# Network Attacks, Part 2

***CS 161: Computer Security***


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*http://inst.eecs.berkeley.edu/~cs161/*

**February 8, 2011**

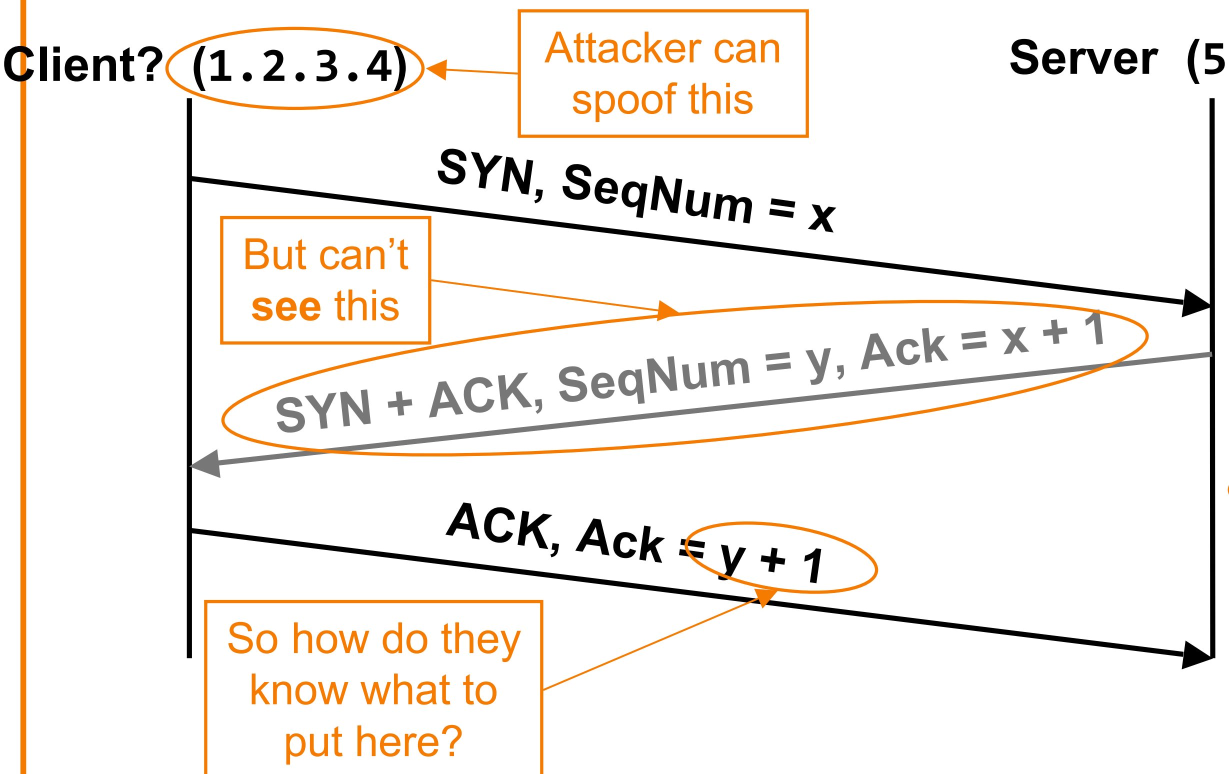
# Game Plan

- Reminder: Homework #1 due tomorrow night, 9:59PM

- Goal for today: more network attacks
  - (Clarifications regarding TCP attacks)
  - DHCP: protocol for bootstrapping Internet access
  - DNS: protocol for mapping hostnames to IP addresses
  - TCP: cheating on “fairness” (time permitting)

# Blind Spoofing: Attacker’s Viewpoint

**Attacker**




Each host tells its *Initial Sequence Number* (ISN) to the other host.

(Spec says to pick based on local clock)

Hmm, any way for the attacker to know ***this?***

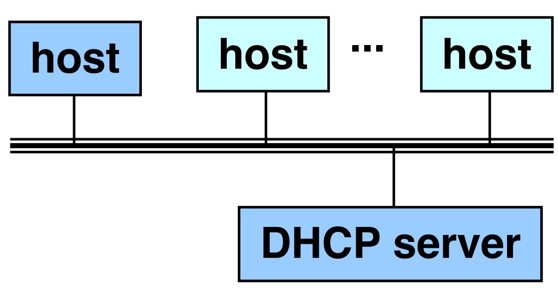
**How Do We Fix This?**

**Use A *Random* ISN**

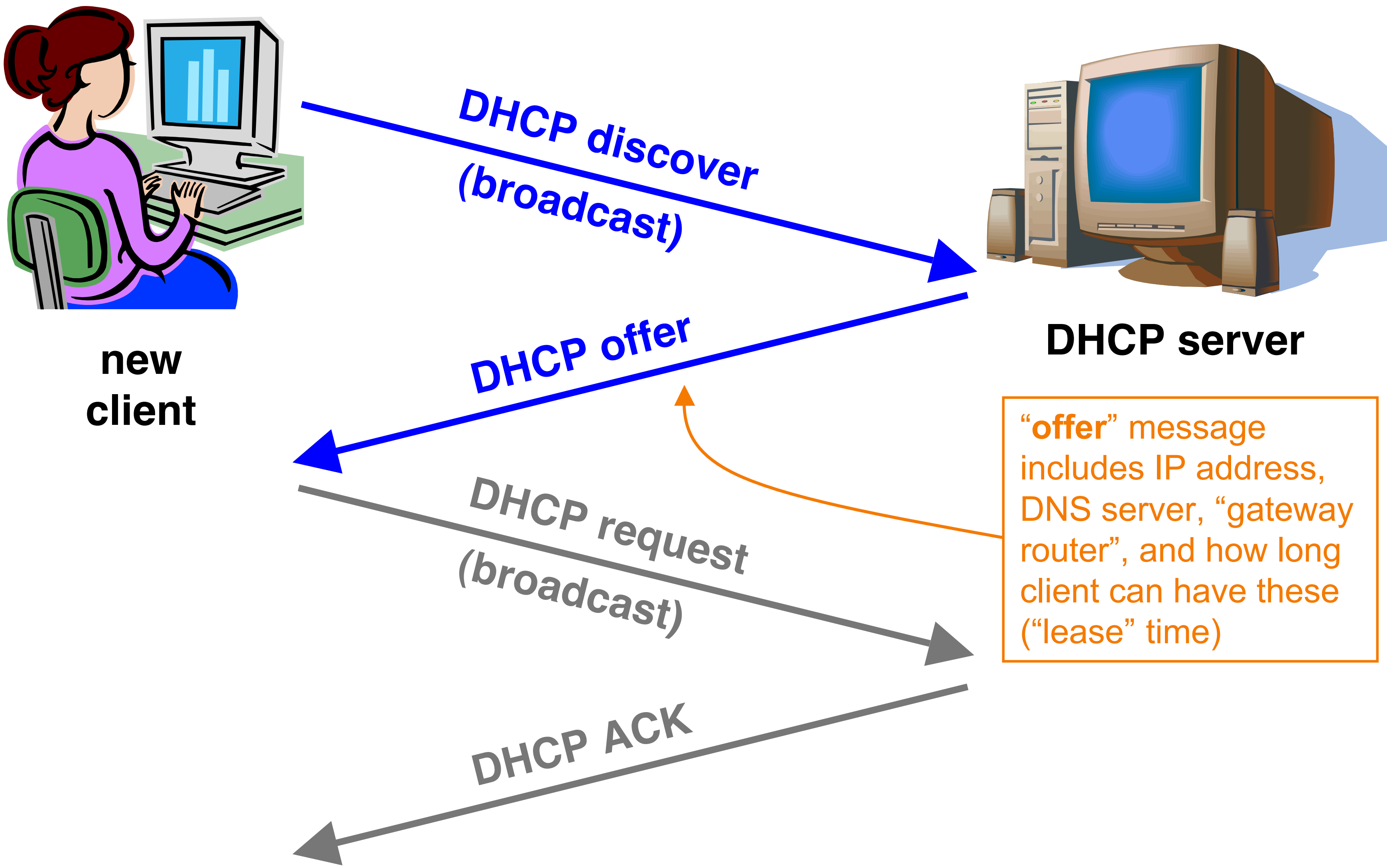
Sure - make a non-spoofed connection *first*, and see what server used for ISN y then!

# Internet Bootstrapping: DHCP

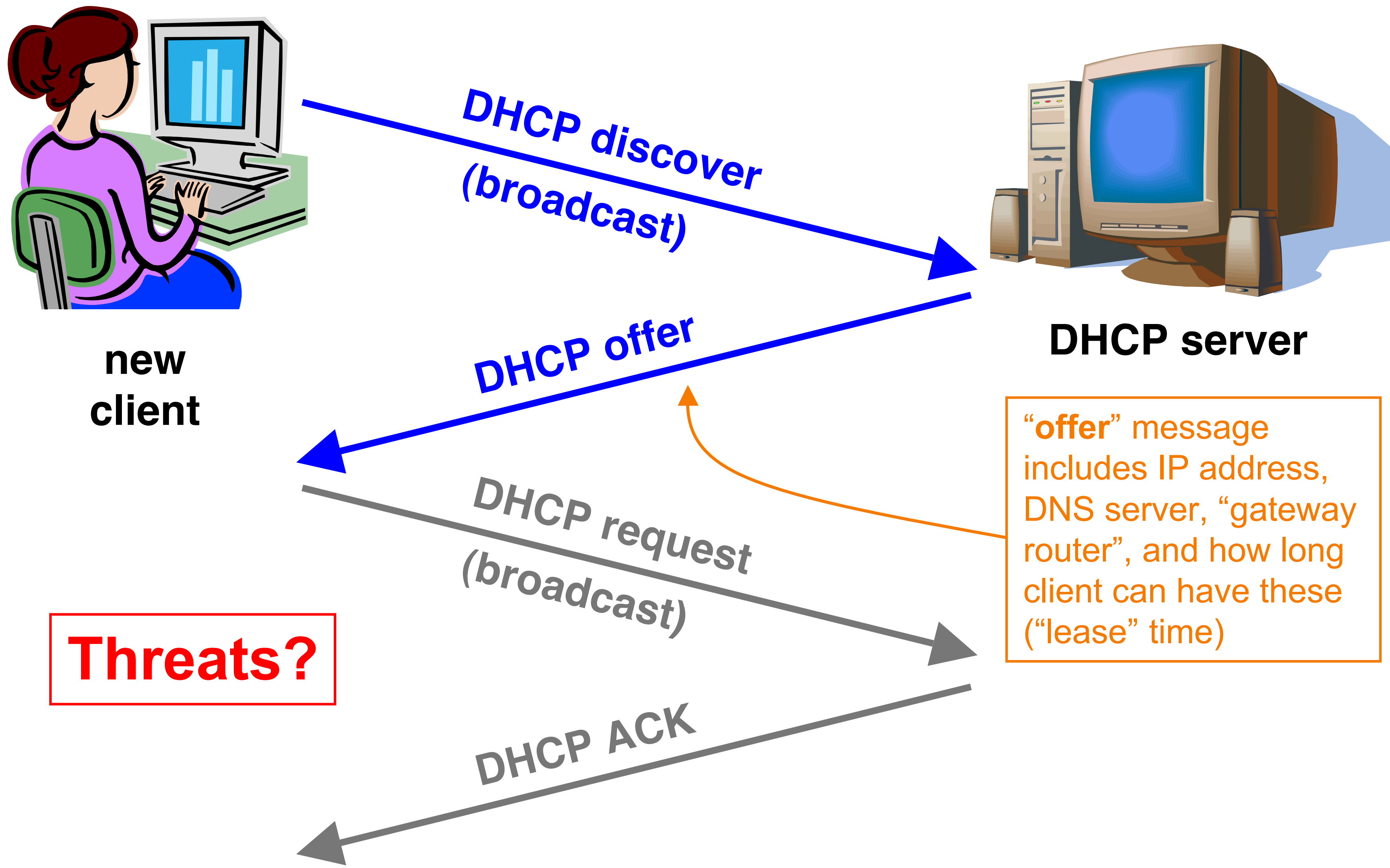
- New host doesn’t have an IP address yet
  - So, host doesn’t know what source address to use
- Host doesn’t know *who to ask* for an IP address
  - So, host doesn’t know what destination address to use
- Solution: shout to “**discover**” server that can help
  - Broadcast a server-discovery message (layer 2)
  - Server(s) sends a reply offering an address



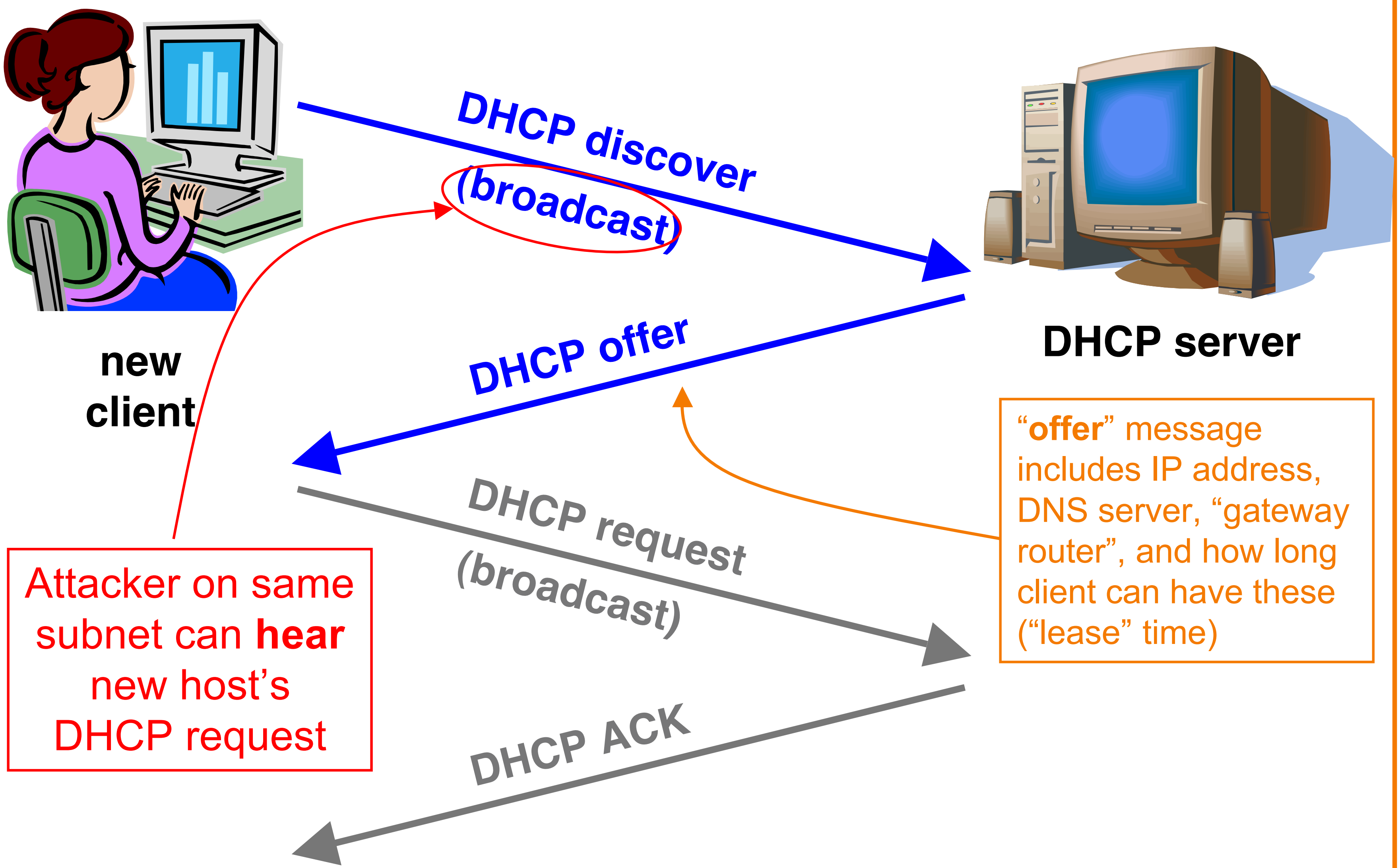
# Dynamic Host Configuration Protocol



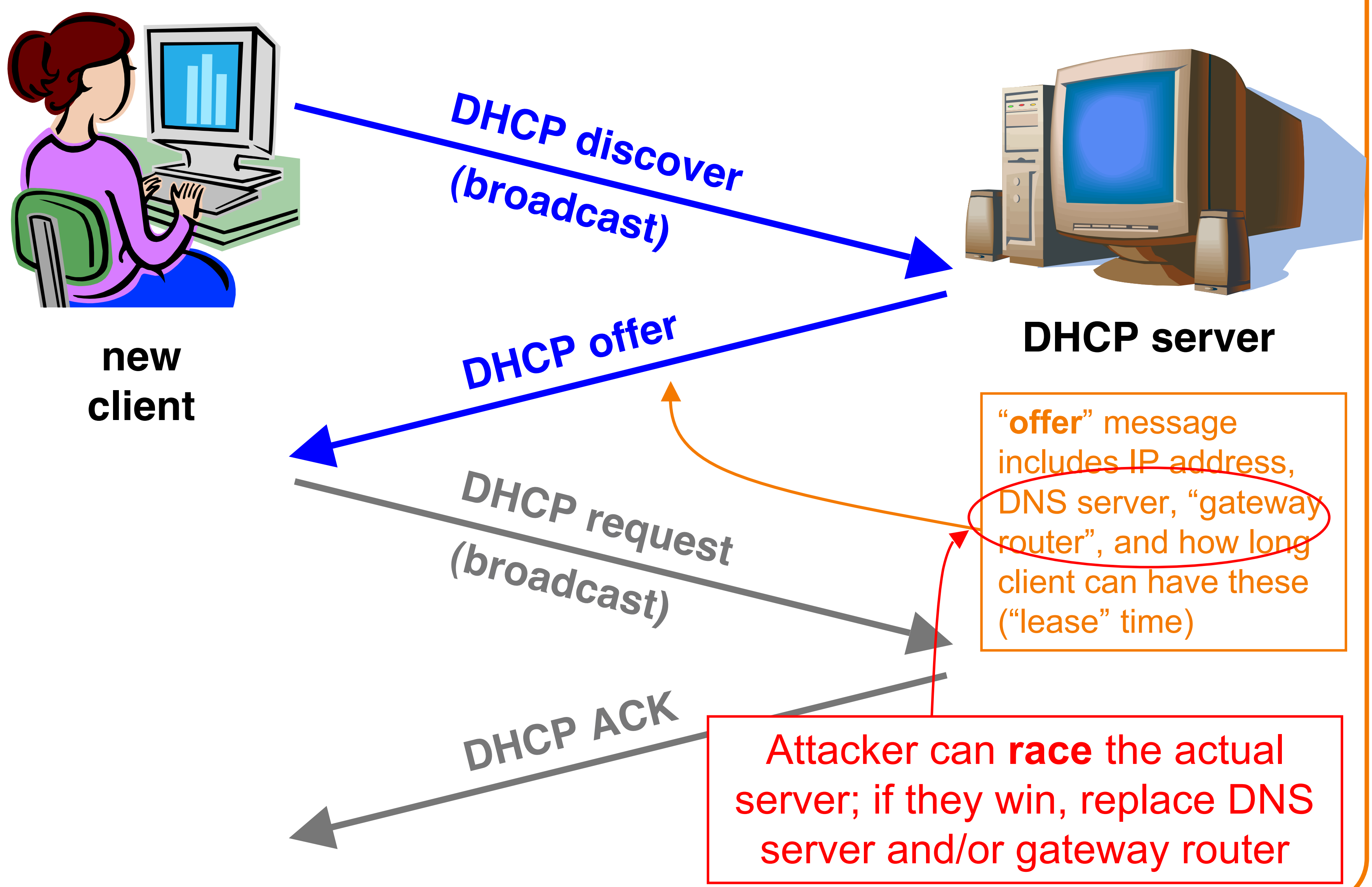
# Dynamic Host Configuration Protocol



# Dynamic Host Configuration Protocol



# Dynamic Host Configuration Protocol

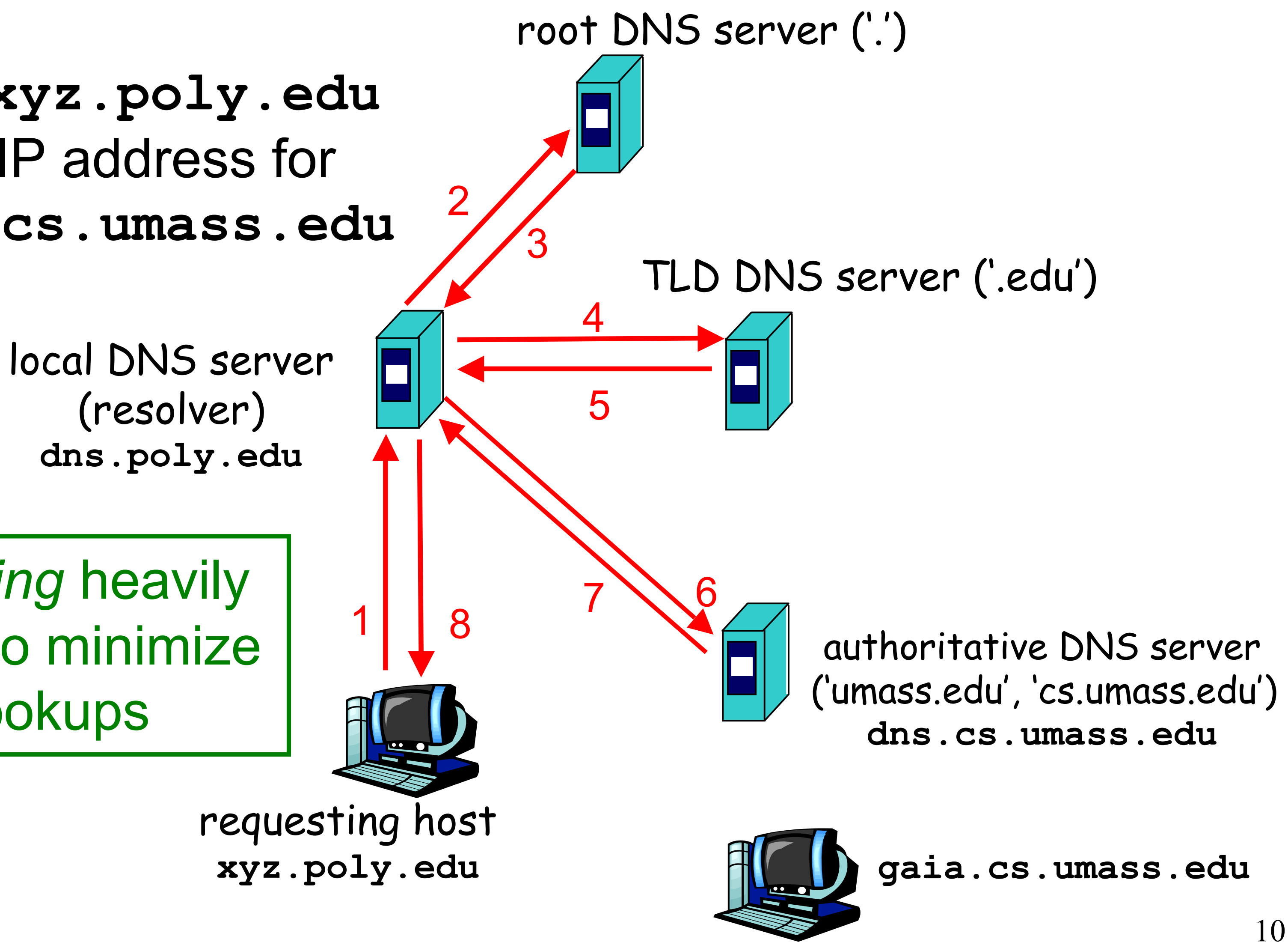


# DHCP Threats

- Substitute a fake DNS server
  - Redirect any of a host's lookups to a machine of attacker's choice
- Substitute a fake "gateway"
  - Intercept all of a host's off-subnet traffic
    - (even if not preceded by a DNS lookup)
  - Relay contents back and forth between host and remote server
    - Modify however attacker chooses
- An invisible *Man In The Middle* (MITM)
  - Victim host has no way of knowing it's happening
    - (Can't necessarily alarm on peculiarity of receiving multiple DHCP replies, since that can happen benignly)
- How can we fix this? ***Hard***

# DNS Lookups via a *Resolver*

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




*Caching* heavily used to minimize lookups

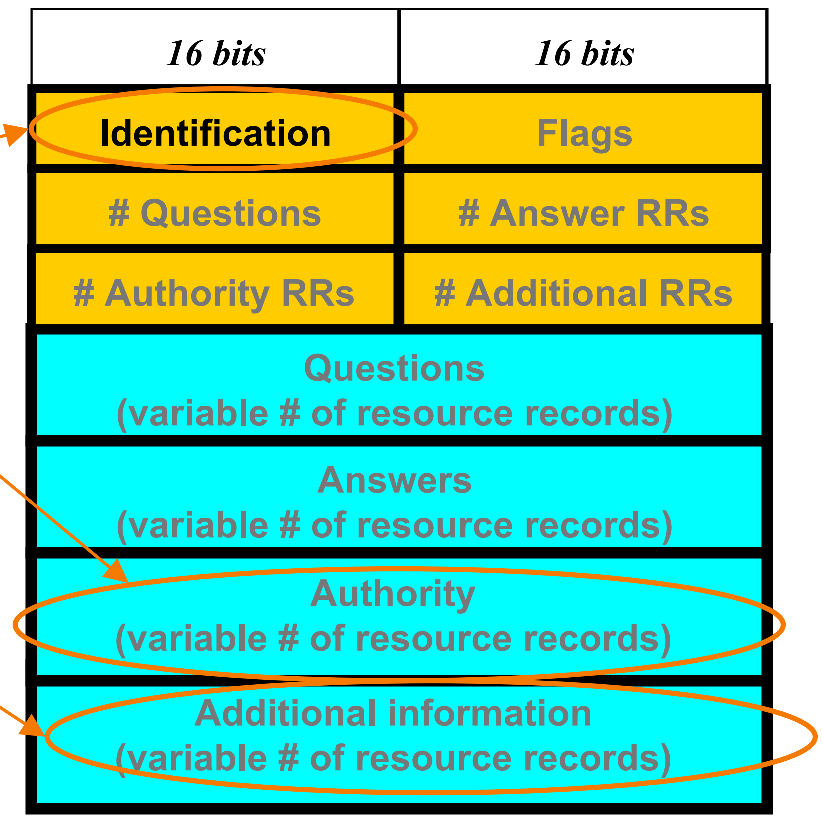
# DNS Protocol

**DNS protocol**: *query* and *reply* messages, both with same *message format*

(Mainly uses UDP transport rather than TCP)

Message header:

- Identification: 16 bit # for query, reply to query uses same #
- Replies can include "Authority" (name server responsible for answer) and "Additional" (info client is likely to look up soon anyway)
- Replies have a Time To Live (in seconds) for **caching**



# DNS Threats

- DNS: path-critical for just about everything we do
  - Maps hostnames ⇔ IP addresses
  - Design only **scales** if we can minimize lookup traffic
    - #1 way to do so: caching
    - #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, can redirect us w/ misinformation
- Consider attackers who *can't* eavesdrop - but still aim to manipulate us via how protocols function
- Directly interacting w/ DNS: **`dig`** program on Unix
  - Allows querying of DNS system
  - Dumps each field in DNS responses

**dig eecs.mit.edu A**

Use Unix “dig” utility to look up DNS address (“A”) for hostname eecs.mit.edu

```
; ; <<>> 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
```

# 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
```

These are just comments from `dig` itself with details of the request/response

# 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
```

Transaction identifier

# 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.              1                                lu.
mit.edu.              1                                lu.
mit.edu.              1                                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
```

Here the server echoes back the question that it is answering.

Typically, mit.edu runs the DNS 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; QU                                        IONAL: 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
```

"Answer" tells us its address is `18.62.1.6` and we can *cache* the result for 21,600 seconds

# 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
```

"Authority" tells us the *name servers* responsible for the answer. Each record gives the *hostname* of a different name server ("NS") for names in `mit.edu.`

We should cache each record for 11,088 seconds.

# 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.

;; 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.

# dig eecs.mit.edu A

```
; ; <<>> DiG 9.6.0-APPLE-P2 <<>> eecs.mit.edu a
;; global options: +cmd
;; Got answer:
;; ->>HEADER<<- opcode: QU                              901
;; flags: qr rd ra; QUERY:                              ADDITIONAL: 3

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

;; ANSWER SECTION:
eecs.mit.edu.           21                              .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
```

What if the mit.edu server is untrustworthy? Could its operator steal, say, all of our web surfing to berkeley.edu's main 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.

;; 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
```

What happens if the mit.edu server returns the following to us instead?

# 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.

;; 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
```

We 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.)

# 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.                                                   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
```

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.

;; 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: +c
;; Got answer:
;; ->>HEADER<<- opcod
;; flags: qr rd ra; Q

;; 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.               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
```

≠

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.

# 5 Minute Break

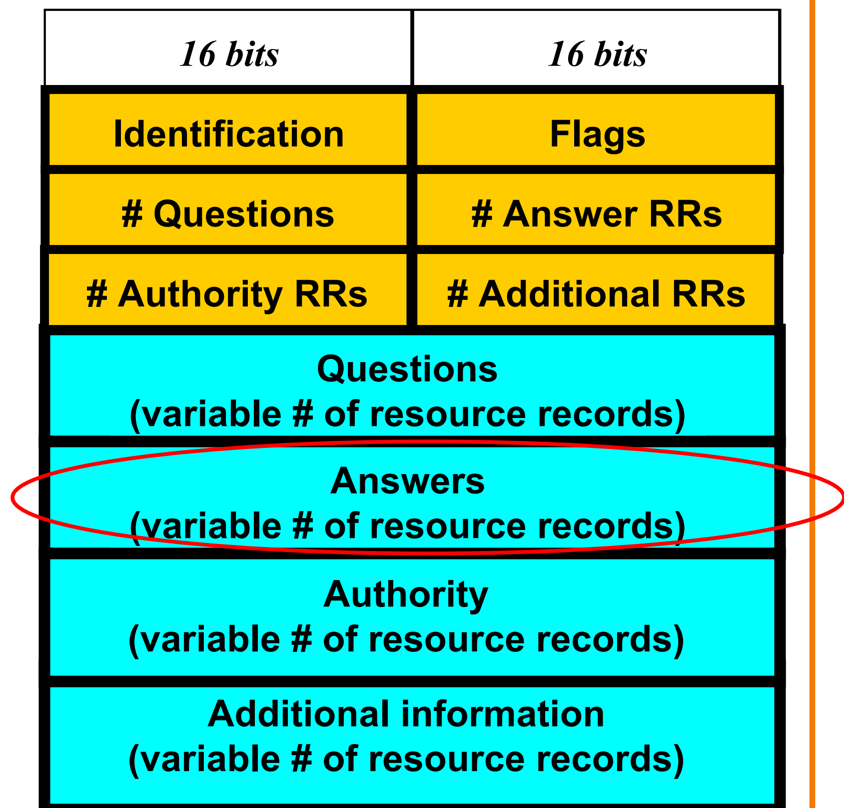
Questions Before We Proceed?

# DNS Threats, con't

What about *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`?




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

# DNS Blind Spoofing, con't

**Fix?**

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?

| 16 bits | 16 bits |
|---|---|
| Identification | Flags |
| # Questions | # Answer RRs |
| # Authority RRs | # Additional RRs |
| Questions (variable # of resource records) | |
| Answers (variable # of resource records) | |
| Authority (variable # of resource records) | |
| Additional information (variable # of resource records) | |

`<img src="http://badguy.com" …>` ← They observe ID k here

`<img src="http://mail.google.com" …>` ← So this will be k+1

# DNS Blind Spoofing, con't

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!

| *16 bits* | *16 bits* |
|---|---|
| **Identification** | **Flags** |
| **# Questions** | **# Answer RRs** |
| **# Authority RRs** | **# Additional RRs** |
| **Questions (variable # of resource records)** | |
| **Answers (variable # of resource records)** | |
| **Authority (variable # of resource records)** | |
| **Additional information (variable # of resource records)** | |

Unless attacker can send 1000s of replies before legit arrives, we're likely safe - phew! **?**

# DNS Blind Spoofing (Kaminsky 2008)

- Two key ideas:
  - Spoof uses Additional field (rather than Answer)
  - 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" …>
```

# Kaminsky Blind Spoofing, con't

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

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

;; 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` …

# Kaminsky Blind Spoofing, con't

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

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

;; 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` … 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.)

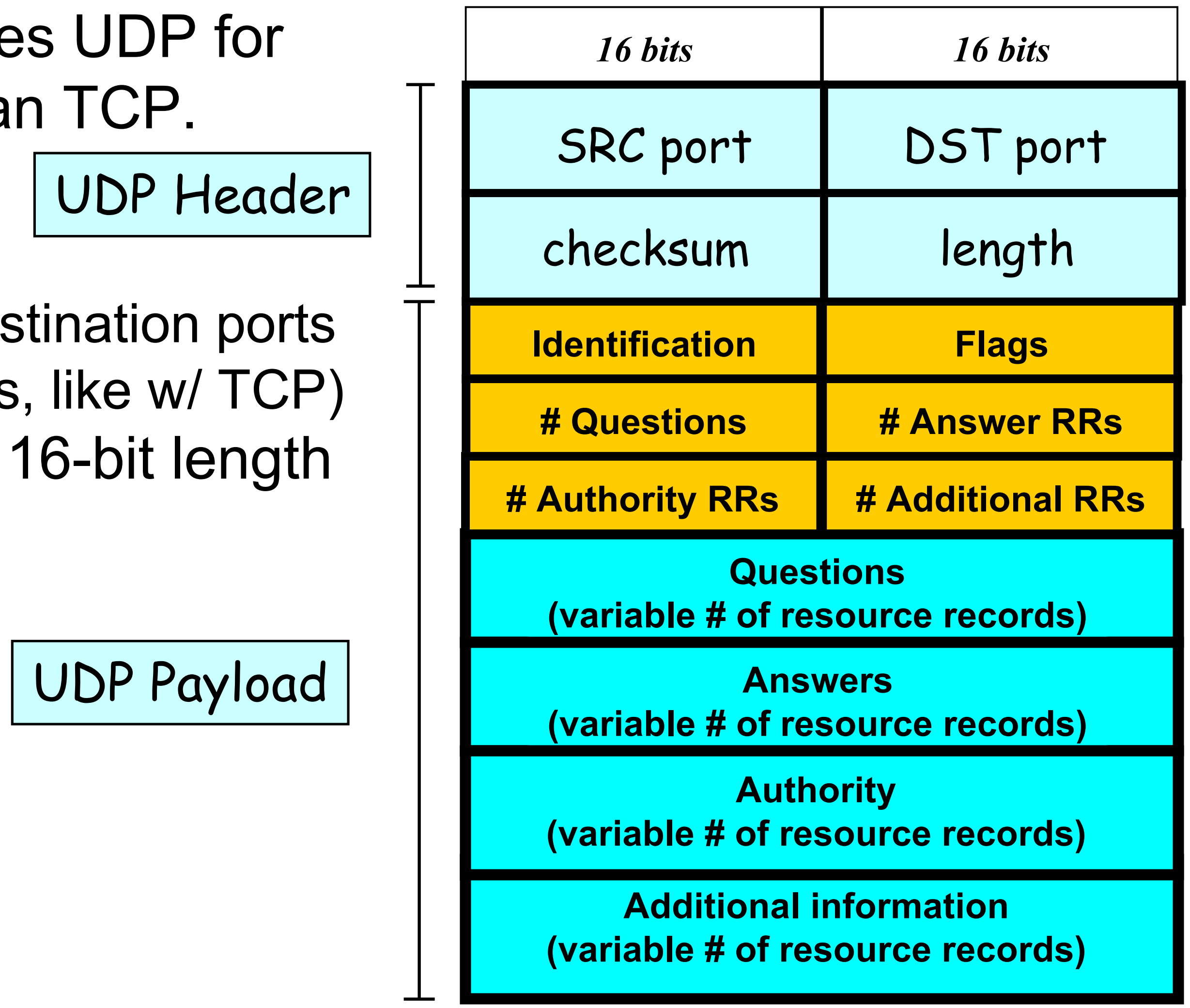
| *16 bits* | *16 bits* |
| --- | --- |
| **Identification** | **Flags** |
| **# Questions** | **# Answer RRs** |
| **# Authority RRs** | **# Additional RRs** |
| **Questions (variable # of resource records)** | |
| **Answers (variable # of resource records)** | |
| **Authority (variable # of resource records)** | |
| **Additional information (variable # of resource records)** | |

# Defending Against Blind Spoofing

DNS (primarily) uses UDP for transport rather than TCP.

UDP header has:

- 16-bit Source & Destination ports (identify processes, like w/ TCP)
- 16-bit checksum, 16-bit length



# Defending Against Blind Spoofing

**Total *entropy*: 16 bits**

DNS (primarily) uses UDP for transport rather than TCP.

UDP header has:

- 16-bit Source & Destination ports (identify processes, like w/ TCP)
- 16-bit checksum, 16-bit length

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

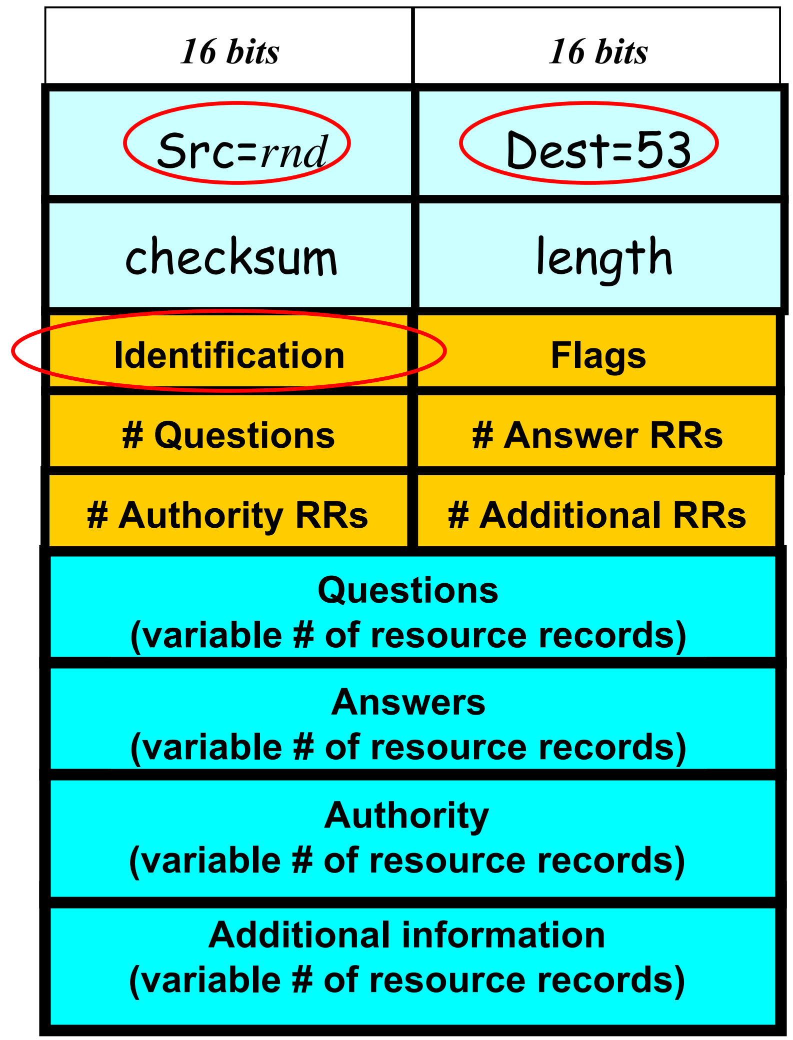
On a request, DST port = 53. SRC port usually also 53 - but not fundamental, just convenient

| *16 bits* | *16 bits* |
|---|---|
| Src=53 | Dest=53 |
| checksum | length |
| **Identification** | **Flags** |
| **# Questions** | **# Answer RRs** |
| **# Authority RRs** | **# Additional RRs** |
| **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

**Total *entropy*: ? bits**

"Fix": use random source port



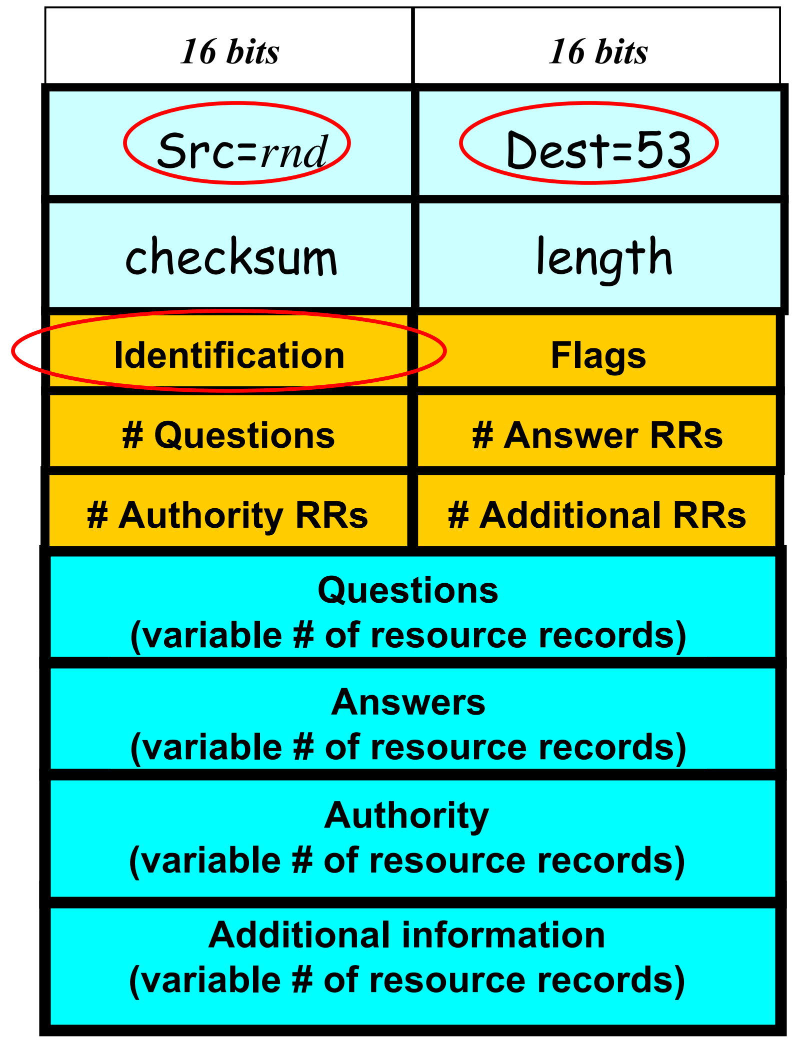
# Defending Against Blind Spoofing

**Total *entropy*: 32 bits**

“Fix”: use random source port

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 today. (Note: not all resolvers have implemented random source ports!)



# Summary of DHCP Security Issues

- DHCP threats highlight:
  - Broadcast protocols inherently at risk of attacker spoofing
    - Attacker knows exactly when to try it …
    - … and can see the victim's messages
  - When initializing, systems are particularly vulnerable because they can *lack a trusted foundation* to build upon
  - Tension between wiring in trust vs. flexibility/convenience
  - MITM attacks insidious because no indicators they're occurring

# Summary of DNS Security Issues

- DNS threats highlight:
  - Attackers can attack opportunistically rather than eavesdropping
    - o Cache poisoning only requires victim to look up some name under attacker's control
  - 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