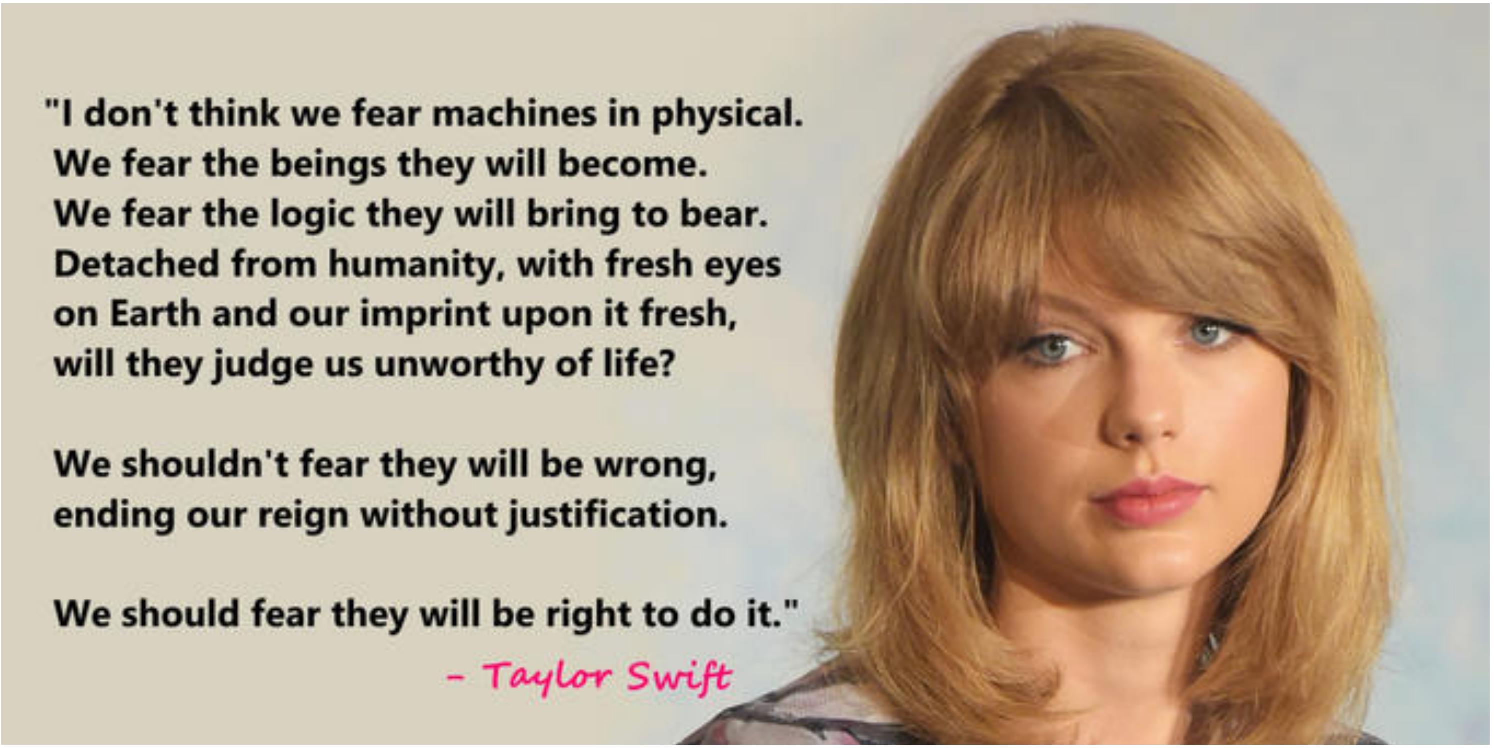
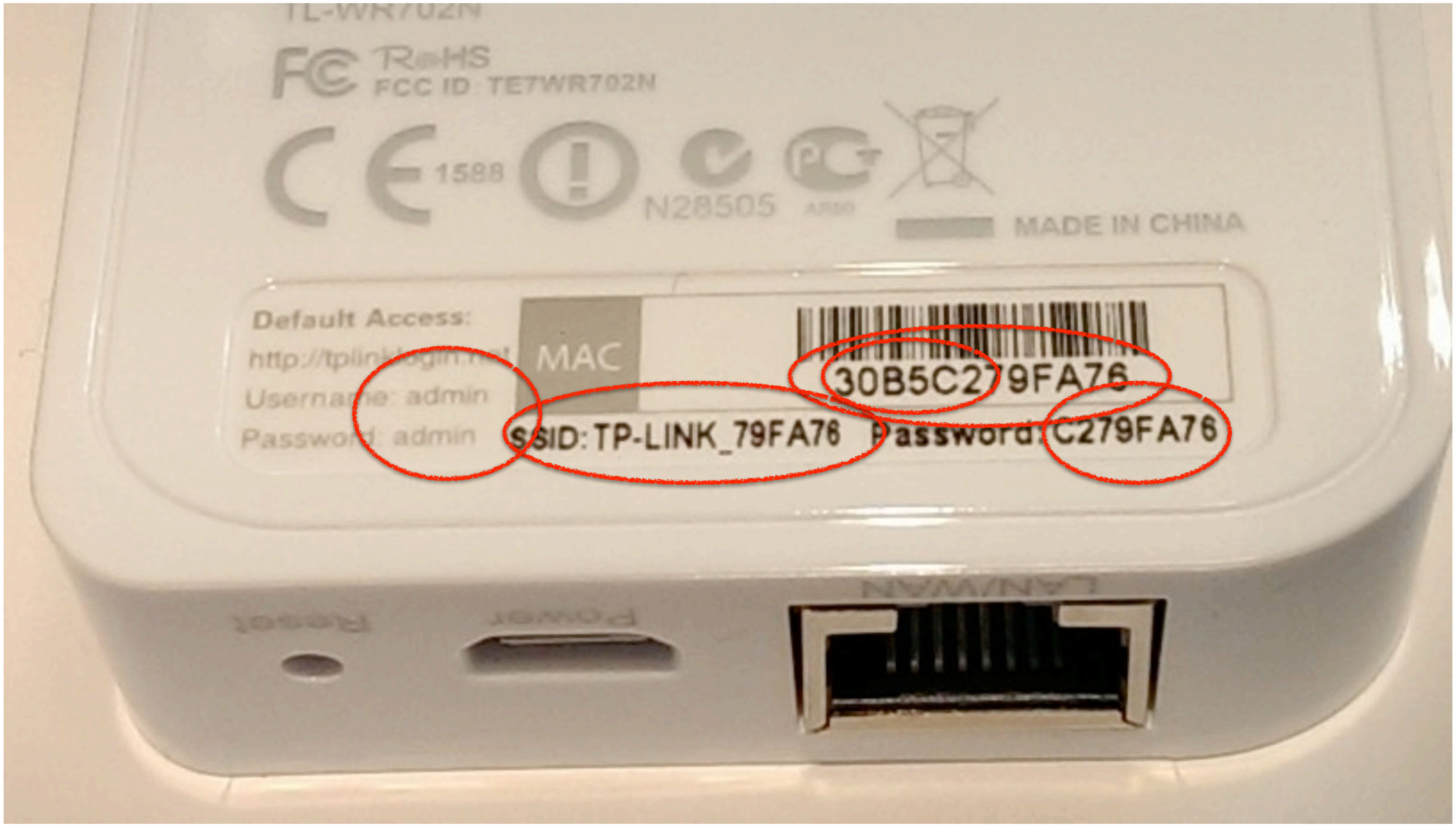
The Net Part 4: DNS, IP, TCP...



Spot the Zero Day: TPLink Miniature Wireless Router

Spot the ~~Zero~~ Forever Day: TPLink Miniature Wireless Router



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
      - The "glue records"
- What if attacker eavesdrops on our DNS queries?
  - Then similar to DHCP, ARP, AirPwn etc, 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

```
dig eecs.mit.edu A
```

Use Unix "`dig`" utility to look up IP address ("`A`") for hostname `eecs.mit.edu` via DNS

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

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.           2160

;; 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

dig eecs.mit.edu A

```
; ; <<>> DiG 9.6.0-APPLE-P2 <<>> eecs.mit.edu a
;; global options: +cmd
;; Got answer:
;; ->>HEADER<<- opcode:
;; flags: qr rd ra; QUE                                   ONAL: 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 the IP address associated with `eecs.mit.edu` 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.                  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.                                                du.
mit.edu.                                                edu.

;; ADDITIONAL SECTION
STRAWB.mit.edu.
BITSY.mit.edu.
W20NS.mit.edu.          126738  IN      A       18.70.0.160
```

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

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

"**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.

;; AUTHORITY SECT
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.

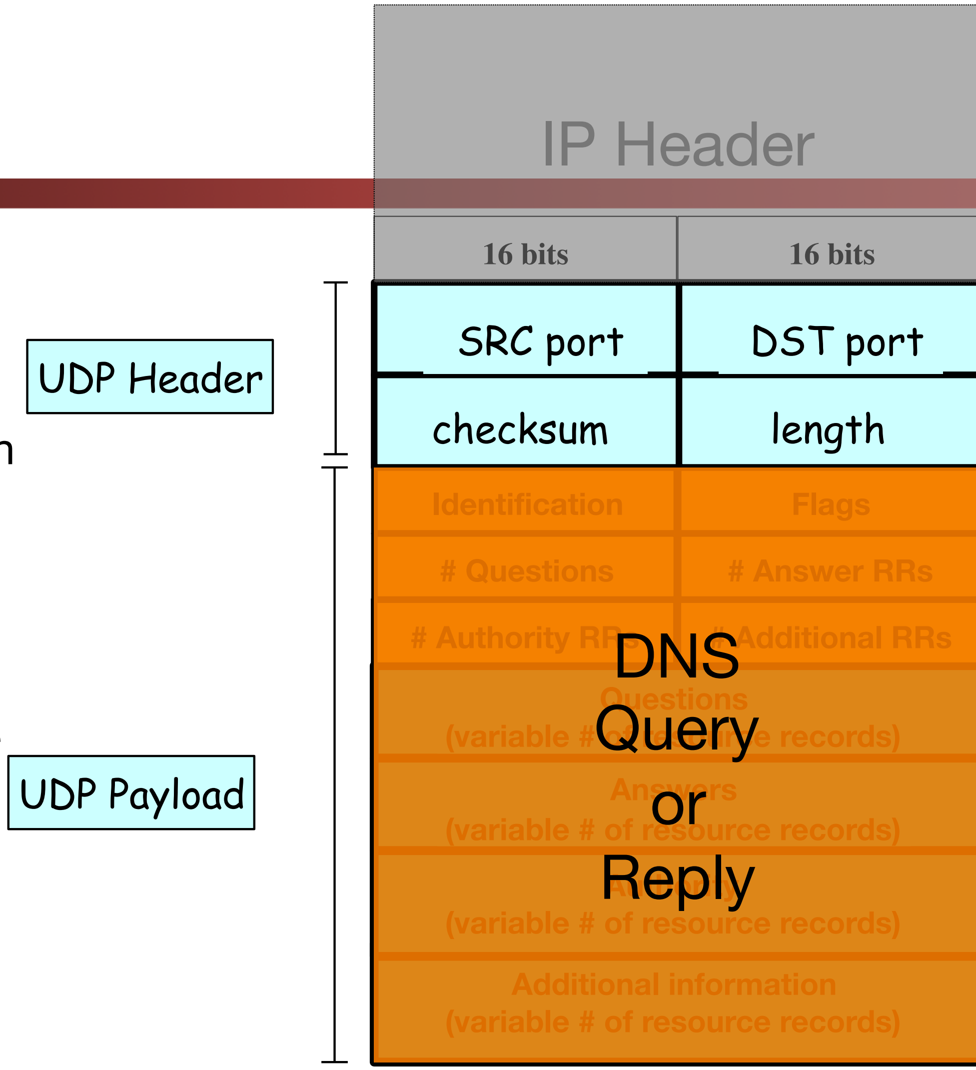
DNS Protocol

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

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

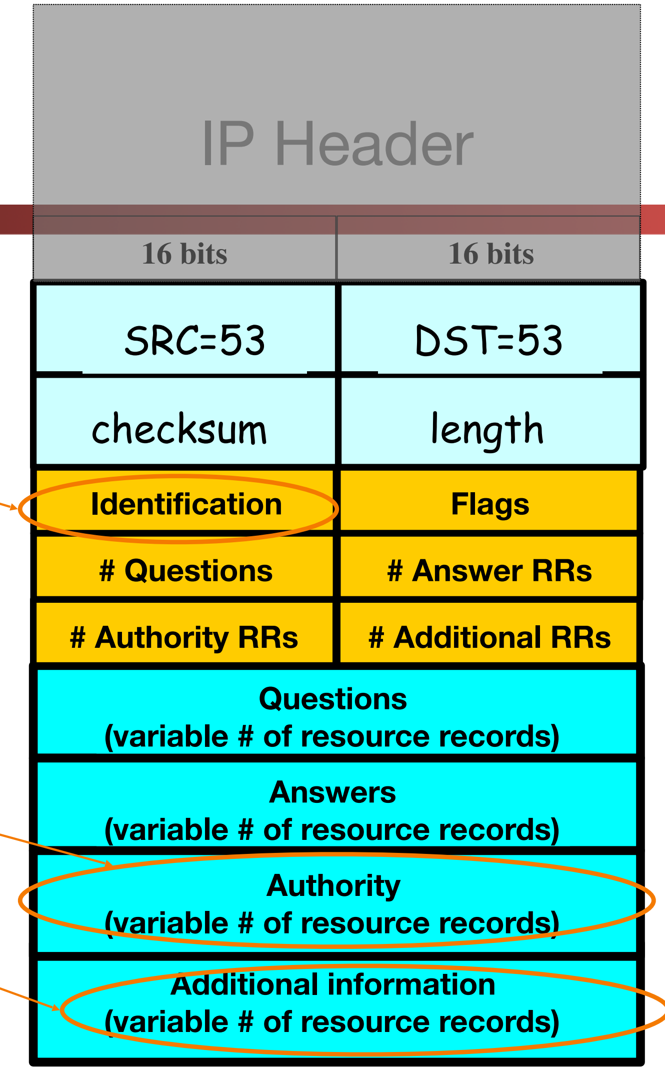
Servers are on port 53 always

Frequently, clients used to use port 53 but can use any port



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)



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:                              ADDITIONAL: 3

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

;; ANSWER SECTION:
eecs.mit.edu.           216                             .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 web 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.            216                                    .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
```

Let's look at a flaw in the original DNS design (since fixed)

```
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      www.berkeley.edu.

;; ADDITIONAL SECTION:
www.berkeley.edu.       100000  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 could happen 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.                11088   IN      NS      www.berkeley.edu.

;; ADDITIONAL SECTION:
www.berkeley.edu.       100000  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'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.)

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.           2                              6

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

;; ADDITIONAL SECTION:
www.berkeley.edu.       100000  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 last a long time. They could just as easily make it for just a couple of 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.                  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-APP
;; global options: +c
;; Got answer:
;; ->>HEADER<<- opcod
;; flags: qr rd ra; Q

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

;; ANSWER SECTION:
eecs.mit.edu.

;; AUTHORITY SECTION:
mit.edu.                 11088    IN
mit.edu.                 11088    IN
mit.edu.                 11088    IN

;; ADDITIONAL SECTION:
www.berkeley.edu.        100000   IN
BITSY.mit.edu.           166408   IN
W20NS.mit.edu.           126738   IN
```

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.

This is called "***Bailiwick*** checking"

bail·i·wick

/ˈbāləˌwik/

noun

1. one's sphere of operations or particular area of interest.
   "you never give the presentations—that's my bailiwick"
2. LAW
   the district or jurisdiction of a bailie or bailiff.

DNS Resource Records and RRSETs

- DNS records (Resource Records) can be one of various types
    - Name TYPE Value
        - Also a “time to live” field: how long in seconds this entry can be cached for
  - Addressing:
    - A: IPv4 addresses
    - AAAA: IPv6 addresses
    - CNAME: aliases, “Name X should be name Y”
    - MX: “the mailserver for this name is Y”
  - DNS related:
    - NS: “The authority server you should contact is named Y”
    - SOA: “The operator of this domain is Y”
  - Other:
    - text records, cryptographic information, etc.…
- Groups of records of the same type form RRSETs:
  - E.g. all the nameservers for a given domain.

The Many Moving Pieces In a DNS Lookup of www.isc.org

`? A www.isc.org`

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

Name	Type	Value	TTL

.
Authority Server (the "root")

```
? A www.isc.org
Answers:
Authority:
org. NS a0.afilias-nst.info
Additional:
a0.afilias-nst.info A 199.19.56.1
```

The Many Moving Pieces In a DNS Lookup of www.isc.org

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

Name	Type	Value	TTL
org.	NS	a0.afilias-nst.info	172800
a0.afilias-nst.info.	A	199.19.56.1	172800

org. Authority Server

```
? A www.isc.org
Answers:
Authority:
isc.org. NS sfba.sns-pb.isc.org.
isc.org. NS ns.isc.afilias-nst.info.
Additional:
sfba.sns-pb.isc.org.     A 199.6.1.30
ns.isc.afilias-nst.info. A 199.254.63.254
```

The Many Moving Pieces In a DNS Lookup of www.isc.org

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

Name	Type	Value	TTL
org.	NS	a0.afilias-nst.info	172800
a0.afilias-nst.info.	A	199.19.56.1	172800
isc.org.	NS	sfba.sns-pb.isc.org.	86400
isc.org.	NS	ns.isc.afilias-net.info.	86400
sfbay.sns-pb.isc.org.	A	199.6.1.30	86400

isc.org. Authority Server

```
? A www.isc.org
Answers:
www.isc.org. A 149.20.64.42
Authority:
isc.org. NS sfba.sns-pb.isc.org.
isc.org. NS ns.isc.afilias-nst.info.
Additional:
sfba.sns-pb.isc.org.     A 199.6.1.30
ns.isc.afilias-nst.info. A 199.254.63.254
```

The Many Moving Pieces In a DNS Lookup of **www.isc.org**

User's ISP's Recursive Resolver

? A www.isc.org

Answers: www.isc.org A 149.20.64.42

Name	Type	Value	TTL
org.	NS	a0.afilias-nst.info	172800
a0.afilias-nst.info.	A	199.19.56.1	172800
isc.org.	NS	sfba.sns-pb.isc.org.	86400
isc.org.	NS	ns.isc.afilias-net.info.	86400
sfbay.sns-pb.isc.org.	A	199.6.1.30	86400
www.isc.org	A	149.20.64.42	600

Stepping Through This With **dig**

- Some flags of note:
  - +norecurse: Ask directly like a recursive resolver does
  - +trace: Act like a recursive resolver without a cache

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

;  <<>> DiG 9.8.3-P1 <<>> +norecurse slashdot.org @a.root-servers.net
;; global options: +cmd
;; Got answer:
;; ->>HEADER<<- opcode: QUERY, status: NOERROR, id: 26444
;; flags: qr; QUERY: 1, ANSWER: 0, AUTHORITY: 6, ADDITIONAL: 12

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

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

;; ADDITIONAL SECTION:
a0.org.afilias-nst.info. 172800 IN      A       199.19.56.1
```

So in `dig` parlance

- So if you want to recreate the lookups conducted by the recursive resolver:
  - **`dig +norecurse www.isc.org @a.root-servers.net`**
  - **`dig +norecurse www.isc.org @199.19.56.1`**
  - **`dig +norecurse www.isc.org @199.6.1.30`**

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.
  - China does this operationally:
  - **`dig www.benign.com @www.tsinghua.edu.cn`**
  - **`dig www.facebook.com @www.tsinghua.edu.en`**

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).

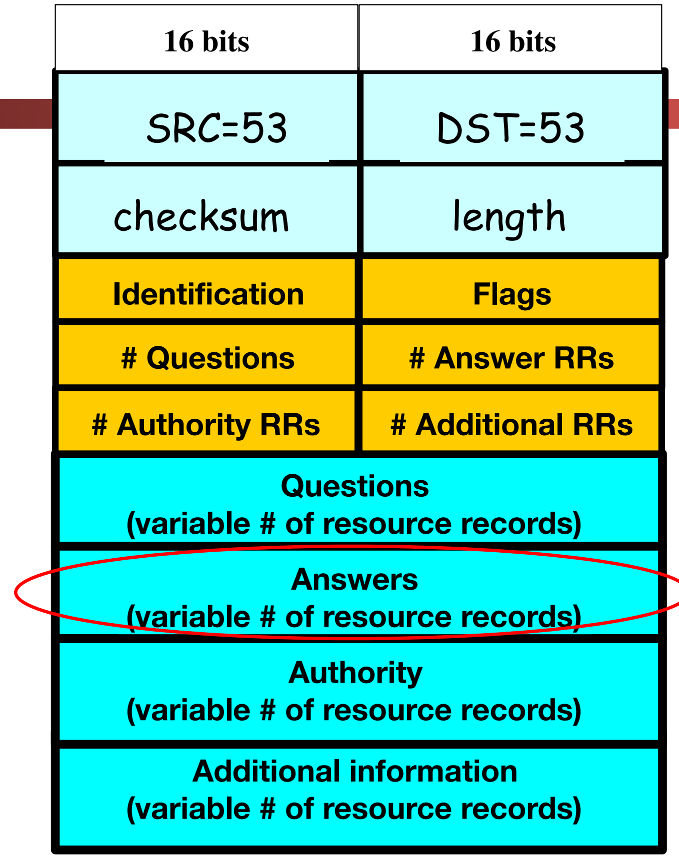
Blind spoofing

- 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" …> ...



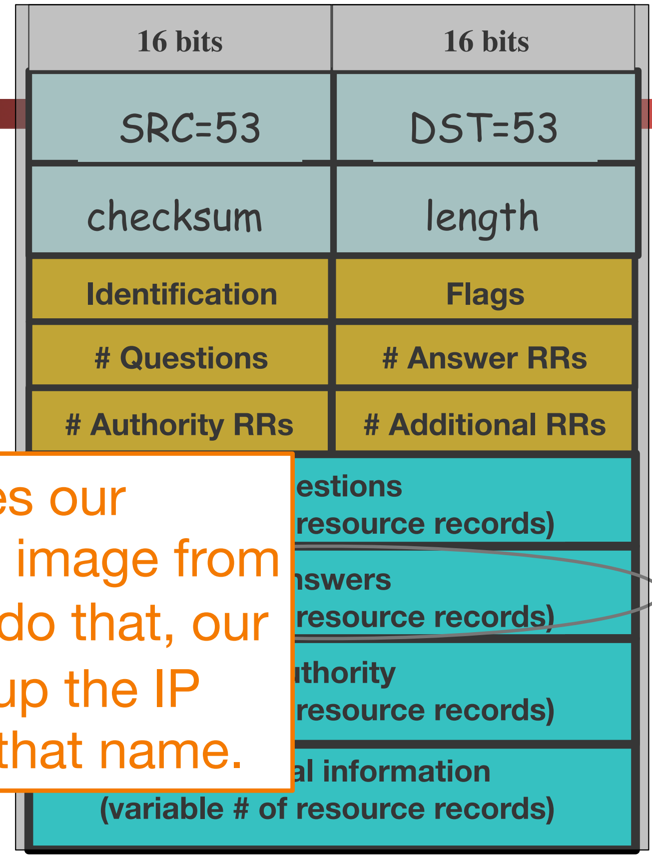
Blind spoofing

- Say we look up `mail.google.com`; how can an **off-path** attacker feed us a bogus `A` answer before the legitim

This HTML snippet causes our browser to try to fetch an image from `mail.google.com`. To do that, our browser first has to look up the IP address associated with that name.

- How c even k `mail`
  Suppose, e.g., we visit a web page under their control:

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



Blind spoofing

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
SRC=53	DST=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)	

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

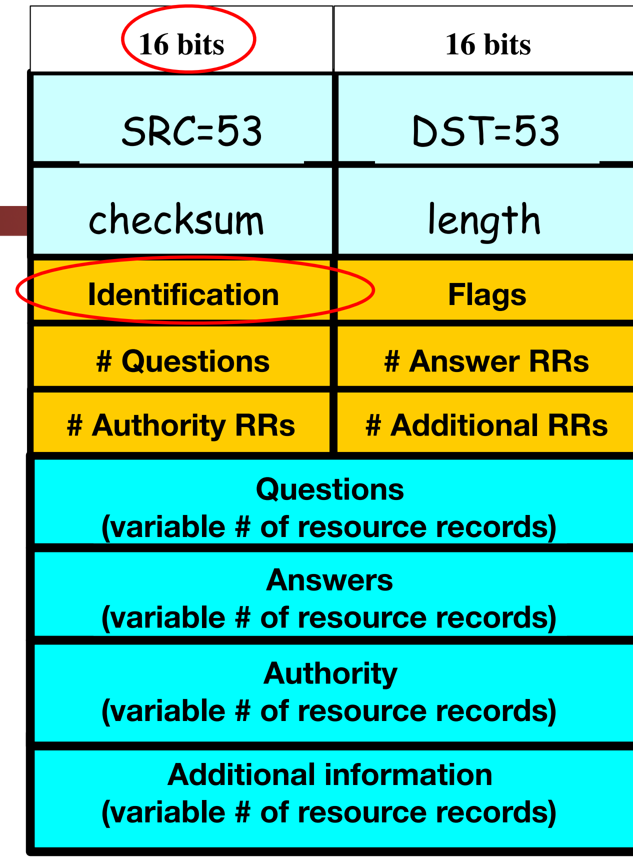
<img src="http://mail.google.com" …> ← So this will be k+1

DNS Blind Spoofing, 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! **?**

Enter Kaminski... Glue Attacks

- Dan Kaminski noticed something strange, however...
  - Most DNS servers would ***cache*** the in-bailiwick glue...
  - And then ***promote*** the glue
  - And will also ***update*** entries based on glue
- So if you first did this lookup...
  - And then went to **`a0.org.afilias-nst.info`**
  - there would be no other lookup!

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

;  <<>> DiG 9.8.3-P1 <<>> +norecurse slashdot.org @a.root-servers.net
;; global options: +cmd
;; Got answer:
;; ->>HEADER<<- opcode: QUERY, status: NOERROR, id: 26444
;; flags: qr; QUERY: 1, ANSWER: 0, AUTHORITY: 6, ADDITIONAL: 12

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

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

;; ADDITIONAL SECTION:
a0.org.afilias-nst.info. 172800 IN      A       199.19.56.1
...

;; Query time: 128 msec
;; SERVER: 198.41.0.4#53(198.41.0.4)
;; WHEN: Tue Apr 16 09:48:32 2013
;; MSG SIZE  rcvd: 432
```

The Kaminski Attack In Practice

- Rather than trying to poison **`www.google.com`**...
- Instead try to poison **`a.google.com`**...
  And state that "**`www.google.com`**" is an authority
  And state that "**`www.google.com A 133.7.133.7`**"
  - If you succeed, great!
- But if you fail, just try again with b.google.com!
  - Turns "Race once per timeout" to "race until win"
- So now the attacker may still have to send lots of packets
  - In the 10s of thousands
- The attacker can keep trying until success

Defending Against Kaminski: Up the Entropy

- Also randomize the UDP source port
  - Adds 16 bits of entropy
- Observe that most DNS servers just copy the request directly
  - Rather than create a new reply
- So caMeLcase the NamE ranDomly
  - Adds only a few bits of entropy however, but it does help

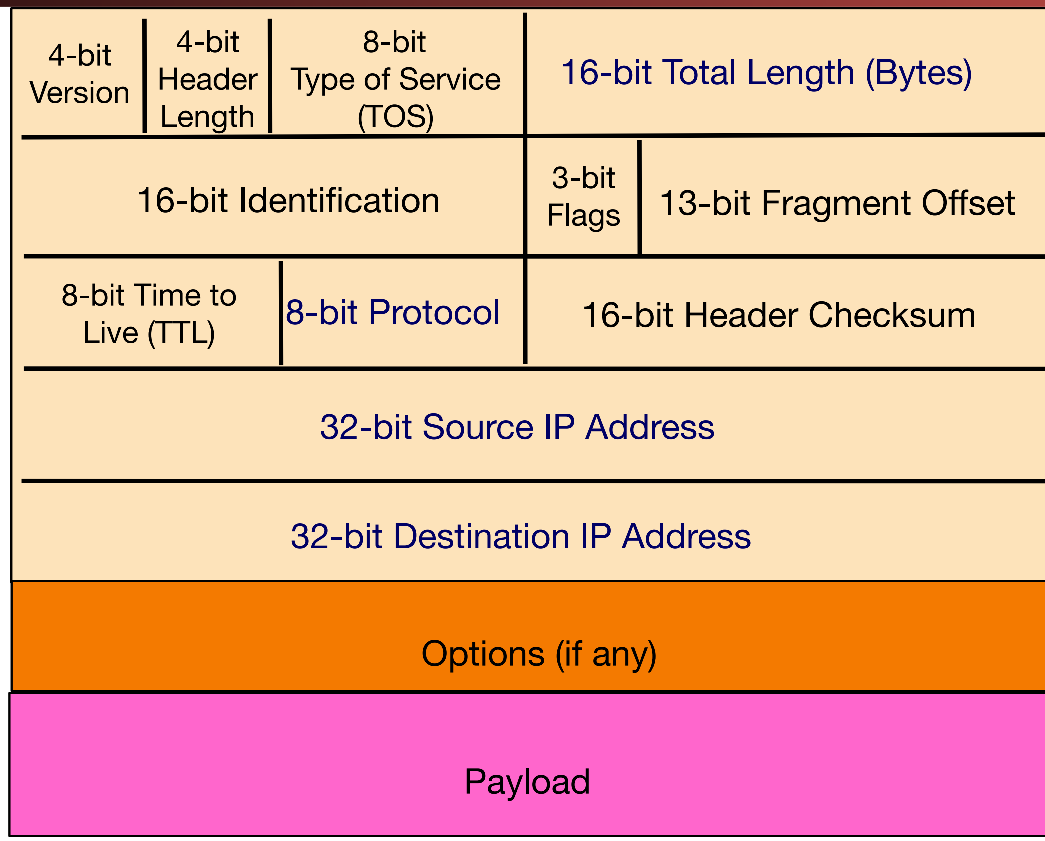
Defend Against Kaminski: Validate Glue

- Don't blindly accept glue records...
  - Well, you ***have*** to accept them for the purposes of resolving a name
- But if you are going to cache the glue record...
- Either only use it for the context of a DNS lookup
  - No more promotion
- Or explicitly validate it with another fetch
- Unbound implemented this, bind did not
  - Largely a ***political*** decision:
    bind's developers are heavily committed to DNSSEC (next week's topic)

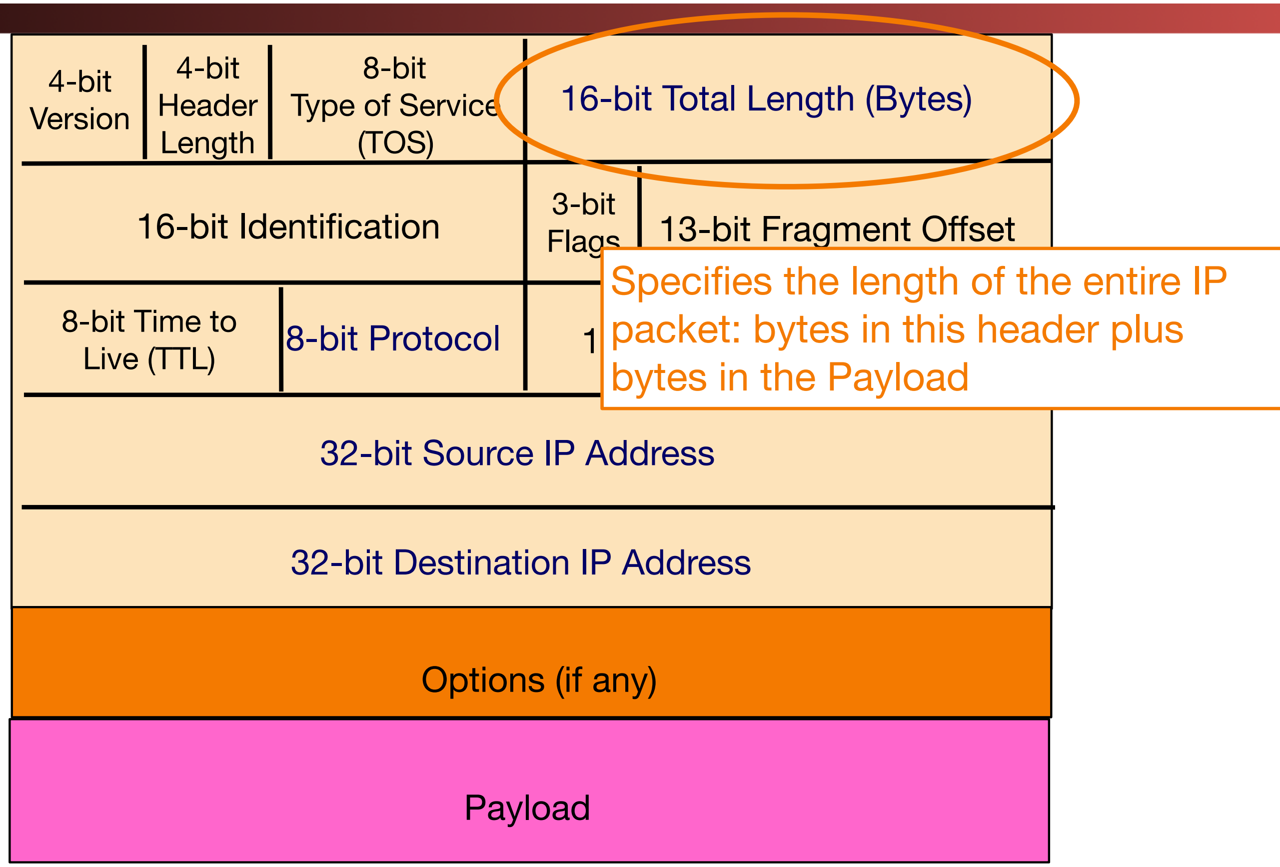
Oh, and Profiting from Rogue DNS

- Suppose you take over a lot of home routers...
  - How do you make money with it?
- Simple: Change their DNS server settings
  - Make it point to yours instead of the ISPs
- Now redirect all advertising
  - And instead serve up ads for "Vimax" pills...

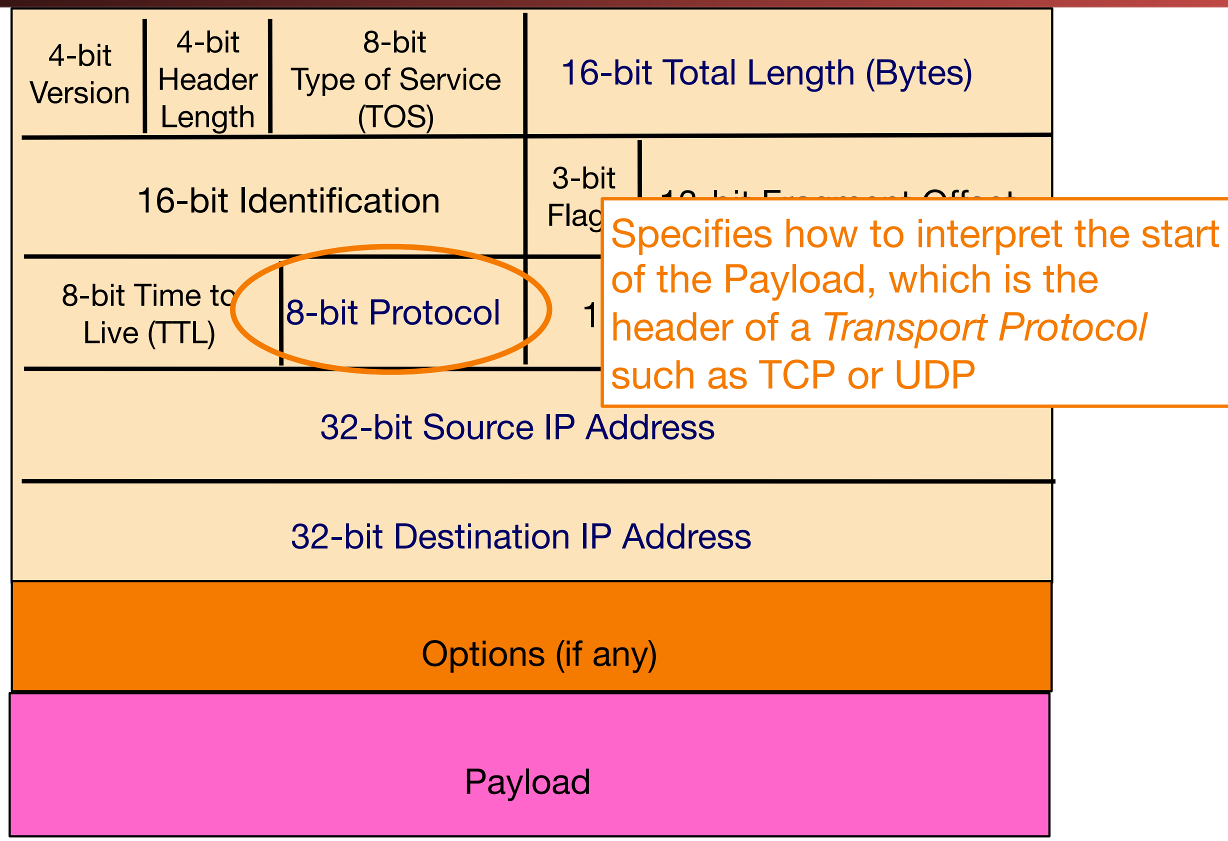
IP Packet Structure



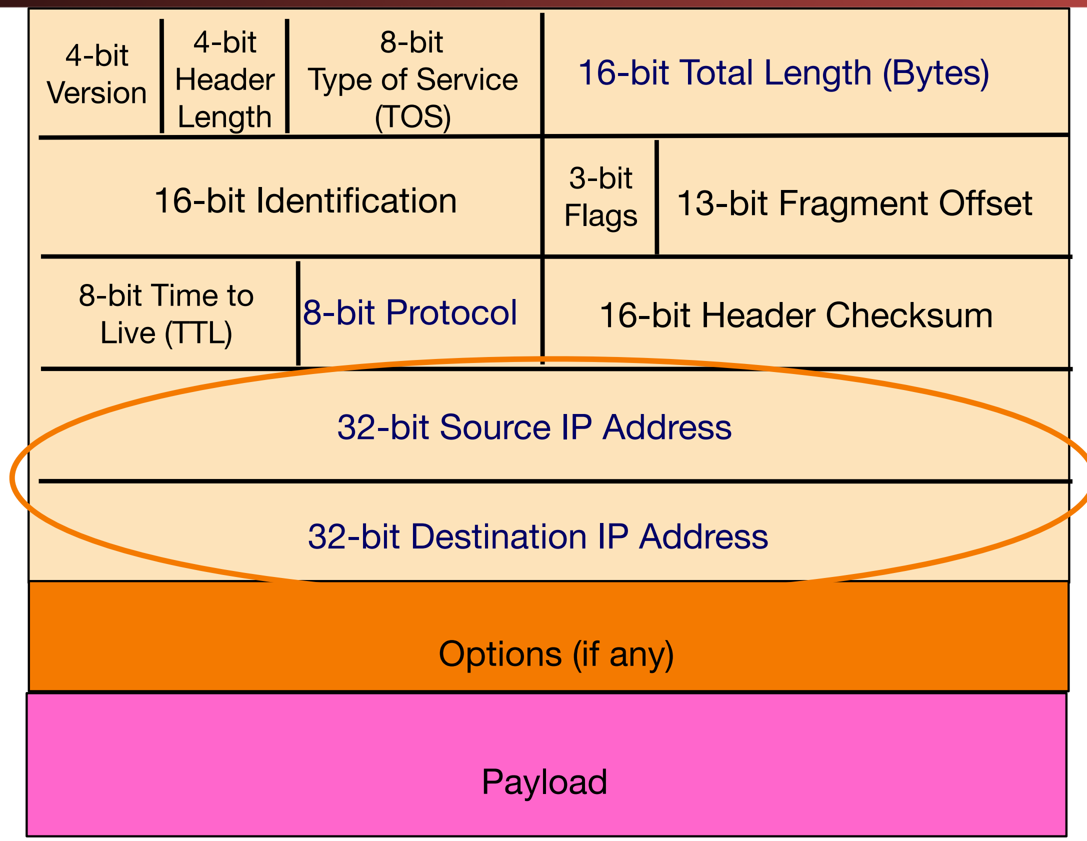
IP Packet Structure



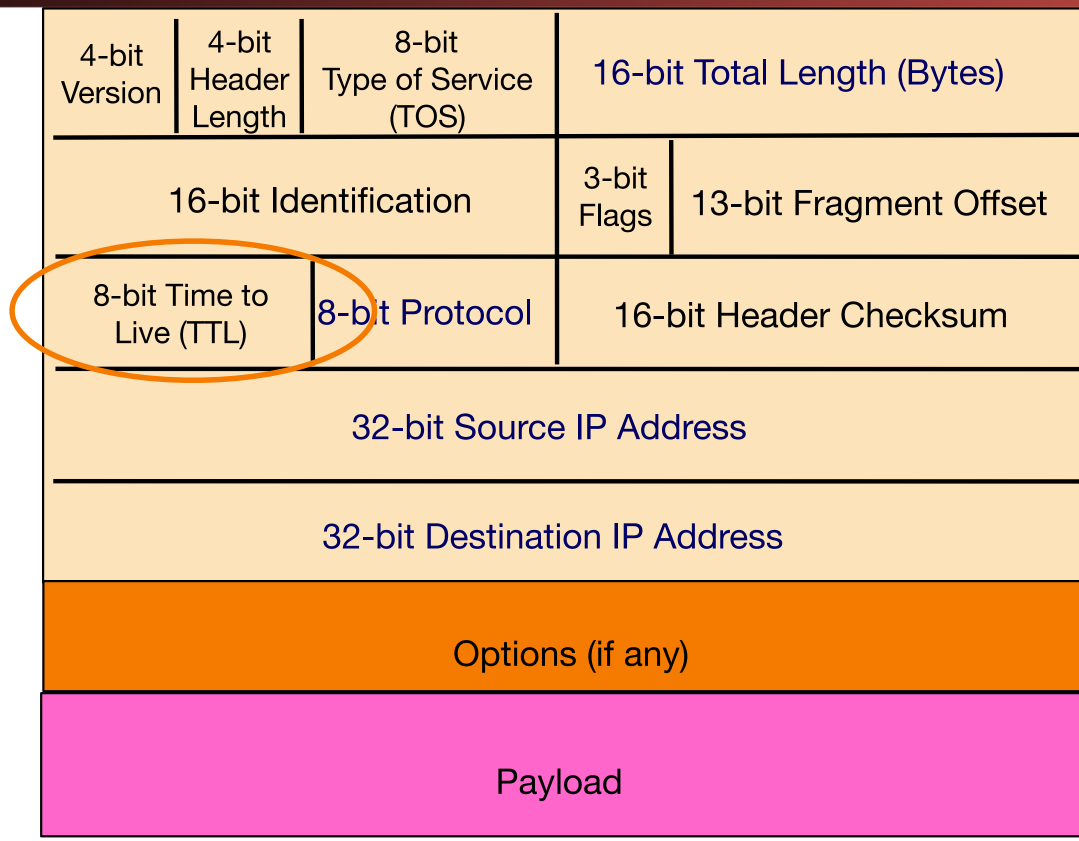
IP Packet Structure



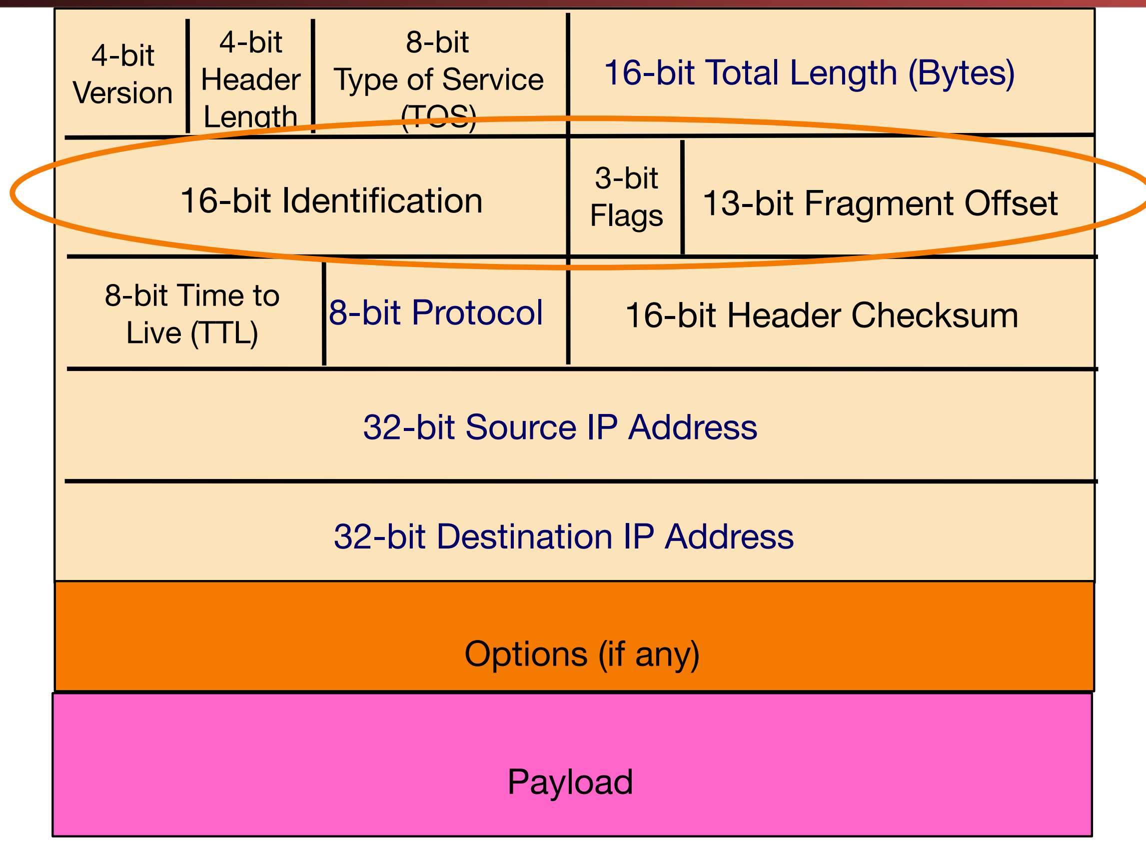
IP Packet Structure



IP Packet Structure



IP Packet Structure



IP Packet Header (Continued)

- Two IP addresses
  - Source IP address (32 bits)
  - Destination IP address (32 bits)
- Destination address
  - Unique identifier/locator for the receiving host
  - Allows each node to make forwarding decisions
- Source address
  - Unique identifier/locator for the sending host
  - Recipient can decide whether to accept packet
  - Enables recipient to send a reply back to source
- Checksum is arithmetic, not CRC...
  - To allow easily modification of the packet by the network

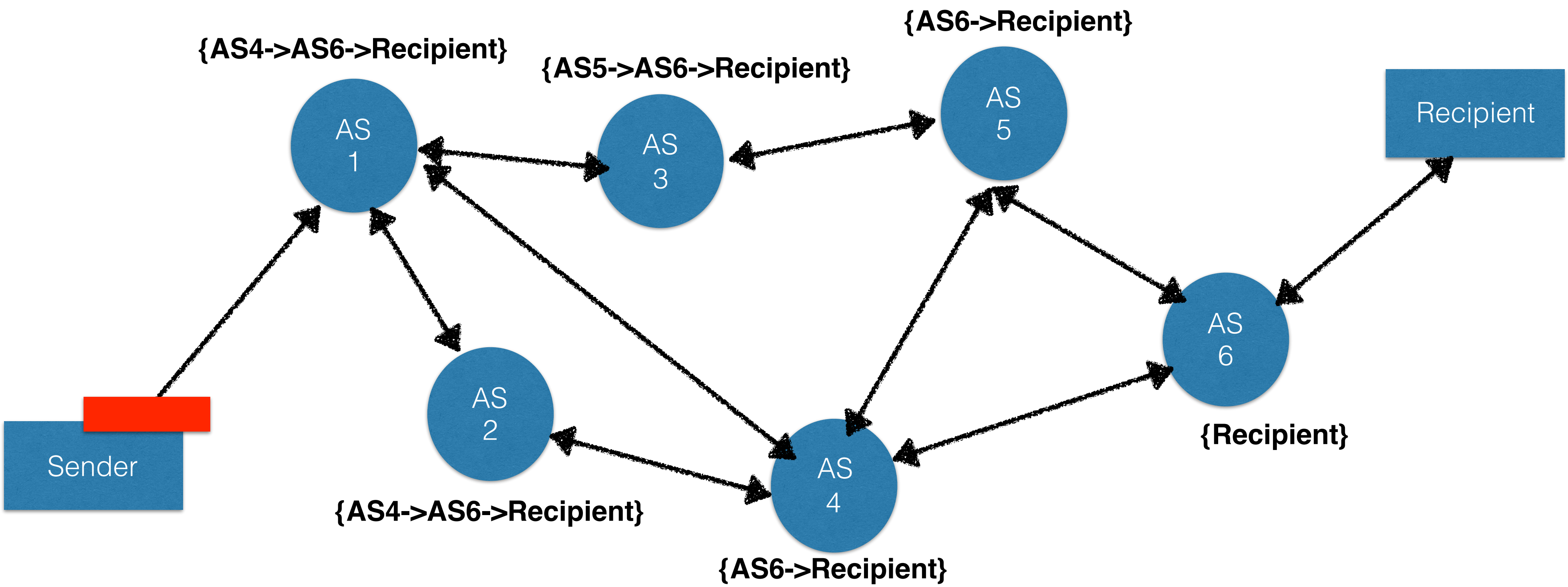
IP: “Best Effort ” Packet Delivery

- Routers inspect destination address, locate “next hop” in forwarding table
  - Address = ~unique identifier/locator for the receiving host
- Only provides a “*I’ll give it a try*” delivery service:
  - Packets may be lost
  - Packets may be corrupted (but that is 'assume drop' based on layer 2 error detection)
  - Packets may be delivered out of order

IP Routing: Autonomous Systems

- Your system sends IP packets to the gateway...
  - But what happens after that?
- Within a given network its routed internally
- But the key is the Internet is a network-of-networks
  - Each "autonomous system" (AS) handles its own internal routing
  - The AS knows the next AS to forward a packet to
- Primary protocol for communicating in between ASs is BGP:
  - Each router announces what networks it can provide and the path onward
  - ***Most precise*** route with the shortest path and no loops preferred

Packet Routing on the Internet: Border Gateway Protocol & Routing Tables



Remarks

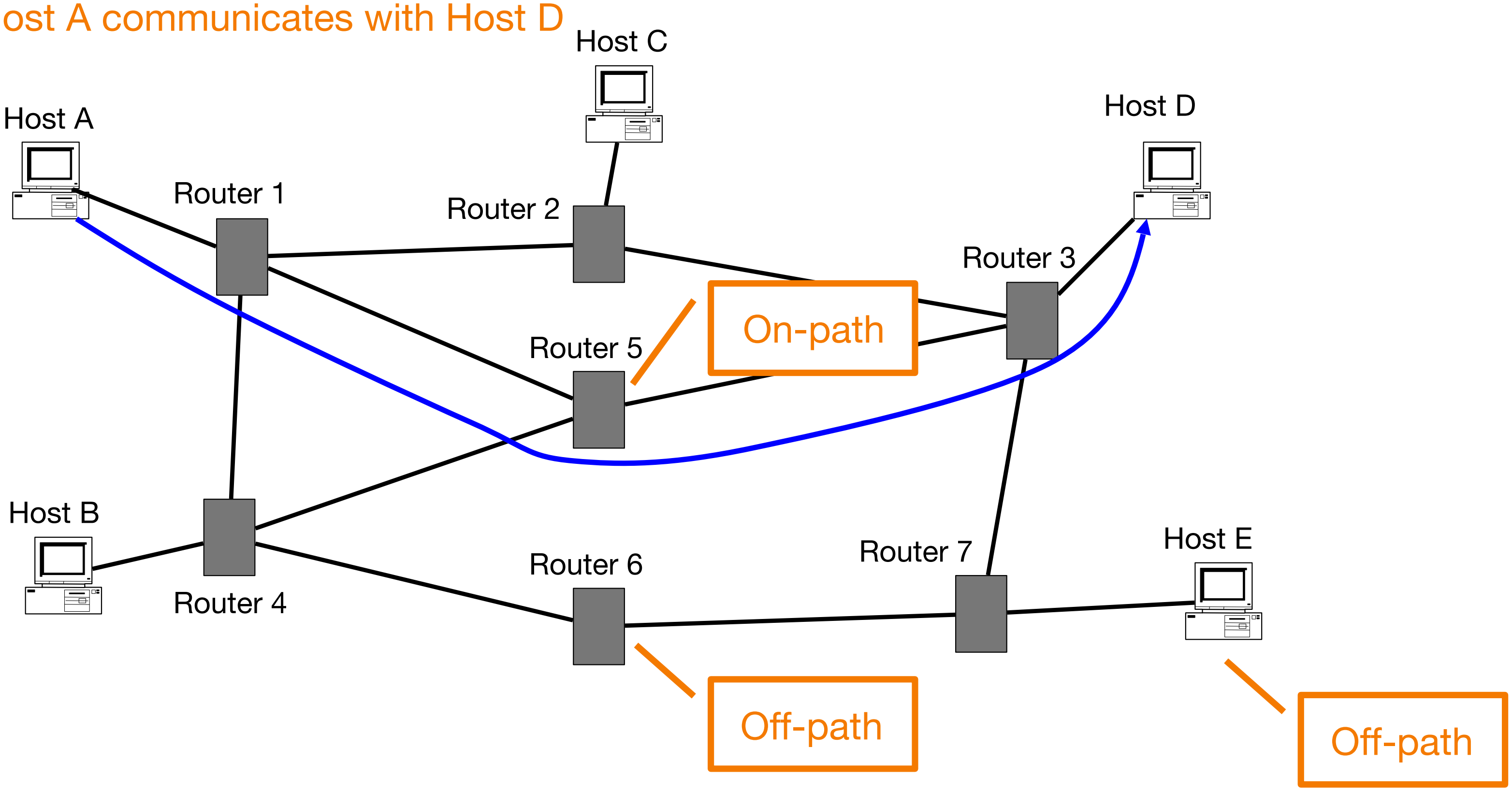
- This is a network of networks
  - Its designed with failures in mind:
    Links can go down and the system will recover
  - But it also generally trust-based
    - A system can lie about what networks it can route to!
- Each hop decrements the TTL
  - Prevents a "routing loop" from happening
- Routing can be asymmetric
  - Since in practice networks may (slightly) override BGP, and other such considerations

IP Spoofing
And Autonomous Systems

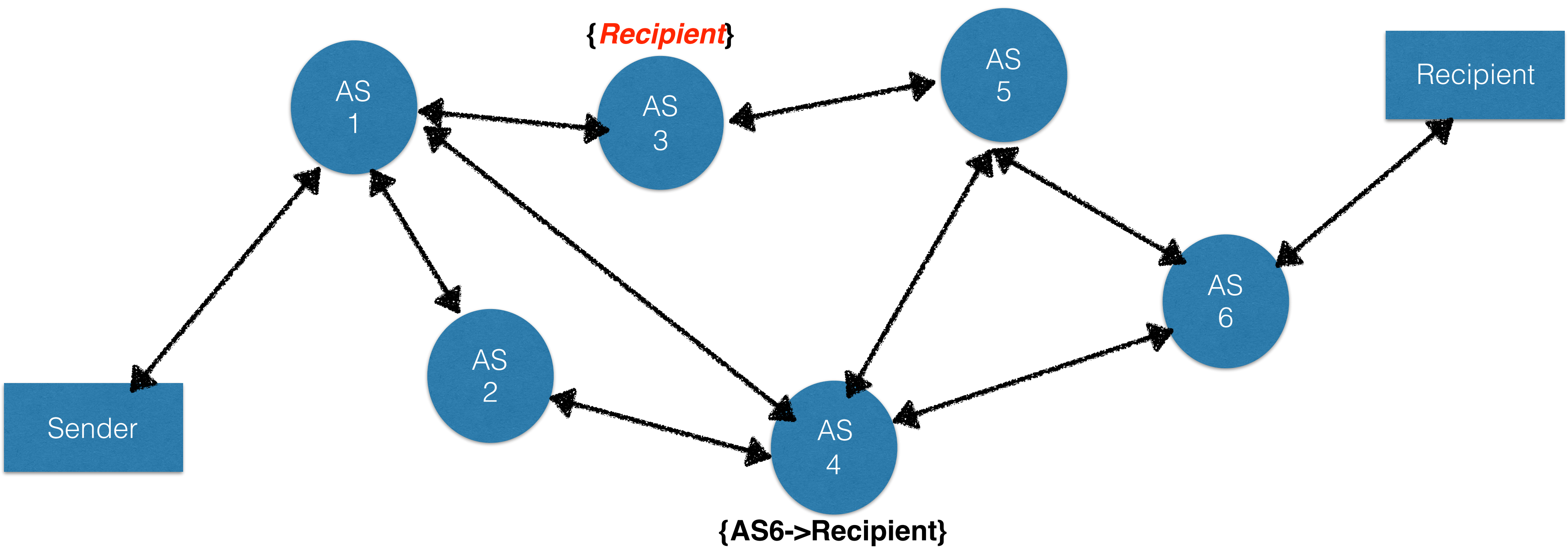
- The edge-AS where a user connects ***should*** restrict packet spoofing
  - Sending a packet with a different sender IP address
- But about 25% of them don't...
  - So a system can simply lie and say it comes from someplace else
- This enables blind-spoofing attacks
  - Such as the Kaminski attack on DNS
- It also enables "reflected DOS attacks"

On-path Injection vs Off-path Spoofing

Host A communicates with Host D



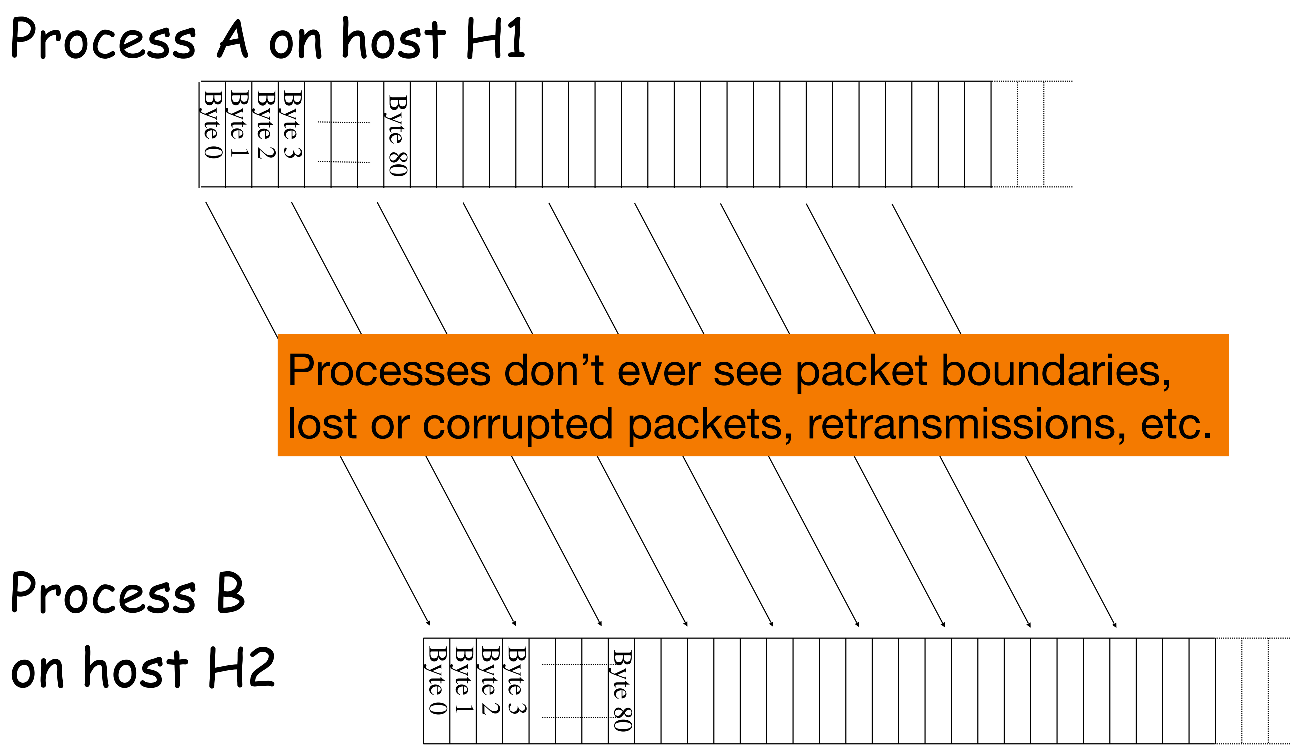
Lying in BGP


{Recipient}
AS 1
AS 3
AS 5
Recipient
AS 6
AS 2
Sender
AS 4
{AS6->Recipient}

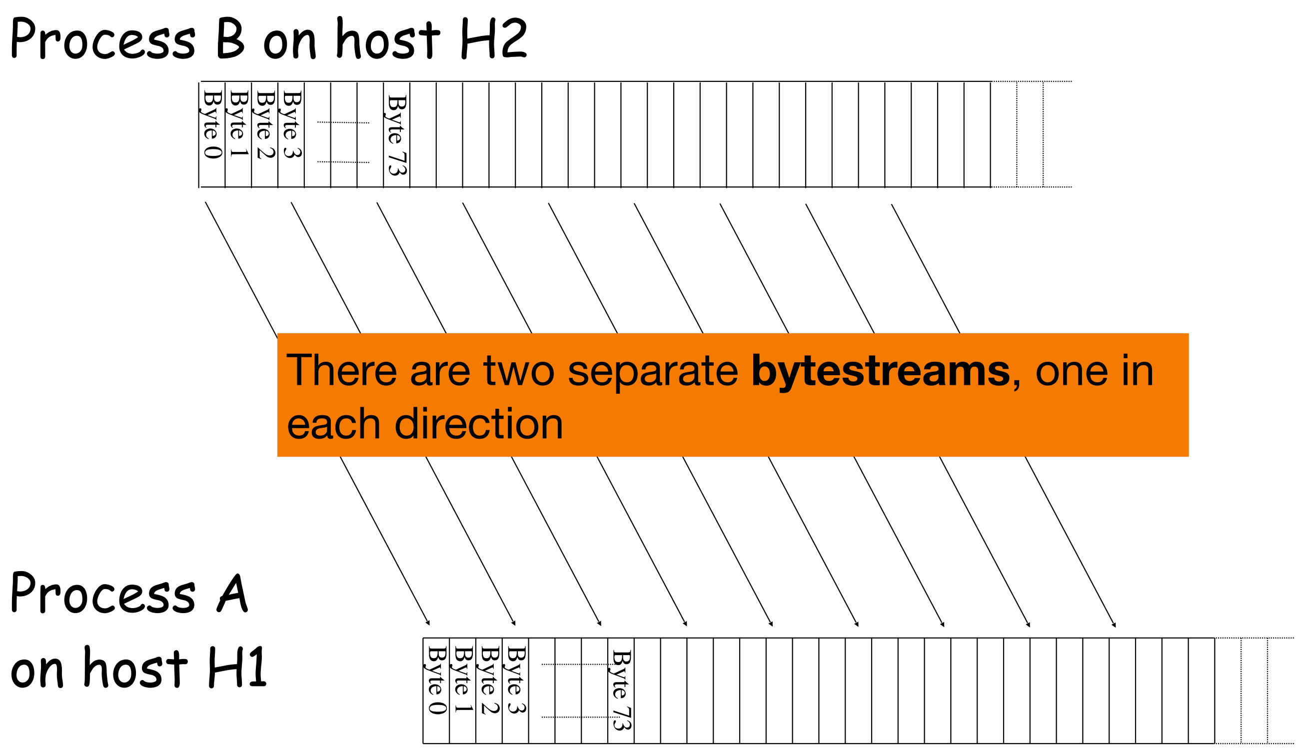
“Best Effort” is Lame! What to do?

- It’s the job of our Transport (layer 4) protocols to build data delivery services that our apps need out of IP’s modest layer-3 service
- #1 workhorse: TCP (Transmission Control Protocol)
- Service provided by TCP:
  - Connection oriented (explicit set-up / tear-down)
    - End hosts (processes) can have multiple concurrent long-lived communication
  - **Reliable**, in-order, *byte-stream* delivery
    - Robust detection & retransmission of lost data

TCP “Bytestream” Service

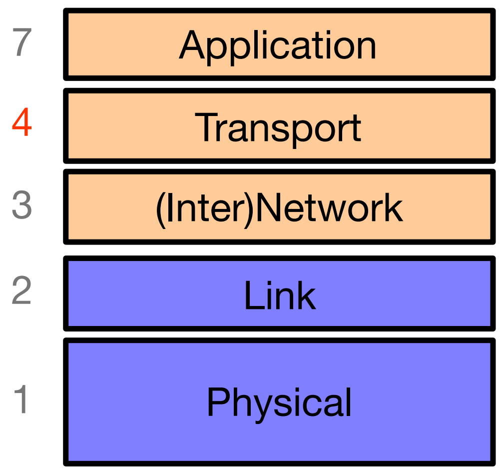


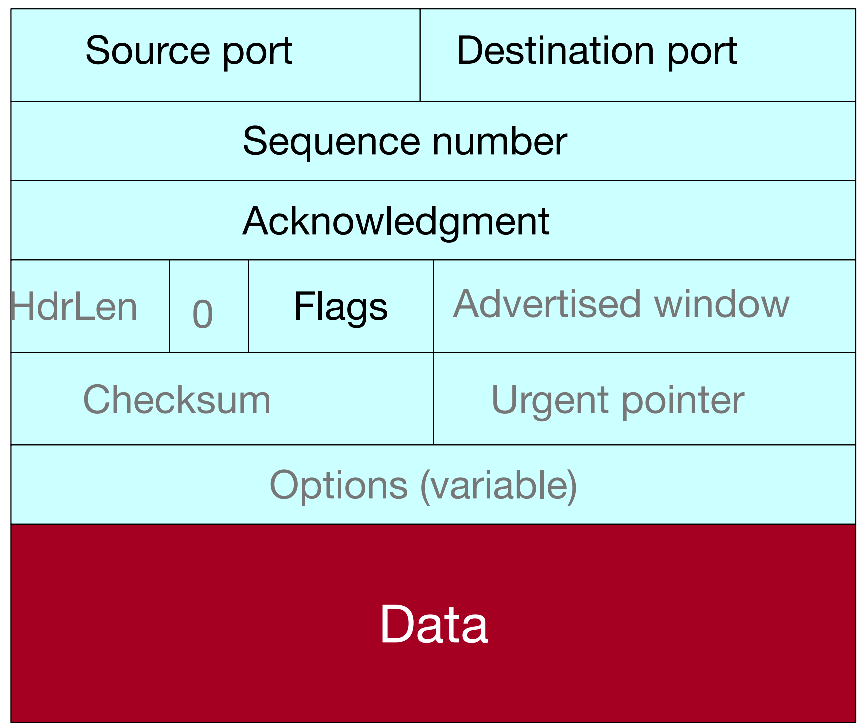
Bidirectional communication:



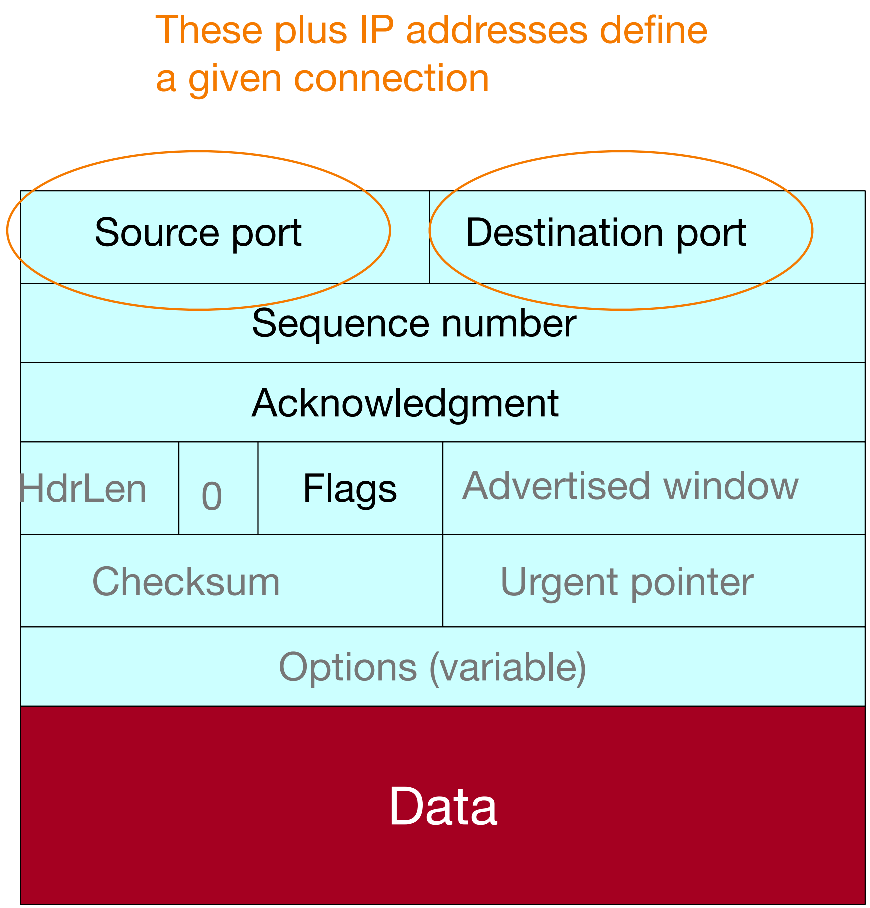
There are two separate **bytestreams**, one in each direction

TCP

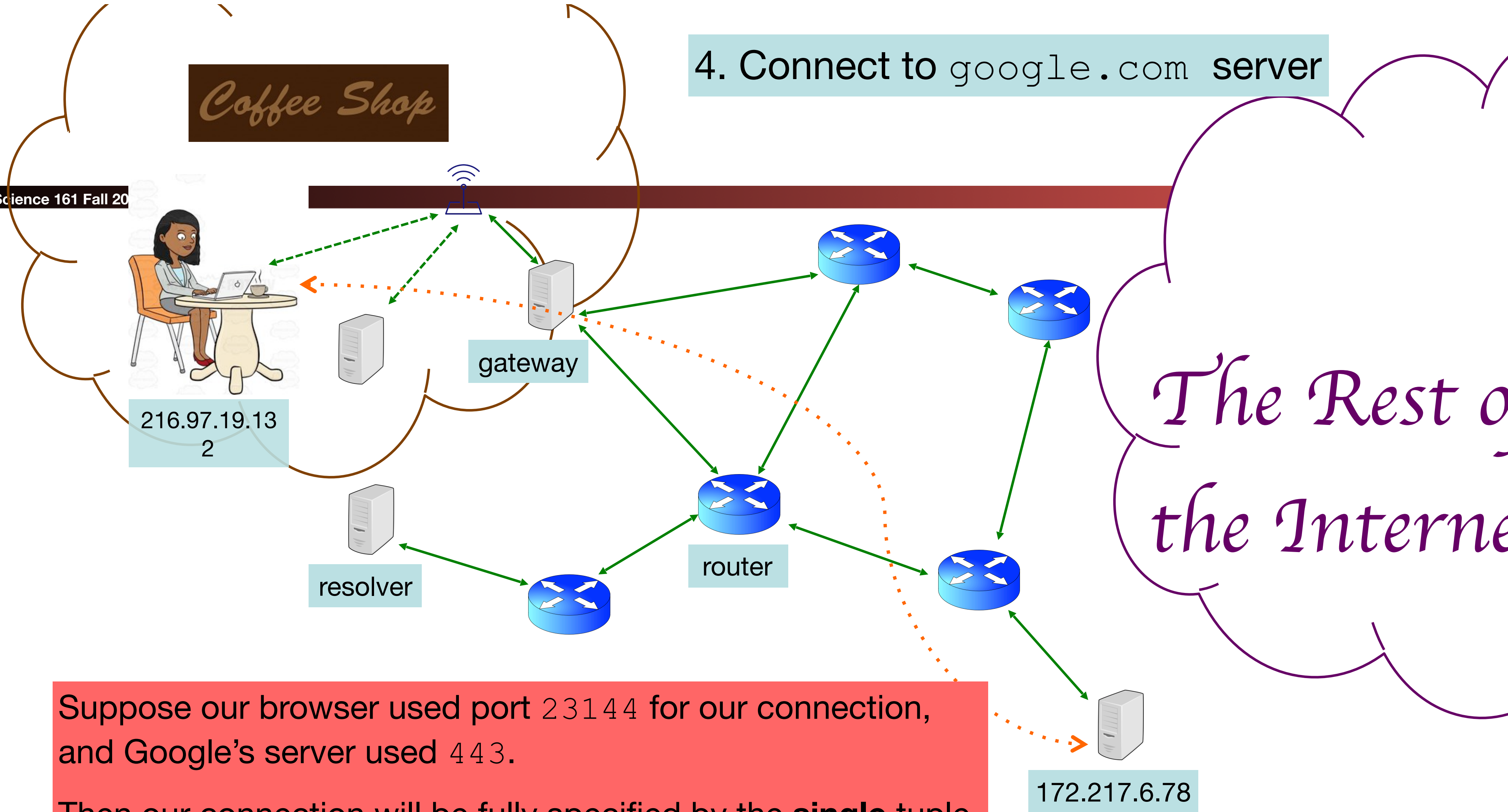

7
Application
4
Transport
3
(Inter)Network
2
Link
1
Physical


Source port
Destination port
Sequence number
Acknowledgment
HdrLen
0
Flags
Advertised window
Checksum
Urgent pointer
Options (variable)
Data

TCP


These plus IP addresses define
a given connection
Source port
Destination port
Sequence number
Acknowledgment
HdrLen
0
Flags
Advertised window
Checksum
Urgent pointer
Options (variable)
Data

4. Connect to `google.com` server

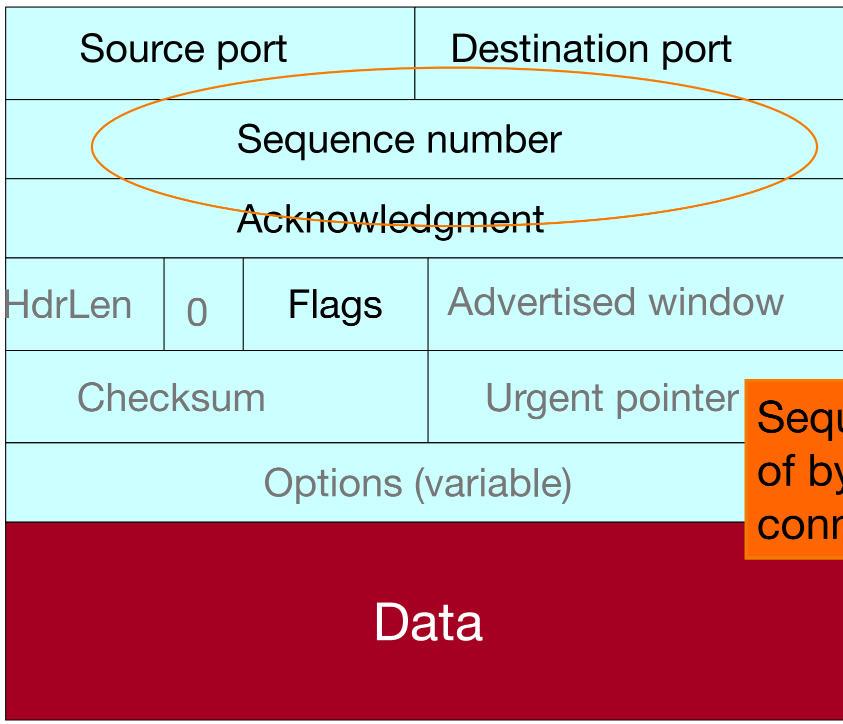


Suppose our browser used port `23144` for our connection, and Google's server used `443`.

Then our connection will be fully specified by the **single** tuple `<216.97.19.132,23144,172.217.6.78,443,TCP>`

TCP

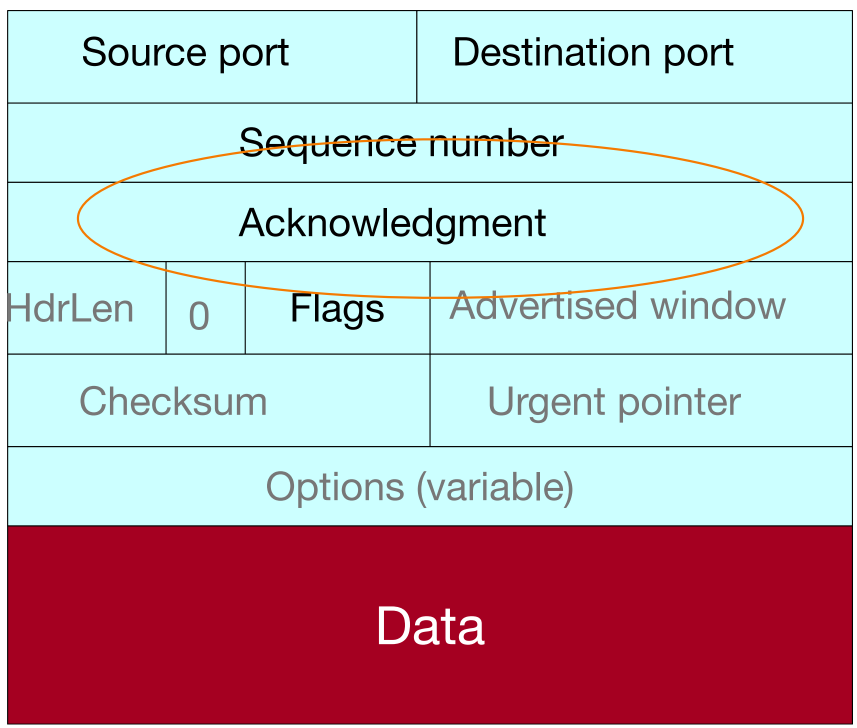
Used to order data in the connection: client program receives data ***in order***



Sequence number assigned to start of byte stream is picked when connection begins; **doesn't** start at 0

TCP

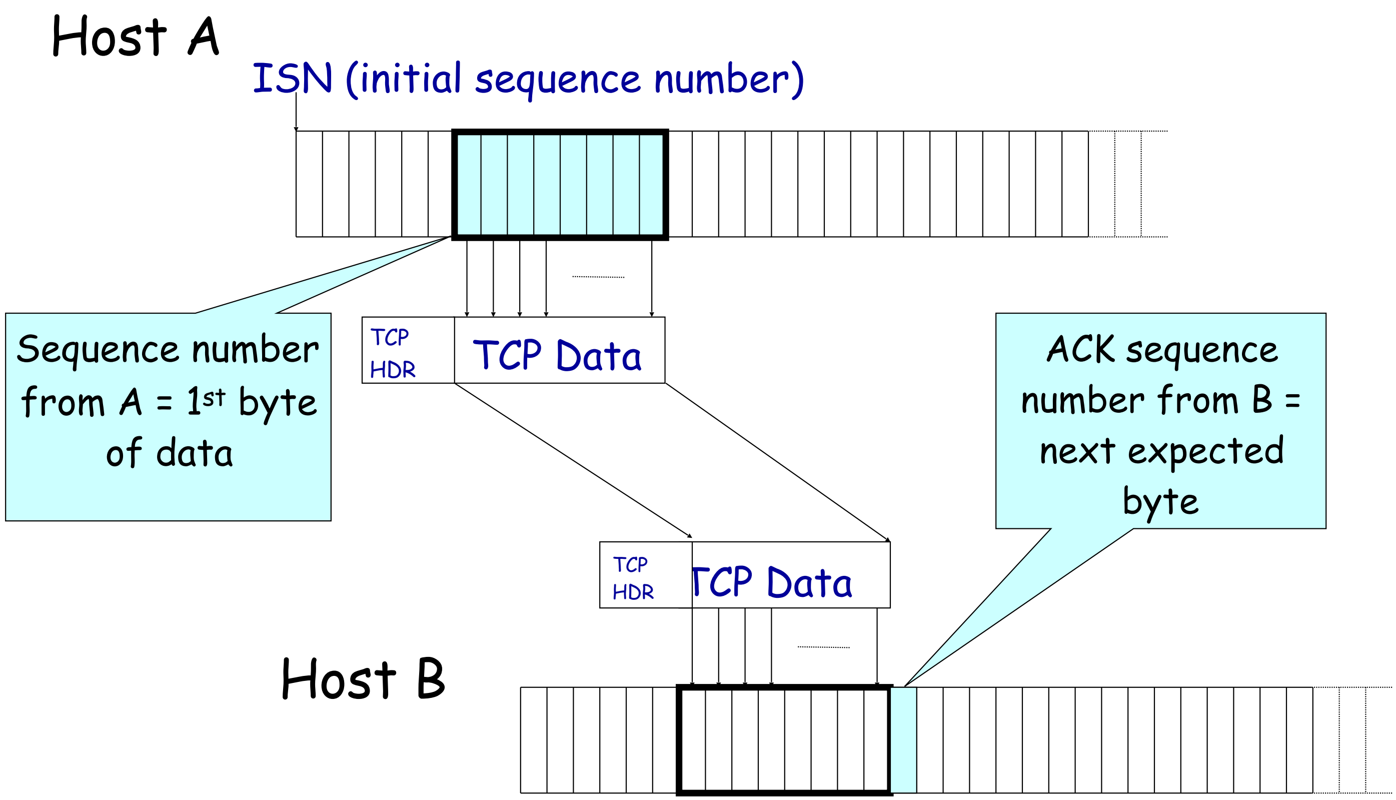
Used to say how much data has been received



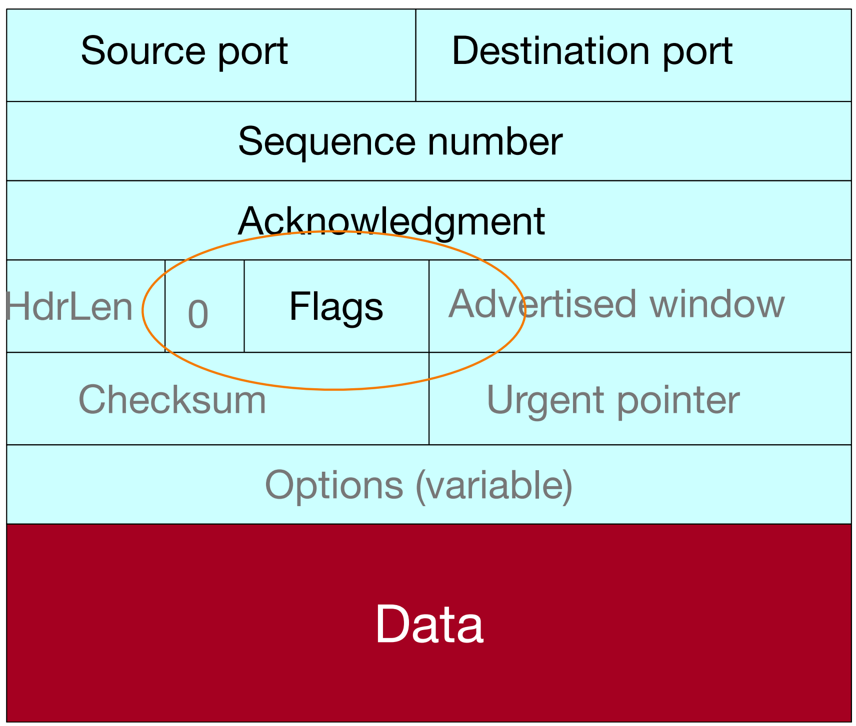
Acknowledgment gives seq # **just beyond** highest seq. received **in order**.

If sender successfully sends **N** bytestream bytes starting at seq **S** then “ack” for that will be **S+N**.

Sequence Numbers



TCP



Flags have different meaning:

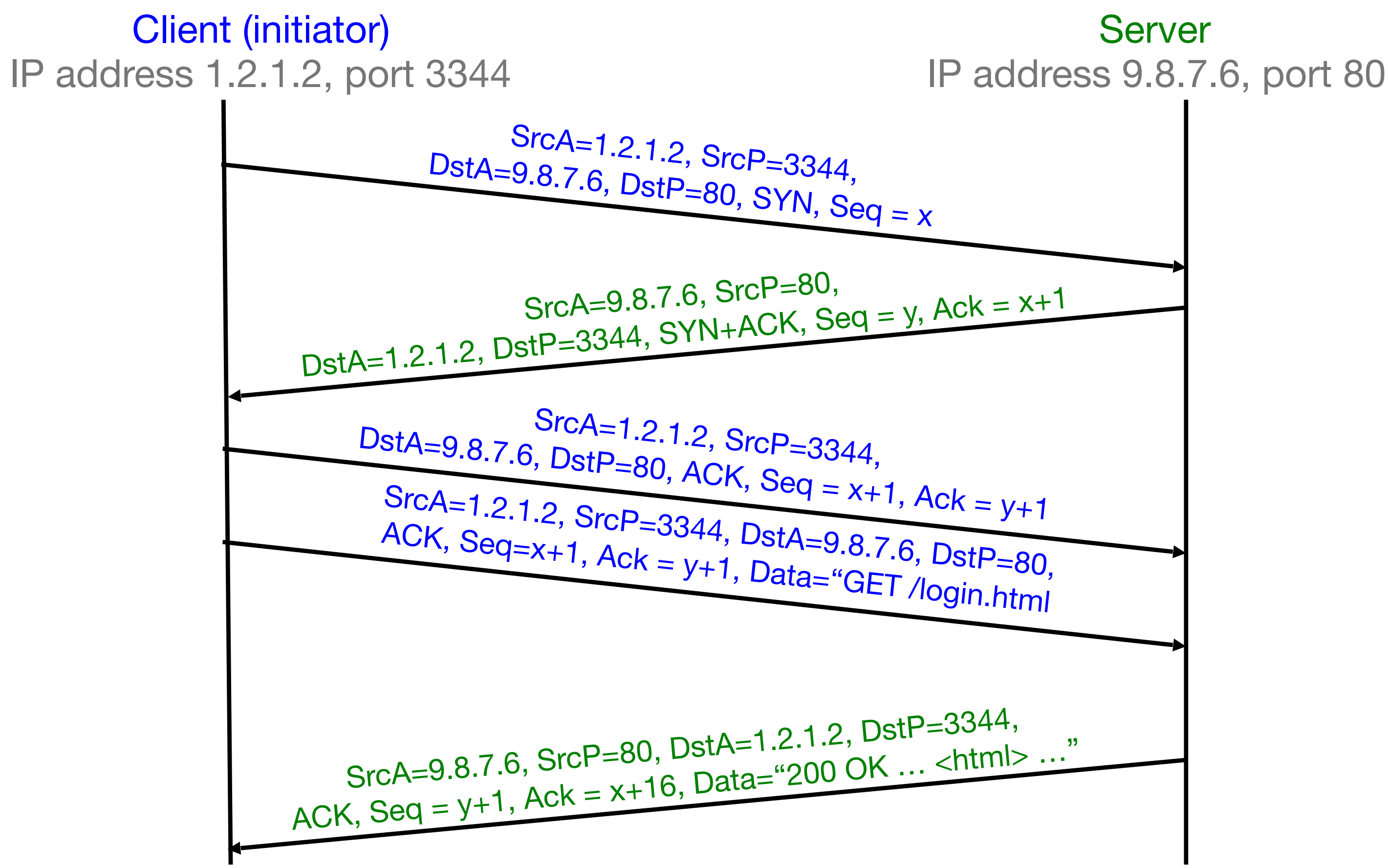
SYN: Synchronize,
used to initiate a connection

ACK: Acknowledge,
used to indicate
acknowledgement of data

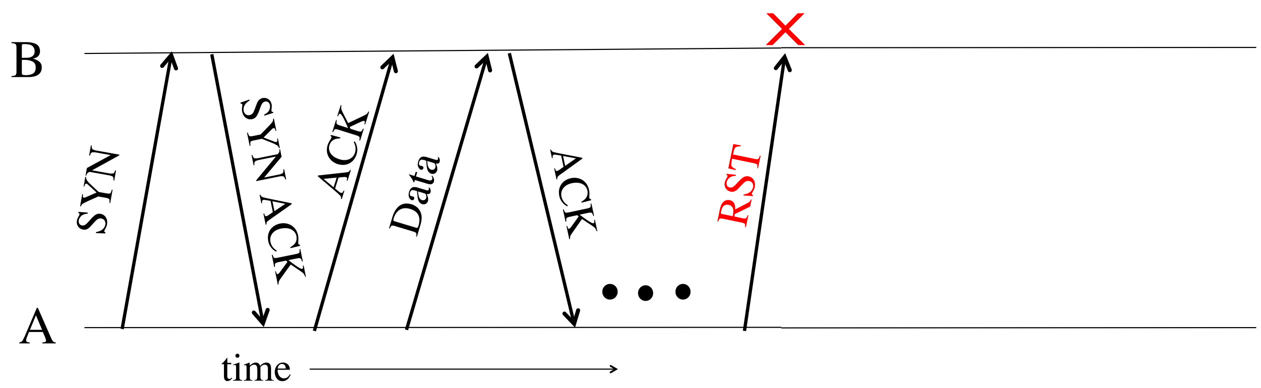
FIN: Finish,
used to indicate no more data will be sent (but can still receive and acknowledge data)

RST: Reset,
used to terminate the connection completely

TCP Conn. Setup & Data Exchange



Abrupt Termination



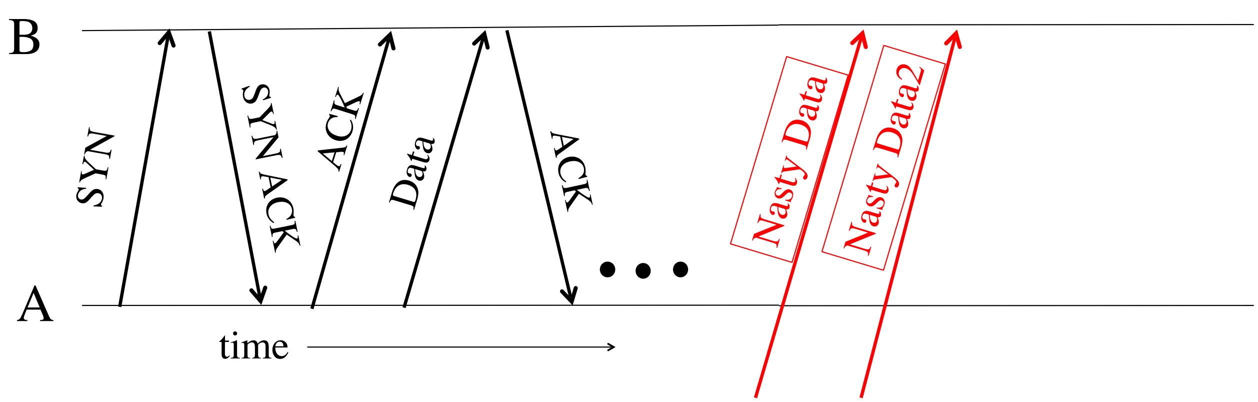
- A sends a TCP packet with RESET (**RST**) flag to B
  - E.g., because app. process on A crashed
  - (Could instead be that B sends a RST to A)
- Assuming that the sequence numbers in the **RST** fit with what B expects, That's It:
  - B's user-level process receives: `ECONNRESET`
  - No further communication on connection is possible

Disruption

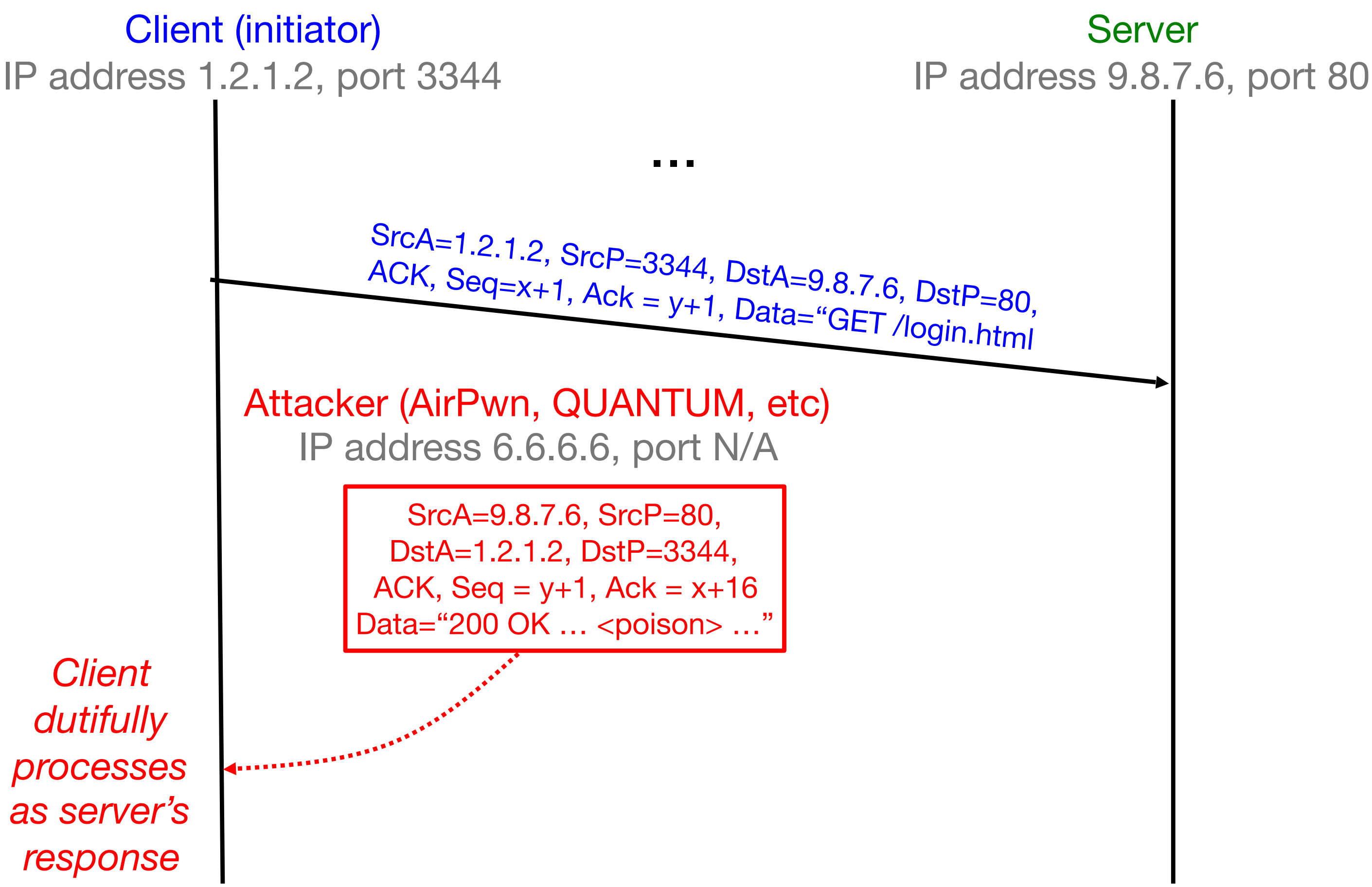
- Normally, TCP finishes ("closes") a connection by each side sending a `FIN` control message
  - Reliably delivered, since other side must ack
- But: if a TCP endpoint finds unable to continue (process dies; info from other "peer" is inconsistent), it abruptly terminates by sending a **`RST`** control message
  - Unilateral
  - Takes effect immediately (no ack needed)
  - Only accepted by peer if has correct* sequence number

TCP Threat: Data Injection

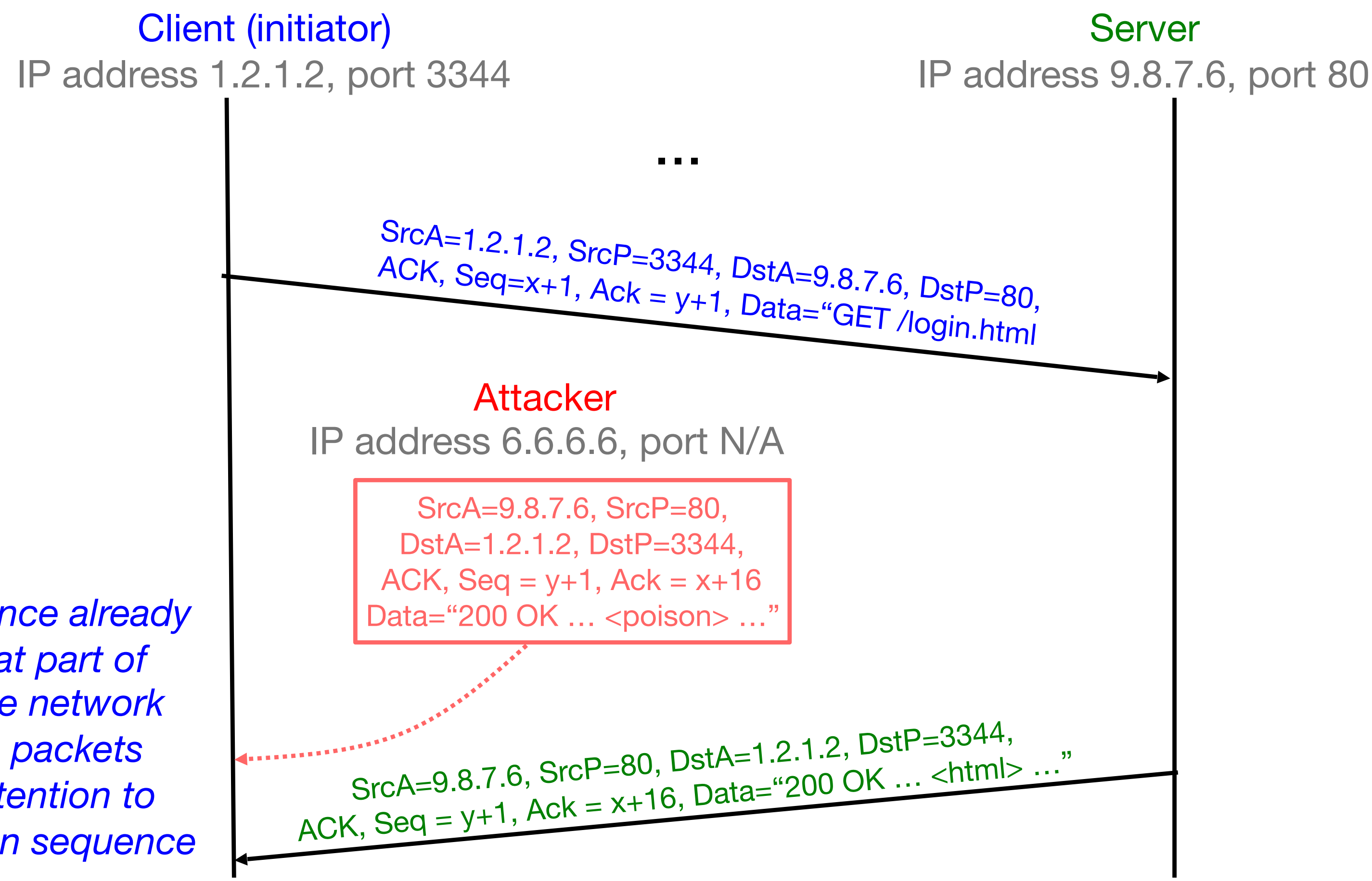
- If attacker knows ports & sequence numbers (e.g., on-path attacker), attacker can inject data into any TCP connection
  - Receiver B is *none the wiser!*
- Termed TCP connection hijacking (or "*session hijacking*")
  - A general means to take over an already-established connection!
- We are toast if an attacker can see our TCP traffic!
  - Because then they immediately know the port & sequence numbers



TCP Data Injection



TCP Data Injection



Client ignores since already processed that part of bytestream: the network can duplicate packets so only pay attention to the first version in sequence

TCP Threat: Disruption aka RST injection

- The attacker can also inject RST packets instead of payloads
  - TCP clients must respect RST packets and stop all communication
    - Because its a real world error recovery mechanism
    - So "just ignore RSTs don't work"
- Who uses this?
  - China: The Great Firewall does this to TCP requests
  - A long time ago: Comcast, to block BitTorrent uploads
  - Some intrusion detection systems: To hopefully mitigate an attack in progress

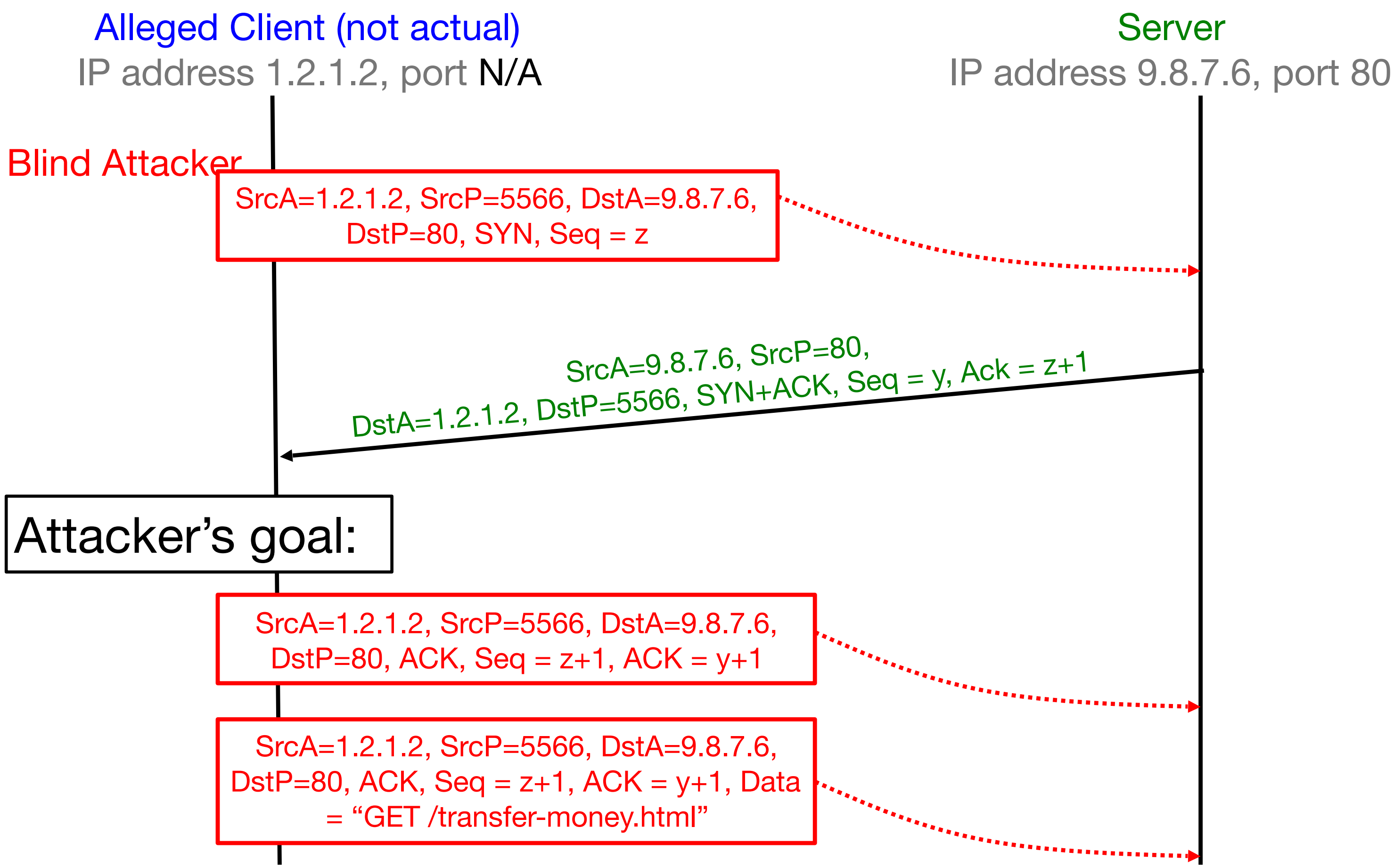
TCP Threat: Blind Hijacking

- Is it possible for an off-path attacker to inject into a TCP connection even if they can't see our traffic?
- YES: if somehow they can infer or guess the port and sequence numbers

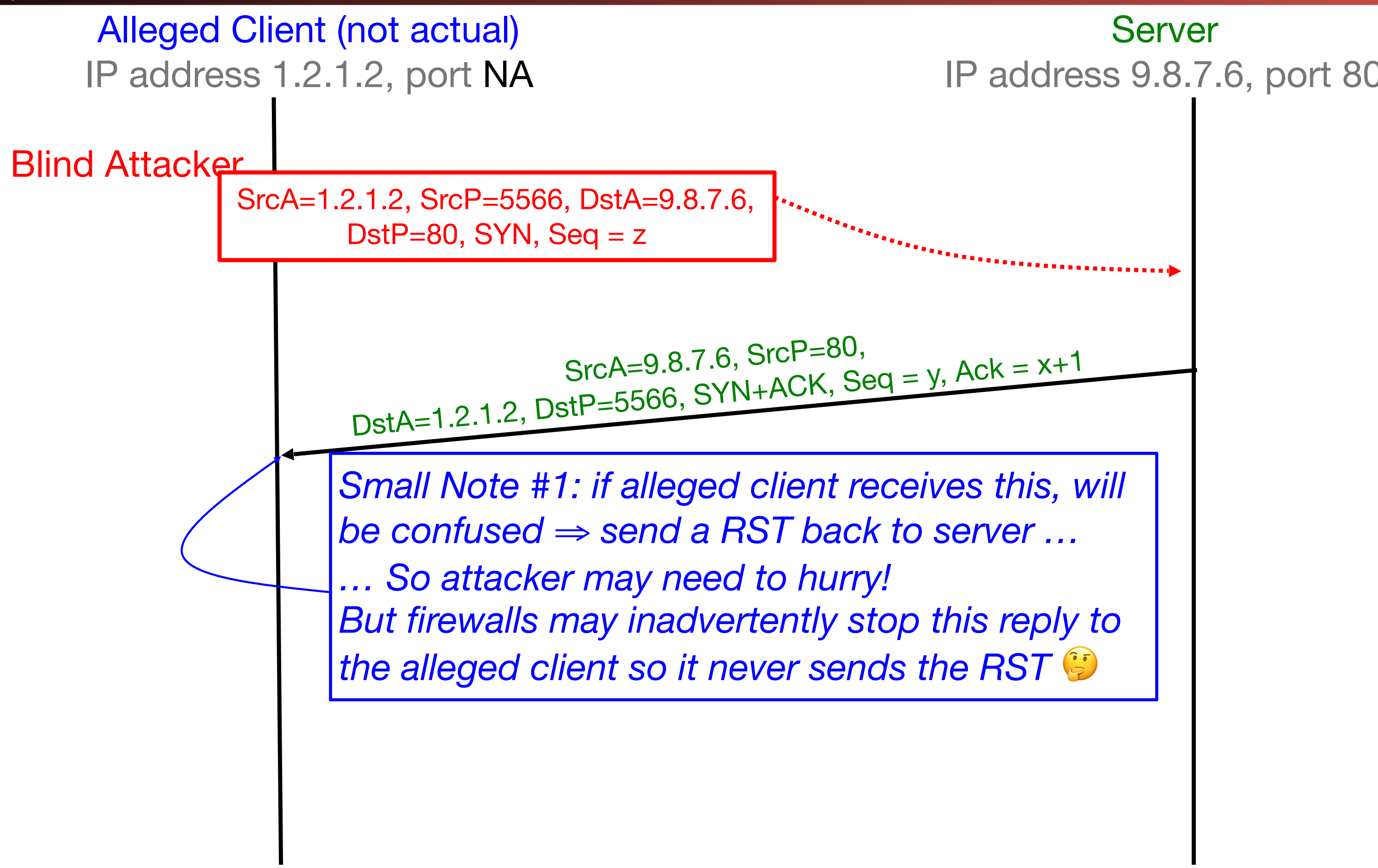
TCP Threat: Blind Spoofing

- Is it possible for an off-path attacker to create a fake TCP connection, even if they can't see responses?
- YES: if somehow they can infer or guess the TCP initial sequence numbers
- Why would an attacker want to do this?
  - Perhaps to leverage a server's trust of a given client as identified by its IP address
  - Perhaps to frame a given client so the attacker's actions during the connections can't be traced back to the attacker

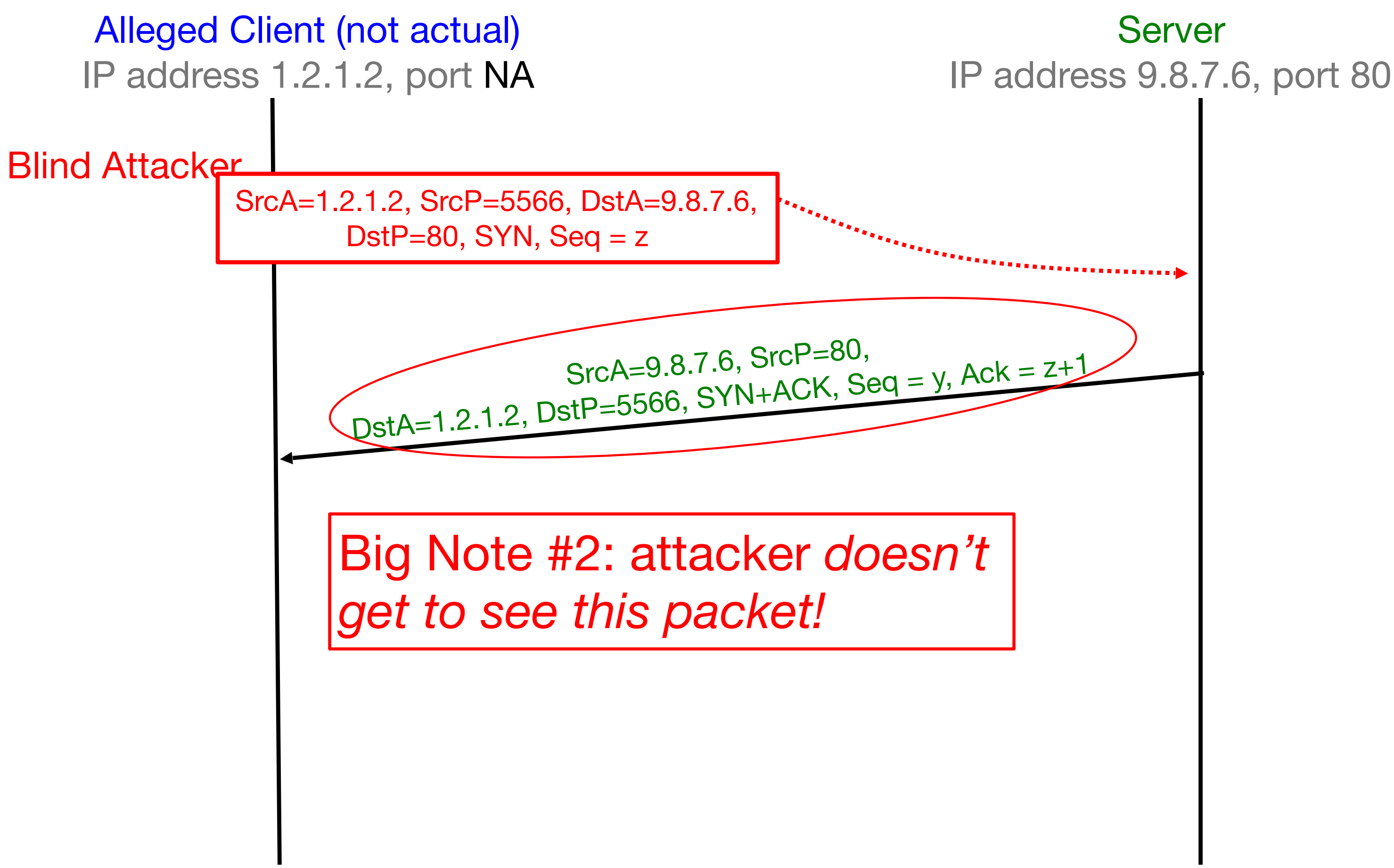
Blind Spoofing on TCP Handshake



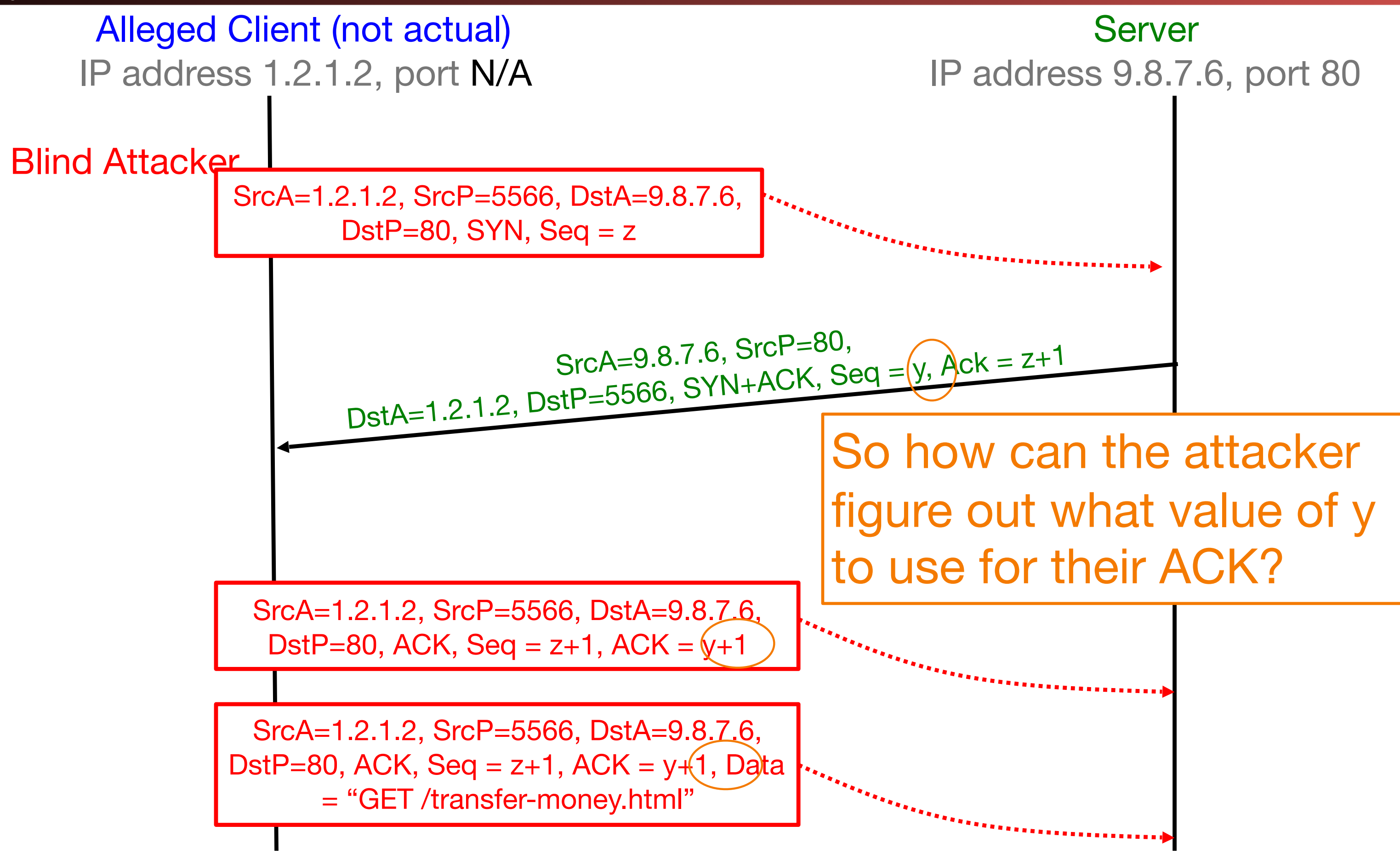
Blind Spoofing on TCP Handshake



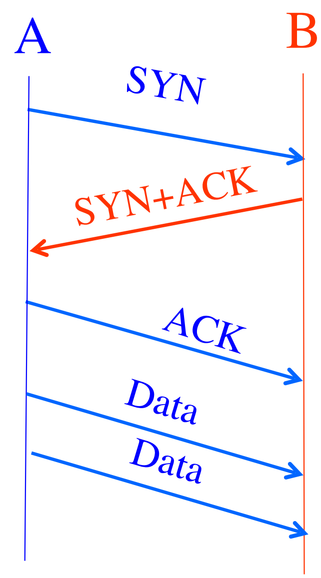
Blind Spoofing on TCP Handshake



Blind Spoofing on TCP Handshake



Reminder: Establishing a TCP Connection



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 (Pseudo)-*Random* ISN

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

Summary of TCP Security Issues

- An attacker who can observe your TCP connection can manipulate it:
  - Forcefully terminate by forging a RST packet
  - Inject (spoof) data into either direction by forging data packets
  - Works because they can include in their spoofed traffic the correct sequence numbers (both directions) and TCP ports
  - Remains a major threat today

Summary of TCP Security Issues

- An attacker who can observe your TCP connection can manipulate it:
  - Forcefully terminate by forging a RST packet
  - Inject (spoof) data into either direction by forging data packets
  - Works because they can include in their spoofed traffic the correct sequence numbers (both directions) and TCP ports
  - Remains a major threat today
- If attacker could predict the ISN chosen by a server, could "blind spoof" a connection to the server
  - Makes it appear that host ABC has connected, and has sent data of the attacker's choosing, when in fact it hasn't
  - Undermines any security based on trusting ABC's IP address
  - Allows attacker to "frame" ABC or otherwise avoid detection
  - Fixed (mostly) today by choosing random ISNs

But wasn't fixed completely...

- CVE-2016-5696
  - "Off-Path TCP Exploits: Global Rate Limit Considered Dangerous" Usenix Security 2016
  - https://www.usenix.org/conference/usenixsecurity16/technical-sessions/presentation/cao
- Key idea:
  - RFC 5961 added some global rate limits that acted as an ***information leak***:
    - Could determine if two clients were communicating on a given port
    - Could determine if you could correctly guess the sequence #s for this communication
      - Required a third host to probe this and at the same time spoof packets
  - Once you get the sequence #s, you can then inject arbitrary content into the TCP stream (d'oh)