Attacks on DNS

CS 161: Computer Security
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March 3, 2013
Today

• Reminder: Project due tonight, 11:59pm
• Today, **DNS**: protocol for mapping hostnames to IP addresses, and attacks on DNS.
DNS Overview

• DNS translates www.google.com to 74.125.25.99
• It’s a performance-critical distributed database.
• DNS security is critical for the web. (Same-origin policy assumes DNS is secure.)
• Analogy: If you don’t know the answer to a question, ask a friend for help (who may in turn refer you to a friend of theirs, and so on).
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- DNS security is critical for the web. (Same-origin policy assumes DNS is secure.)
- Analogy: If you don’t know the answer to a question, ask a friend for help (who may in turn refer you to a friend of theirs, and so on).
- Security risks: friend might be malicious, communication channel to friend might be insecure, friend might be well-intentioned but misinformed
DNS Lookups via a Resolver

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

- **local DNS server (resolver)**: dns.poly.edu
- **root DNS server (‘.’)**
- **TLD DNS server (‘.edu’)**
- **authoritative DNS server (for ‘mit.edu’)**: dns.mit.edu

Caching heavily used to minimize lookups
Security risk #1: malicious DNS server

• Of course, if *any* of the DNS servers queried are malicious, they can lie to us and fool us about the answer to our DNS query

• (In fact, they used to be able to fool us about the answer to other queries, too. We’ll come back to that.)
Security risk #2: on-path eavesdropper

• If attacker can eavesdrop on our traffic… we’re hosed.

• Why? We’ll see why.
Security risk #3: off-path attacker

- If attacker can’t eavesdrop on our traffic, can he inject spoofed DNS responses?
- This case is especially interesting, so we’ll look at it in detail.
DNS Threats

• DNS: path-critical for just about everything we do
  – Maps hostnames ⇔ IP addresses
  – Design only **scales** if we can minimize lookup traffic
    o #1 way to do so: caching
    o #2 way to do so: return not only answers to queries, but additional info that will likely be needed shortly

• What if attacker eavesdrops on our DNS queries?
  – Then similar to DHCP/TCP, can spoof responses

• Consider attackers who *can’t* eavesdrop - but still aim to manipulate us via *how the protocol functions*

• Directly interacting w/ DNS: **dig** program on Unix
  – Allows querying of DNS system
  – Dumps each field in DNS responses
Use Unix “dig” utility to look up IP address (“A”) for hostname eecs.mit.edu via DNS
The question we asked the server
dig eecs.mit.edu A

; ; <<>> DiG 9.6.0-APPLE-P2 <<>> eecs.mit.edu a
; ; global options: +cmd
; ; Got answer:
; ; ->>HEADER<<- opcode: QUERY, status: NOERROR, id: 19901
; ; flags: qr rd ra; QUERY: 1, ANSWER: 1, AUTHORITY: 3, ADDITIONAL: 3

; ; QUESTION SECTION:
;eecs.mit.edu. IN A

; ; ANSWER SECTION:
eecs.mit.edu. 21600 IN A 18.62.1.6

; ; AUTHORITY SECTION:
mit.edu. 11088 IN NS BITSY.mit.edu.
mit.edu. 11088 IN NS W20NS.mit.edu.
mit.edu. 11088 IN NS STRAWB.mit.edu.

; ; ADDITIONAL SECTION:
STRAWB.mit.edu. 126738 IN A 18.71.0.151
BITSY.mit.edu. 166408 IN A 18.72.0.3
W20NS.mit.edu. 126738 IN A 18.70.0.160

A 16-bit transaction identifier that enables the DNS client (dig, in this case) to match up the reply with its original request.
Answer tells us the IP address associated with eecs.mit.edu is 18.62.1.6 and we can cache the result for 21,600 seconds.
In general, a single Resource Record (RR) like this includes, left-to-right, a DNS name, a time-to-live, a family (IN for our purposes - ignore), a type (A here), and an associated value.
dig eecs.mit.edu A

"Authority" tells us the *name servers* responsible for the answer. Each RR gives the *hostname* of a different name server ("NS") for names in *mit.edu*. We should cache each record for 11,088 seconds.

If the "Answer" had been empty, then the resolver’s next step would be to send the original query to one of these name servers.
dig eecs.mit.edu A

; ; <<>> DiG 9.6.0-APPLE-P2 <<>> eecs.mit.edu a
;; global options: +cmd
;; Got answer:
;; ->>HEADER<<- opcode: QUERY, status: NOERROR, id: 19901
;; flags: qr rd ra; QUERY: 1, ANSWER: 1, AUTHORITY: 3, ADDITIONAL: 3

;; QUESTION SECTION:
;eecs.mit.edu.

;; ANSWER SECTION:
eecs.mit.edu.           21600   IN      A       18.62.1.6

;; AUTHORITY SECTION:
mit.edu.                11088   IN      NS      BITSY.mit.edu.
mit.edu.                11088   IN      NS      W20NS.mit.edu.
mit.edu.                11088   IN      NS      STRAWB.mit.edu.

;; ADDITIONAL SECTION:
STRAWB.mit.edu.         126738  IN      A       18.71.0.151
BITSY.mit.edu.          166408  IN      A       18.72.0.3
W20NS.mit.edu.          126738  IN      A       18.70.0.160

“Additional” provides extra information to save us from making separate lookups for it, or helps with bootstrapping. Here, it tells us the IP addresses for the hostnames of the name servers. We add these to our cache.
DNS Protocol

Lightweight exchange of *query* and *reply* messages, both with the same message format.

Primarily uses UDP for its transport protocol, which is what we’ll assume.

Frequently, both clients and servers use port 53.

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**UDP Header**

- **SRC port**
- **DST port**
- **checksum**
- **length**

**UDP Payload**

- **Identification**
- **Flags**
- **# Questions**
- **# Answer RRs**
- **# Authority RRs**
- **# Additional RRs**
- **Questions** (variable # of resource records)
- **Answers** (variable # of resource records)
- **Additional information** (variable # of resource records)
**DNS Protocol**

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**UDP Header**

- **SRC=53**
- **DST=53**
- **checksum**
- **length**

**UDP Payload**

- **Identification**
- **Flags**
- **# Questions**
- **# Answer RRs**
- **# Authority RRs**
- **# Additional RRs**
  - Questions (variable # of resource records)
  - Answers (variable # of resource records)
  - Additional information (variable # of resource records)

**DNS**

- **Query or Reply**
**Message header:**

- **Identification**: 16 bit # for query, reply to query uses same #

- Along with repeating the Question and providing Answer(s), replies can include “**Authority**” (name server responsible for answer) and “**Additional**” (info client is likely to look up soon anyway)

- Each **Resource Record** has a **Time To Live** (in seconds) for **caching** (not shown)
What if the mit.edu server is untrustworthy? Could its operator steal, say, all of our web surfing to berkeley.edu’s main web server?
Let's look at a flaw in the original DNS design (since fixed)
What could happen if the mit.edu server returns the following to us instead?
We’d dutifully store in our cache a mapping of www.berkeley.edu to an IP address under MIT’s control. (It could have been any IP address they wanted, not just one of theirs.)
In this case they chose to make the mapping disappear after 30 seconds. They could have made it persist for weeks, or disappear even quicker.
dig eecs.mit.edu A

; ; <<>> DiG 9.6.0-APPLE-P2 <<>> eecs.mit.edu a
;; global options: +cmd
;; Got answer:
;; ->>HEADER<<- opcode: QUERY, status: NOERROR, id: 19901
;; flags: qr rd ra; QUERY: 1, ANSWER: 1, AUTHORITY: 3, ADDITIONAL: 3

;; QUESTION SECTION:
eecs.mit.edu.                  IN      A

;; ANSWER SECTION:
eecs.mit.edu.           21600   IN      A       18.62.1.6

;; AUTHORITY SECTION:
mit.edu.                11088   IN      NS      BITSY.mit.edu.
mit.edu.                11088   IN      NS      W20NS.mit.edu.
mit.edu.                30      IN      NS      www.berkeley.edu.

;; ADDITIONAL SECTION:
www.berkeley.edu.       30      IN      A       18.6.6.6
BITSY.mit.edu.          166408  IN      A       18.72.0.3
W20NS.mit.edu.          126738  IN      A       18.70.0.160

How do we fix such cache poisoning?
dig eecs.mit.edu A

; ; <<>> DiG 9.6.0-APPLE-P2 <<>> eecs.mit.edu a
;; global options: +cmd
;; Got answer:
;; ->>HEADER<<- opcode: QUERY, status: NOERROR, id: 19901
;; flags: qr rd ra; QUERY: 1, ANSWER: 1, AUTHORITY: 3, ADDITIONAL: 3

;; QUESTION SECTION:
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mit.edu.                11088   IN      NS      BITSY.mit.edu.
mit.edu.                11088   IN      NS      W20NS.mit.edu.
mit.edu.                30      IN      NS      www.berkeley.edu.

;; ADDITIONAL SECTION:
www.berkeley.edu.       30      IN      A       18.6.6.6
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Don’t accept **Additional** records unless they’re for the domain we’re looking up
E.g., looking up eecs.mit.edu ⇒ only accept additional records from *.mit.edu

No extra risk in accepting these since server could return them to us directly in an **Answer** anyway.
Security risk #1: malicious DNS server

• Of course, if any of the DNS servers queried are malicious, they can lie to us and fool us about the answer to our DNS query…

• and they used to be able to fool us about the answer to other queries, too, using cache poisoning. Now fixed (phew).
Security risk #2: on-path eavesdropper

- If attacker can eavesdrop on our traffic… we’re hosed.
- Why?
Security risk #2: on-path eavesdropper

• If attacker can eavesdrop on our traffic… we’re hosed.

• Why? They can see the query and the 16-bit transaction identifier, and race to send a spoofed response to our query.
Security risk #3: off-path attacker

- If attacker can’t eavesdrop on our traffic, can he inject spoofed DNS responses?
- Answer: It used to be possible, via blind spoofing. We’ve since deployed mitigations that makes this harder (but not totally impossible).
Blind spoofing

- Say we look up mail.google.com; how can an off-path attacker feed us a bogus A answer before the legitimate server replies?

- How can such a remote attacker even know we are looking up mail.google.com?

Suppose, e.g., we visit a web page under their control:

...<img src="http://mail.google.com" ...> ...
Blind spoofing

- Say we look up mail.google.com; how can an off-path attacker feed us a bogus A answer before the legitimate server replies?
- How can such an attacker even know we are looking up mail.google.com?

Suppose, e.g., we visit a webpage under their control:

```html
...<img src="http://mail.google.com" ...
```
Blind spoofing

Once they know we’re looking it up, they just have to guess the Identification field and reply before legit server.

How hard is that?

Originally, identification field incremented by 1 for each request. How does attacker guess it?

<img src="http://badguy.com" ...>
<img src="http://mail.google.com" ...>

They observe ID k here
So this will be k+1
DNS Blind Spoofing, cont.

Once we **randomize** the Identification, attacker has a 1/65536 chance of guessing it correctly.

*Are we pretty much safe?*

Attacker can send *lots* of replies, not just one …

**However:** once reply from legit server arrives (with correct Identification), it’s **cached** and no more opportunity to poison it. Victim is innoculated!

Unless attacker can send 1000s of replies before legit arrives, we’re likely safe - phew!
DNS Blind Spoofing (Kaminsky 2008)

- Two key ideas:
  - Attacker can get around caching of legit replies by generating a series of different name lookups:
    
    ```
    <img src="http://random1.google.com" …> 
    <img src="http://random2.google.com" …> 
    <img src="http://random3.google.com" …> 
    ... 
    <img src="http://randomN.google.com" …>
    ```

  - Trick victim into looking up a domain you don’t care about, use Additional field to spoof the domain you do
Kaminsky Blind Spoofing

For each lookup of `randomk.google.com`, attacker **spoofs** a **bunch** of records like this, each with a different Identifier

```
;; QUESTION SECTION:
;randomk.google.com.

;; ANSWER SECTION:
randomk.google.com 21600 IN A doesn’t matter

;; AUTHORITY SECTION:
google.com. 11088 IN NS mail.google.com

;; ADDITIONAL SECTION:
mail.google.com 126738 IN A 6.6.6.6
```

Once they win the race, not only have they poisoned `mail.google.com`...
For each lookup of `randomk.google.com`, attacker *spoofs* a bunch of records like this, each with a different Identifier.

Once they win the race, not only have they poisoned `mail.google.com` ... but also the cached NS record for `google.com`'s name server - so any future `X.google.com` lookups go through the attacker’s machine.
Defending Against Blind Spoofing

Central problem: all that tells a client they should accept a response is that it matches the Identification field.

With only 16 bits, it lacks sufficient entropy: even if truly random, the search space an attacker must brute force is too small.

Where can we get more entropy? (Without requiring a protocol change.)

<table>
<thead>
<tr>
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**Questions** (variable # of resource records)

**Answers** (variable # of resource records)

**Authority** (variable # of resource records)

**Additional information** (variable # of resource records)
Defending Against Blind Spoofing

For requestor to receive DNS reply, needs both correct Identification and correct ports.

On a request, DST port = 53. SRC port usually also 53 - but not fundamental, just convenient.
Defending Against Blind Spoofing

“Fix”: client uses random source port ⇒ attacker doesn’t know correct dest. port to use in reply

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</table>

Questions
(variable # of resource records)

Answers
(variable # of resource records)

Authority
(variable # of resource records)

Additional information
(variable # of resource records)

Total entropy: ? bits
Defending Against Blind Spoofing

“Fix”: client uses random source port ⇒ attacker doesn’t know correct dest. port to use in reply

32 bits of entropy makes it orders of magnitude harder for attacker to guess all the necessary fields and dupe victim into accepting spoof response.

This is what primarily “secures” DNS against blind spoofing today.
Lessons learned

• Security risks: friend might be malicious
• Communication channel to friend might be insecure
• Friend might be well-intentioned but misinformed
Extra Material
Summary of DNS Security Issues

• DNS threats highlight:
  – Attackers can attack opportunistically rather than eavesdropping
    o Cache poisoning only required victim to look up some name under attacker’s control (*has been fixed*)
  – Attackers can often manipulate victims into vulnerable activity
    o E.g., IMG SRC in web page to force DNS lookups
  – Crucial for identifiers associated with communication to have sufficient entropy (= a lot of bits of unpredictability)
  – “Attacks only get better”: threats that appears technically remote can become practical due to unforeseen cleverness
Common Security Assumptions

• (Note, these tend to be pessimistic … but prudent)

• Attackers can interact with our systems without particular notice
  – *Probing* (poking at systems) may go unnoticed …
  – … even if highly repetitive, leading to crashes, and easy to detect

• It’s easy for attackers to know general information about their targets
  – OS types, software versions, usernames, server ports, IP addresses, usual patterns of activity, administrative procedures
Common Assumptions

• Attackers can obtain access to a copy of a given system to measure and/or determine how it works.
• Attackers can make energetic use of automation.
  – They can often find clever ways to automate.
• Attackers can pull off complicated coordination across a bunch of different elements/systems.
• Attackers can bring large resources to bear if needed.
  – Computation, network capacity.
  – But they are not super-powerful (e.g., control entire ISPs).
Common Assumptions

• If it helps the attacker in some way, assume they can obtain privileges
  – But if the privilege gives everything away (attack becomes trivial), then we care about unprivileged attacks

• The ability to robustly detect that an attack has occurred does not replace desirability of preventing

• Infrastructure machines/systems are well protected (hard to directly take over)
  – So a vulnerability that requires infrastructure compromise is less worrisome than same vulnerability that doesn’t
Common Assumptions

• Network routing is hard to alter ... other than with physical access near clients (e.g., “coffeeshop”)
  – Such access helps fool clients to send to wrong place
  – Can enable *Man-in-the-Middle (MITM)* attacks
• We worry about attackers who are lucky
  – Since often automation/repetition can help “make luck”
• Just because a system does not have apparent value, it may still be a target
• Attackers are undaunted by fear of getting caught