

Securing DNS: DNSSEC

CS 161: Computer Security

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Special request: Please spread out!
Pair up. Each pair, sit far away from anyone else.
If you're just arriving, sit next to someone who is alone.

Securing DNS Lookups

- Topic for today:
How can we ensure that when clients look up names with DNS, they can **trust** the answers they receive?
- But first, a diversion...

An Experiment

- Today: Active learning + peer instruction
 - I'm going to ask you to work out how to secure DNS, on your own.
 - I'll give you a series of problems. I want you to break into groups of two, decide what you think a solution might be, then report back to the class.
 - TAs and I will circulate. Ask us for help!
 - Research suggests this might be more effective than lecturing. Let's give it a try!
- This is an experiment – I need your feedback on whether it helps you learn.

Outsourcing Data Lookups

- **Problem 1.** Berkeley has a database of all its graduates, $D = \{d_1, d_2, \dots, d_n\}$, replicated across many mirror sites. Given a name x , any client should be able to query any mirror and learn whether $x \in D$. We don't trust the mirrors, so if answer to query is "yes" (i.e., if $x \in D$), client should receive a proof that it can verify. If answer is "no" (i.e., $x \notin D$), no proof is necessary. Make performance as good as possible.

Solutions

Give to the mirror:

- Signatures: $d_1, \text{Sign}(H(d_1)), \dots, d_n, \text{Sign}(H(d_n))$
- Signatures: $d_1, \text{Sign}(d_1), \dots, d_n, \text{Sign}(d_n)$

Outsourcing Data Lookups

- **Question 2.** Suppose we use your solution, with client connecting to mirror via HTTP – but there is a man-in-the-middle (on-path attacker). What can attacker do, without being detected?
 - A. Can spoof both “yes” ($x \in D$) and “no” ($x \notin D$) responses.
 - B. Can spoof “yes”, but can’t spoof “no”.
 - C. Can spoof “no”, but can’t spoof “yes”.
 - D. Can’t spoof either kind of response.

Authenticating “Yes” and “No”

- **Problem 3.** Same as Problem 1, except now, if answer is “no” (i.e., $x \notin D$), client should receive a proof that it can verify.

Authenticating “Yes” and “No”

- **Problem 3.** Same as Problem 1, except now, if answer is “no” (i.e., $x \notin D$), client should receive a proof that it can verify.

Hint: Organize the elements as a binary tree or hash table, then....

Solutions

Say $D = \{\text{Alice, Bob, Jim, Xavier}\}$.

Give to mirror:

- $\text{Sign}(1, \text{Alice}), \text{Sign}(2, \text{Bob}), \text{Sign}(3, \text{Jim}), \text{Sign}(4, \text{Xavier})$
- $\text{Sign}(\text{Alice}, \text{Bob}), \text{Sign}(\text{Bob}, \text{Jim}), \text{Sign}(\text{Jim}, \text{Xavier})$

To answer query “Doug”:

- Doug \rightarrow no, Bob, Jim, $\text{Sign}(2, \text{Bob}), \text{Sign}(3, \text{Jim})$; or Doug \rightarrow no, $\text{Sign}(\text{Bob}, \text{Jim})$

DNS

- **Problem 4.** Now Berkeley wants to protect its DNS records; how could it do it? What would be the advantages and disadvantages of your solution?

DNSSEC

- Guess what – you just invented DNSSEC!
- Sign all DNS records. Signatures let you verify answer to DNS query, without having to trust the network or resolvers involved.

Securing DNS Lookups

- How can we ensure that when clients look up names with DNS, they can **trust** the answers they receive?
- Idea #1: do DNS lookups over TLS (SSL)

Securing DNS using SSL / TLS?

Host at `xyz.poly.edu`
wants IP address for
`gaia.cs.umass.edu`

local DNS server
(resolver)
`dns.poly.edu`

root DNS server (‘.’)

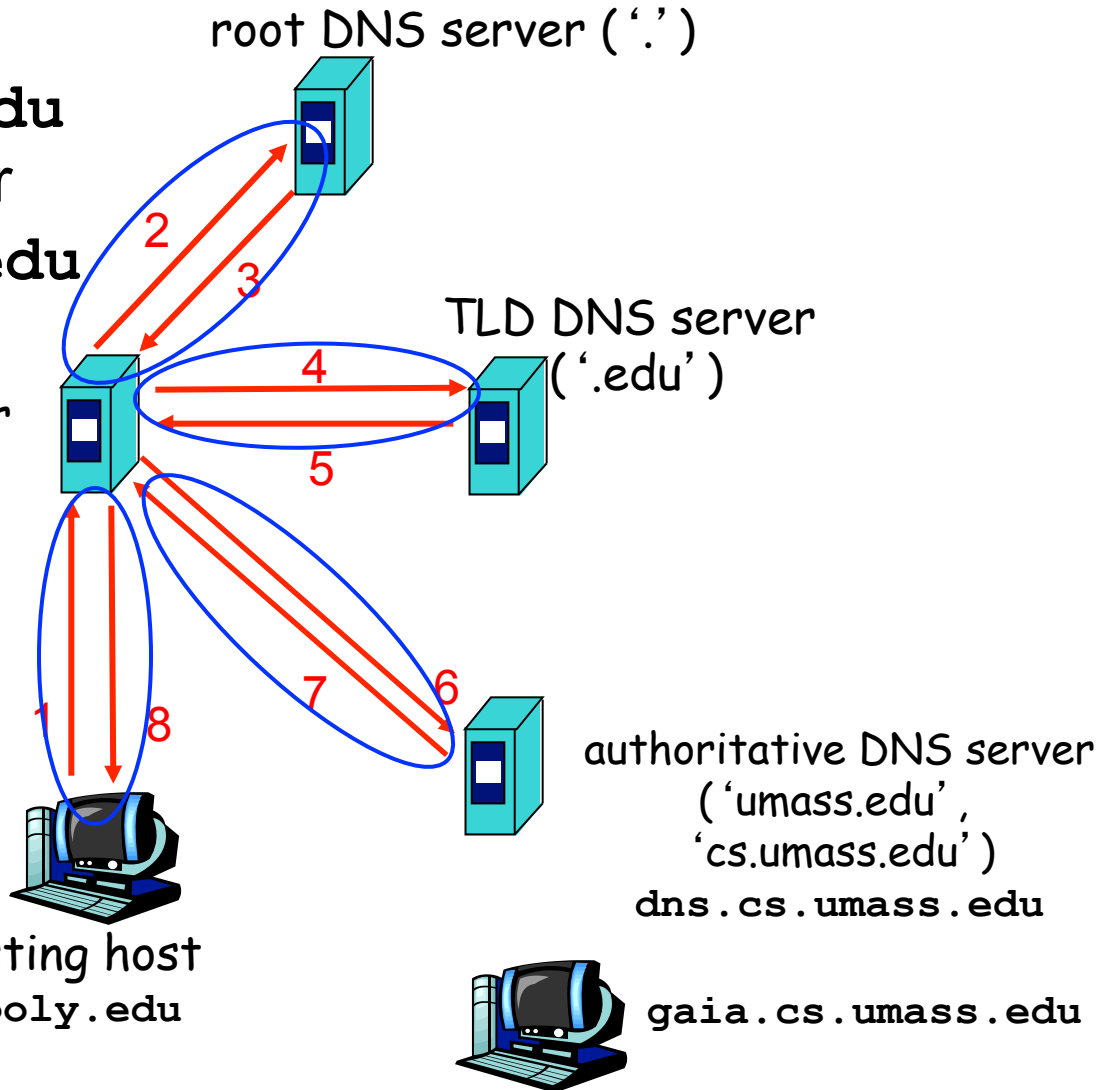
TLD DNS server
(‘.edu’)

authoritative DNS server
(‘umass.edu’,
‘cs.umass.edu’)
`dns.cs.umass.edu`

Idea: connections
{1,8}, {2,3}, {4,5}
and {6,7} all run
over SSL / TLS

requesting host
`xyz.poly.edu`

`gaia.cs.umass.edu`



Securing DNS Lookups

- How can we ensure that when clients look up names with DNS, they can trust the answers they receive?
- Idea #1: do DNS lookups over TLS (SSL)
 - **Performance**: DNS is very lightweight. TLS is not.
 - **Caching**: crucial for DNS scaling. But then how do we keep authentication assurances?
 - **Security**: must trust the resolver.
Object security vs. Channel security
- Idea #2: make DNS results like *certs*
 - I.e., a **verifiable signature** that guarantees who generated a piece of data; signing happens **off-line**

Operation of DNSSEC

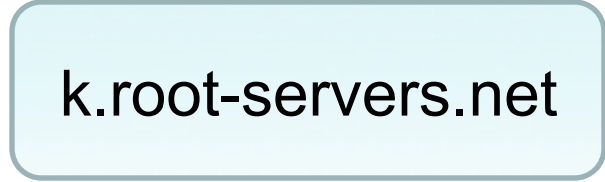
- DNSSEC = standardized DNS security extensions currently being deployed
- As a resolver works its way from DNS root down to final name server for a name, at each level it gets a signed statement regarding the key(s) used by the next level
 - This builds up a chain of trusted keys
 - Resolver has root's key **wired into it**
- The final answer that the resolver receives is signed by that level's key
 - Resolver can trust it's the right key because of chain of support from higher levels
- *All keys as well as signed results are **cacheable***

Ordinary DNS:

www.google.com A?

Client's
Resolver

k.root-servers.net



Ordinary DNS:

www.google.com A?

Client's
Resolver

k.root-servers.net

We start off by sending the query to one of the root name servers. These range from a.root-servers.net through m.root-servers.net. Here we just picked one.

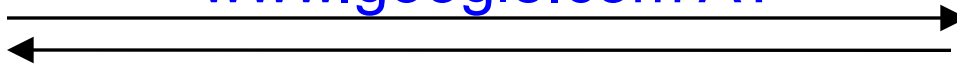
Ordinary DNS:

www.google.com A?

Client's
Resolver

com. **NS** a.gtld-servers.net
a.gtld-servers.net **A** 192.5.6.30
...

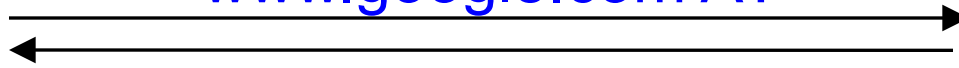
k.root-servers.net



Ordinary DNS:

www.google.com A?

Client's
Resolver



k.root-servers.net

```
com. NS a.gtld-servers.net
a.gtld-servers.net A 192.5.6.30
...
```

The reply *didn't include an answer* for `www.google.com`. That means that `k.root-servers.net` is instead telling us *where to ask next*, namely one of the name servers for `.com` specified in an **NS** record.

Ordinary DNS:

www.google.com A?

Client's
Resolver

k.root-servers.net

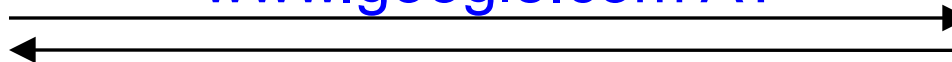
```
com. NS a.gtld-servers.net  
a.gtld-servers.net A 192.5.6.30  
...
```

This *Resource Record (RR)* tells us that one of the name servers for .com is the host a.gtld-servers.net. (GTLD = Global Top Level Domain.)

Ordinary DNS:

www.google.com A?

Client's
Resolver



k.root-servers.net

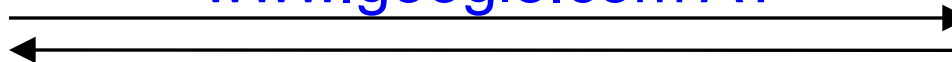
```
com. NS a.gtld-servers.net
a.gtld-servers.net A 192.5.6.30
...
```

(The line above shows com. rather than .com because technically that's the actual name, and that's what the Unix dig utility shows; but the convention is to call it "dot-com")

Ordinary DNS:

www.google.com A?

Client's
Resolver



k.root-servers.net

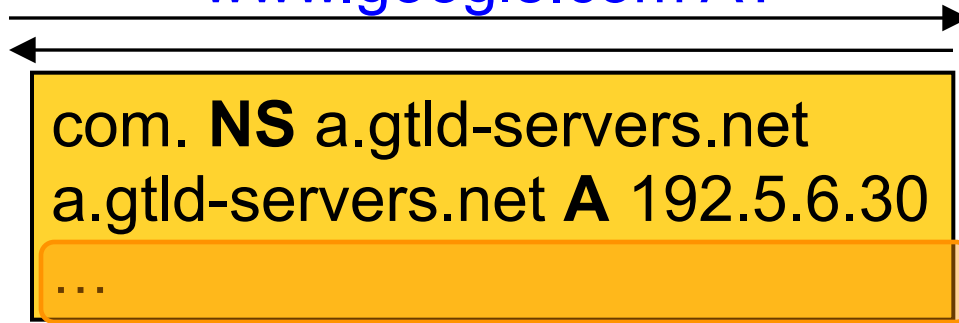
```
com. NS a.gtld-servers.net
a.gtld-servers.net A 192.5.6.30
...
```

This **RR** tells us that an Internet address (“**A**” record) for a.gtld-servers.net is 192.5.6.30. That allows us to know where to send our next query.

Ordinary DNS:

www.google.com A?

Client's
Resolver



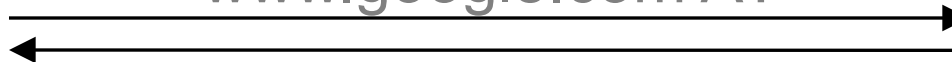
k.root-servers.net

The actual response includes a bunch of **NS** and **A** records for additional .com name servers, which we omit here for simplicity.

Ordinary DNS:

www.google.com A?

Client's
Resolver



```
com. NS a.gtld-servers.net
a.gtld-servers.net A 192.5.6.30
...
```

k.root-servers.net

www.google.com A?

Client's
Resolver



a.gtld-servers.net

We send the same query to one of the .com name servers we've been told about

Ordinary DNS:

www.google.com A?

Client's
Resolver

```
com. NS a.gtld-servers.net  
a.gtld-servers.net A 192.5.6.30  
...
```

k.root-servers.net

www.google.com A?

Client's
Resolver

```
google.com. NS ns1.google.com  
ns1.google.com A 216.239.32.10  
...
```

a.gtld-servers.net

Ordinary DNS:

www.google.com A?

Client's
Resolver

```
com. NS a.gtld-servers.net  
a.gtld-servers.net A 192.5.6.30  
...
```

k.root-servers.net

www.google.com A?

Client's
Resolver

```
google.com. NS ns1.google.com  
ns1.google.com A 216.239.32.10  
...
```

a.gtld-servers.net

That server again doesn't have a direct answer for us, but tells us about a google.com name server we can try

Ordinary DNS:

www.google.com A?

Client's
Resolver

```
com. NS a.gtld-servers.net
a.gtld-servers.net A 192.5.6.30
...
```

k.root-servers.net

www.google.com A?

Client's
Resolver

```
google.com. NS ns1.google.com
ns1.google.com A 216.239.32.10
...
```

a.gtld-servers.net

www.google.com A?

Client's
Resolver

```
www.google.com. A 74.125.24.14
...
```

ns1.google.com

Ordinary DNS:

www.google.com A?

Client's
Resolver

com. NS a.gtld-servers.net
a.gtld-servers.net A 192.5.6.30
...

k.root-servers.net

Trying one of the google.com name servers then gets us an answer to our query, and we're good-to-go ...
... though with **no confidence** that an attacker hasn't led us astray with a bogus reply somewhere along the way :-)

www.google.com A?

Client's
Resolver

www.google.com. A 74.125.24.14
...

ns1.google.com

DNSSEC (with simplifications):

www.google.com A?

Client's
Resolver

k.root-servers.net

```
com. NS a.gtld-servers.net
a.gtld-servers.net. A 192.5.6.30
...
com. DS com's-public-key
com. RRSIG DS signature-of-that-
DS-record-using-root's-key
```

DNSSEC (with simplifications):

Client's
Resolver

www.google.com A?

k.root-servers.net

com. **NS** a.gtld-servers.net
a.gtld-servers.net. **A** 192.5.6.30
...

com. **DS** *com's-public-key*
com. **RRSIG DS** *signature-of-that-
DS-record-using-root's-key*

Up through here is the same as before ...

DNSSEC (with simplifications):

www.google.com A?

Client's
Resolver

k.root-servers.net

```
com. NS a.gtld-servers.net
a.gtld-servers.net. A 192.5.6.30
...
com. DS com's-public-key
com. RRSIG DS signature-of-that-
DS-record-using-root's-key
```

This new RR ("Delegation Signer") lists .com's public key

DNSSEC (with simplifications):

www.google.com A?

Client's
Resolver

k.root-servers.net

```
com. NS a.gtld-servers.net
a.gtld-servers.net. A 192.5.6.30
...
com. DS description-of-com's-key
com. RRSIG DS signature-of-that-
DS-record-using-root's-key
```

The actual process of retrieving .com's public key is complicated (actually involves multiple keys) but for our purposes doesn't change how things work

DNSSEC (with simplifications):

www.google.com A?

Client's
Resolver

k.root-servers.net

```
com. NS a.gtld-servers.net
a.gtld-servers.net. A 192.5.6.30
...
com. DS com's-public-key
com. RRSIG DS signature-of-that-
DS-record-using-root's-key
```

This new **RR** specifies a signature over *another RR*
... in this case, the signature covers the above **DS**
record, and is made using the root's private key

DNSSEC (with simplifications):

www.google.com A?

Client's
Resolver

k.root-servers.net

```
com. NS a.gtld-servers.net
a.gtld-servers.net. A 192.5.6.30
...
com. DS com's-public-key
com. RRSIG DS signature-of-that-
DS-record-using-root's-key
```

The resolver has the root's public key **hardwired** into it. The client only proceeds with DNSSEC if it can validate the signature.

DNSSEC (with simplifications):

www.google.com A?

Client's
Resolver

k.root-servers.net

```
com. NS a.gtld-servers.net
a.gtld-servers.net. A 192.5.6.30
...
com. DS com's-public-key
com. RRSIG DS signature-of-that-
DS-record-using-root's-key
```

Note: there's no signature over the **NS** or **A** information! If an attacker has fiddled with those, the resolver will ultimately find it has a record for which it can't verify the signature.

DNSSEC (with simplifications):

Client's
Resolver

www.google.com A?

a.gtld-servers.net

The resolver again proceeds to trying one of the name servers it's learned about.

Nothing guarantees this is a legitimate name server for the query!

DNSSEC (with simplifications):

Client's
Resolver

www.google.com A?

a.gtld-servers.net

google.com. **NS** ns1.google.com
ns1.google.com. **A** 216.239.32.10

...

google.com. **DS** *google.com's-public-key*
google.com. **RRSIG DS** *signature-
of-that-**DS**-record-using-com's-key*

DNSSEC (with simplifications):

Client's
Resolver

www.google.com A?

a.gtld-servers.net

```
google.com. NS ns1.google.com
ns1.google.com. A 216.239.32.10
...
google.com. DS google.com's-public-key
google.com. RRSIG DS signature-
of-that-DS-record-using-com's-key
```

Back comes similar information as before: google.com's public key, signed by .com's key (which the resolver trusts because the root signed information about it)

DNSSEC (with simplifications):

Client's
Resolver

www.google.com A?

ns1.google.com

The resolver contacts one of the google.com name servers it's learned about.

Again, nothing guarantees this is a legitimate name server for the query!

DNSSEC (with simplifications):

www.google.com A?

Client's
Resolver

ns1.google.com

www.google.com. **A** 74.125.24.14

...

www.google.com. **RRSIG A**
*signature-of-the-A-records-using-
google.com's-key*

DNSSEC (with simplifications):

www.google.com A?

Client's
Resolver

ns1.google.com

www.google.com. **A** 74.125.24.14

...

www.google.com. **RRSIG A**
*signature-of-the-A-records-using-
google.com's-key*

Finally we've received the information we wanted (**A** records for `www.google.com`)! ... *and* we receive a signature over those records

DNSSEC (with simplifications):

Client's
Resolver

www.google.com A?

ns1.google.com

www.google.com. **A** 74.125.24.14
...
www.google.com. **RRSIG A**
*signature-of-the-A-records-using-
google.com's-key*

Assuming the signature validates, then because we believe (due to the signature chain) it's indeed from google.com's key, we can trust that this is a correct set of **A** records ...
Regardless of what name server returned them to us!