record with just two fields
  - Next domain name
    - The next valid name in the domain
  - Valid types for this name
    - In a bitmap for efficiency

NSEC in action

- Name is valid so **NOERROR** but no answers
- Single **NSEC** record for **www.isc.org**:
  - No names exist between **www.isc.org** and **www-dev.isc.org**
  - **www.isc.org** only has an **A**, **AAAA**, **RRSIG**, and **NSEC** record

```
nweaver% dig +dnssec TXT www.isc.org @8.8.8.8
...
;; Got answer:
;; ->>HEADER<<- opcode: QUERY, status: NOERROR, id: 20430
;; flags: qr rd ra ad; QUERY: 1, ANSWER: 0, AUTHORITY: 4, ADDITIONAL: 1
...
;; QUESTION SECTION:
;www.isc.org.                   IN      TXT

;; AUTHORITY SECTION:
...
www.isc.org.            3600    IN      NSEC    www-dev.isc.org. A AAAA RRSIG NSEC
www.isc.org.            3600    IN      RRSIG   NSEC {RRSIG DATA}
```

The Use of **NSEC**

- Proof that a name exists but no type exists for that name
  - Critical for "This subdomain doesn't support DNSSEC":
    Return an **NSEC** record with the authority stating "There is no **DS** record"
- Proof that a name does not exist
  - It falls between the two **NSEC** names
  - Plus an **NSEC** saying "there is no wildcard"
- Allows trivial domain enumeration
  - Attacker just starts at the beginning and walks through the NSEC records
    - Some consider this bad...

So **NSEC3**

- Rather than having the name, use a ***hash*** of the name
  - Hash Algorithm
  - Flags
  - Iterations of the hash algorithm
  - Salt (optional)
  - The next name
  - The RRTYPEs for this name
    - Otherwise acts like **NSEC**, just in a different space

```
nweaver% dig +dnssec TXT org @199.19.57.1
...
;; AUTHORITY SECTION:
...
h9p7u7tr2u91d0v0ljs9l1gidnp90u3h.org. 86400 IN NSEC3 1 1 1 D399EAAB
    H9Q3IMI6H6CIJ4708DK5A3HMJLEIQ0PF NS SOA RRSIG DNSKEY NSEC3PARAM
h9p7u7tr2u91d0v0ljs9l1gidnp90u3h.org. 86400 IN RRSIG NSEC3 {RRSIG}
```

Comments on NSEC3

- It doesn't ***really*** prevent enumeration
  - You get a hash-space enumeration instead, but since people chose reasonable names...
  - An attacker can just do a brute-force attack to find out what names exist and don't exist after enumerating the hash space
- The salt is mostly pointless!
  - Since the ***whole*** name is hashed, `foo.example.com` and `foo.example.org` will have different hashes anyway
- The only way to really prevent enumeration is to ***dynamically*** sign values
  - But that defeats the purpose of DNSSEC's offline signature generation

So what can *possibly* go wrong?

- Screwups on the authority side...
  - Too many ways to count...
    - But comcast is keeping track of it:
      Follow @comcastdns on twitter
- The validator can't access DNSSEC records
- The validator can't process DNSSEC records correctly

Authority Side Screwups...

- Its quite common to screw up
- Tell your registrar you support DNSSEC when you don't
  - Took down HBO Go's launch for Comcast users and those using Google Public DNS
- Rotate your key but present old signatures
- Forget that your signatures expire

And The Recursive Resolver Must Not Be Trusted!

- Most deployments validate at the recursive resolver, not the client
  - Notably Google Public DNS and Comcast
- This provides very little practical security:
  - The recursive resolver has proven to be the biggest threat in DNS
  - And this doesn't protect you between the recursive resolver and your system
- But causes a lot of headaches
  - Comcast or Google invariably get blamed when a zone screws up
  - Fortunately this is getting less common...

DNSSEC transport

- A validating client must be able to fetch the DNSSEC related records
  - It may be through the recursive resolver
  - It may be by contacting arbitrary DNS servers on the Internet
- One of these two must work or the client ***can not validate*** DNSSEC
  - This acts to limit DNSSEC's real use:
    Signing other types such as cryptographic fingerprints (e.g. DANE)

Probe the Root
To Check For DNSSEC Transport

- Can the client get DNSSEC data from the Internet?
  - Probe every root with DO for:
    - DS for .com with RRSIG
    - DNSKEY for . with RRSIG
    - NSEC for an invalid TLD with RRSIG
- Serves two purposes:
  - Some networks have one or more bad root mirrors
    - Notably one Chinese educational network has root mirrors for all but 3 that don't support DNSSEC
  - If no information can be retrieved
    - Proxy which strips out DNSSEC information and/or can't handle DO

DNSSEC Root Transport: Results We've Seen In The Wild

- Bad news at Starbucks: Hotspot gateways often proxy all DNS and can’t handle DO-enabled traffic
  - And then have DNS resolvers that can't handle DNSSEC requests!
- Confirmed the Chinese educational network “Bad root mirror” problem

Implications of "No DNSSEC at Starbucks"

- DNSSEC failure depends on the usage.
- For name->address bindings:
  - If the recursive resolver practices proper port randomization:
    - No problem. The same "attackers" who can manipulate your DNS could do anything they want at the proxy that's controlling your DNS traffic
  - Else:
    - Problem. Network is not secure
- For name->key bindings:
  - Unless the resolver supports it directly, you are Out of Luck
    - DNSSEC information must have an alternate channel if you want to use it to transmit keys instead of just IPs

In fact, my preferred DNSSEC policy For Client Validation

- For name->address mappings
  - Any existing APIs that don't provide DNSSEC status
  - If valid: use
  - If invalid OR no complete DNSSEC chain:
    - Begin an iterative fetch with the most precise DNSSEC-validated data
    - Use the result without question
- For name->data mappings
  - An API which returns DNSSEC status
  - If valid: Use
  - If invalid: Return DNSSEC failure status
    - Up to the application

Oh, And What If Your Registrar Is Compromised...

- The ***registrar*** is the company where you registered your domain name
  - So if you register `foo.com`, you contract with a registrar for `.com`
  - You provide your registrar with your DS record
- So if the bad guy takes over your registrar or your account with your registrar...
  - Your DNSSEC is 🤷, the bad guy just replaces both the DS and NS entries with their own...
  - And now can intercept ***all non-encrypted traffic*** you receive, since they can answer for your DNS

But What About TLS?

- The bad guy can intercept all traffic going to your domain...
  - And TLS certificates like LetsEncrypt work by validating that you can put stuff on ***your domain***...
- So the bad guy can also mint TLS certificates
  - So he can decrypt all the "secure" web traffic, be a Man-in-the-Middle, and then forward traffic onward!
- Some actor has been doing this for espionage in the middle east!
  - Only defense beyond securing your registrar and registration is to also use certificate pinning

And That's The Real Thing...

- DNSSEC in all its *emm* glory.
- OPT records to say "I want DNSSEC"
- RRSIG records are certificates
- DNSKEY records hold public keys
- DS records hold key fingerprints
  - Used by the parent to tell the child's keys
- NSEC/NSEC3 records to prove that a name doesn't exist or there is no record of that type