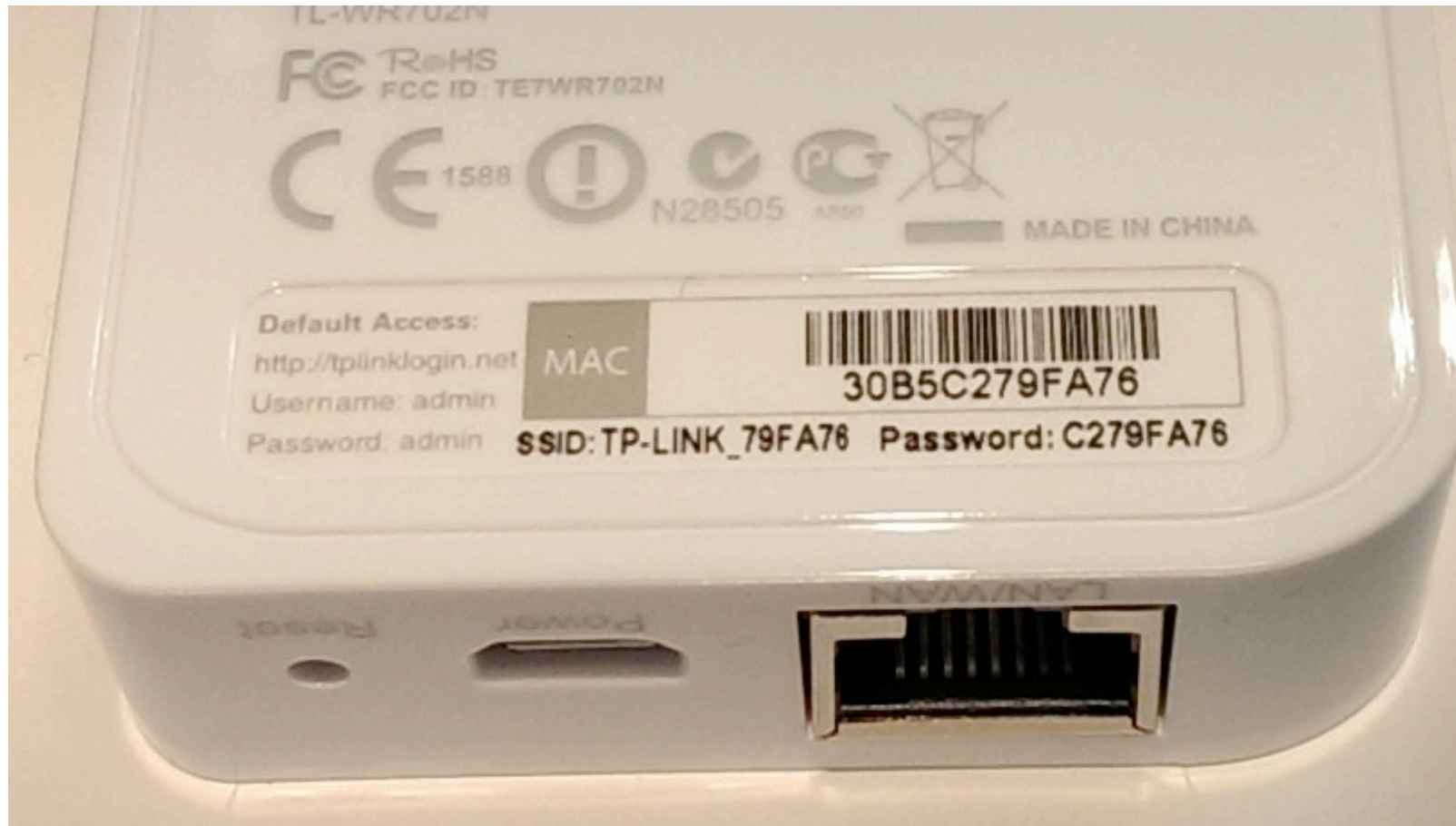


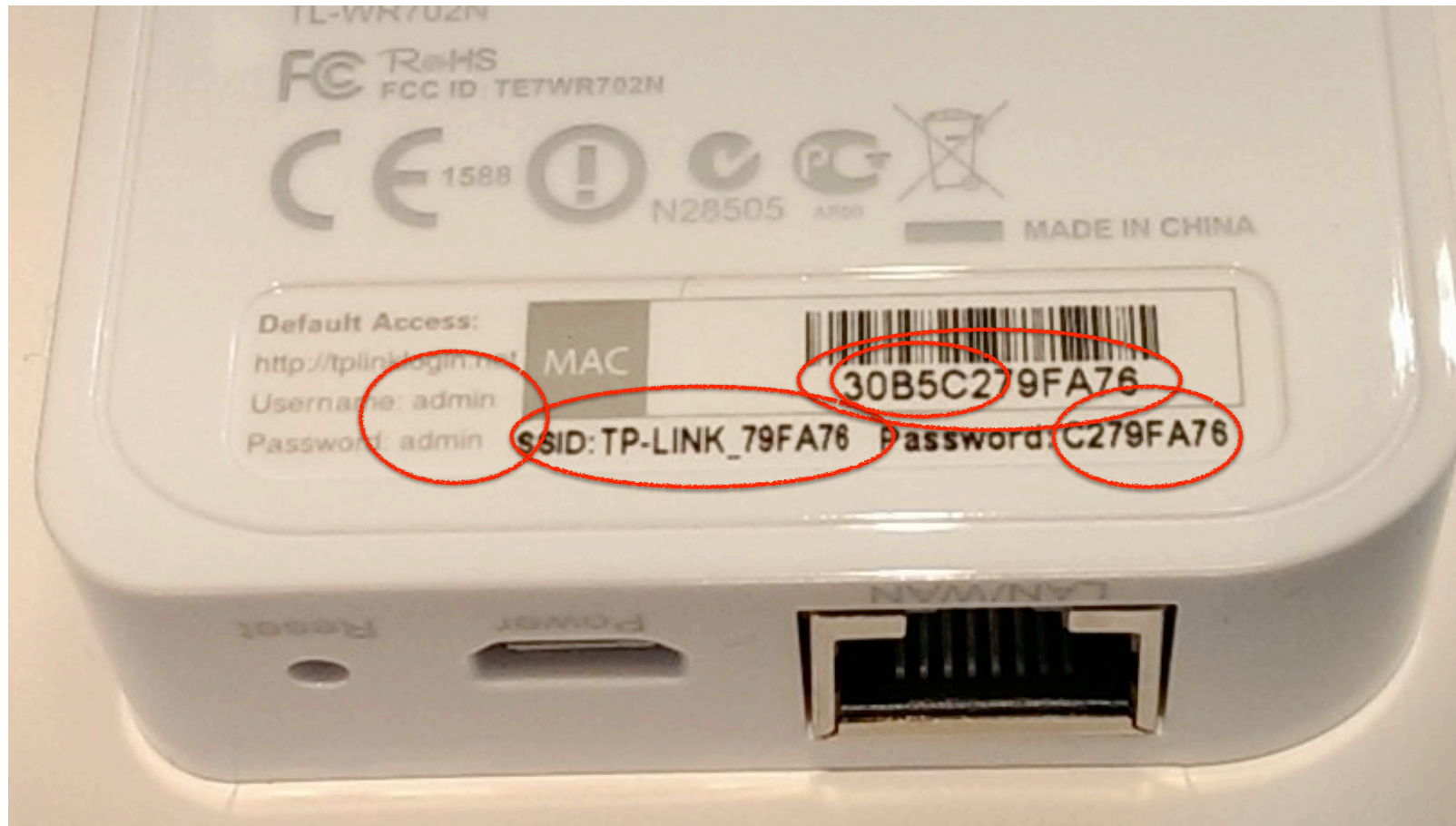
Network Security 3



Spot the Zero Day: TPLink Miniature Wireless Router



Spot the Zero Day: TPLink Miniature Wireless Router



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**



. Authority Server
(the "root")

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

Name	Type	Value	TTL

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.afiliast-nst.info	172800
a0.afiliast-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.afiliast-nst.info.
Additional:
sfba.sns-pb.isc.org.      A 199.6.1.30
ns.isc.afiliast-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.afiliast-nst.info	172800
a0.afiliast-nst.info.	A	199.19.56.1	172800
isc.org.	NS	sfba.sns-pb.isc.org.	86400
isc.org.	NS	ns.isc.afiliast-net.info.	86400
sfba.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.afiliast-nst.info.
Additional:
sfba.sns-pb.isc.org. A 199.6.1.30
ns.isc.afiliast-nst.info. A 199.254.63.254
```

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



User's ISP's

? A **www.isc.org**

Recursive Resolver

Answers: **www.isc.org A 149.20.64.42**

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

;; ADDITIONAL SECTION:
a0.org.afiliast-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:
 - Note: You may need to use the IPv4 address of www.tsinghua.edu
 - `dig www.benign.com @www.tsinghua.edu`
 - `dig www.facebook.com @www.tsinghua.edu`

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:

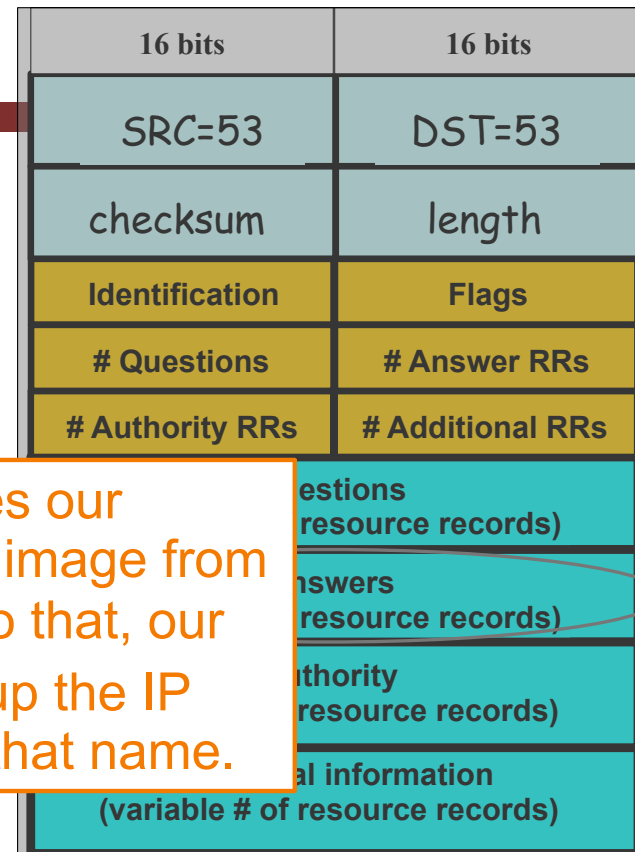
`... ...`

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)	

Blind spoofing

- Say we look up `mail.google.com`; how can an **off-path** attacker feed us a bogus A answer before the legitimate answer arrives?
- How can we cause 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. Suppose, e.g., we visit a web page under their control:

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.



```
... ...
```


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)	

```
 — 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!

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)	

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.afiliast-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.afiliast-nst.info
...

;; ADDITIONAL SECTION:
a0.org.afiliast-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 is 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...

How to get rid of Vimax ads - Boing Boing - Windows Internet Explorer

http://boingboing.net/2009/01/16/how-to-get-rid-of-vi.html

Stand out of the crowd
Try Vimax Pills

boingboing

How to get rid of Vimax ads

POSTED BY MARK FRAUENFELDER, JANUARY 16, 2009 1:42 PM | PERMALINK

Neil Chase at our advertising parter company, Federated Media says:

Several authors have recently found every ad zone on their pages filled with ads for Vimax, which is supposed to enlarge a certain body part. We don't run ads for stuff like that, and of course no FM author or staffer could possibly need it anyway.

But there's malware floating around out there that hijacks your computer's DNS settings and puts its own ads into your zones. Unlike regular viruses, it can attack both PCs and Macs. It seems to often come with free video-processing software.

If it happens to you, rest assured that it's happening only in your Web browser and not to your readers. Here's what to do:

- * For Mac users: Apple's forums have info about a couple fixes in [this thread](#)
- * For PC users, several people suggest Trend Micro's free [HijackThis](#) tool.

Over 1 Million Men Have Already Tried Vimax Pills

Visit PhotoWorks.com

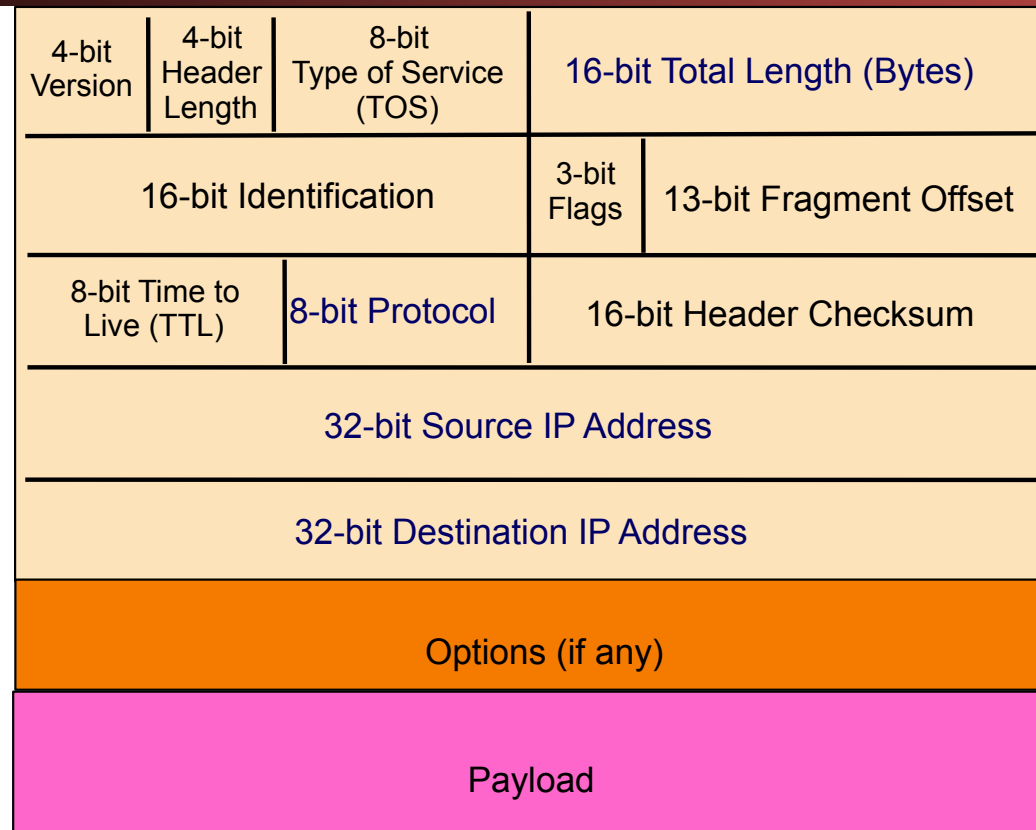
Get 25 Free Prints

Today:

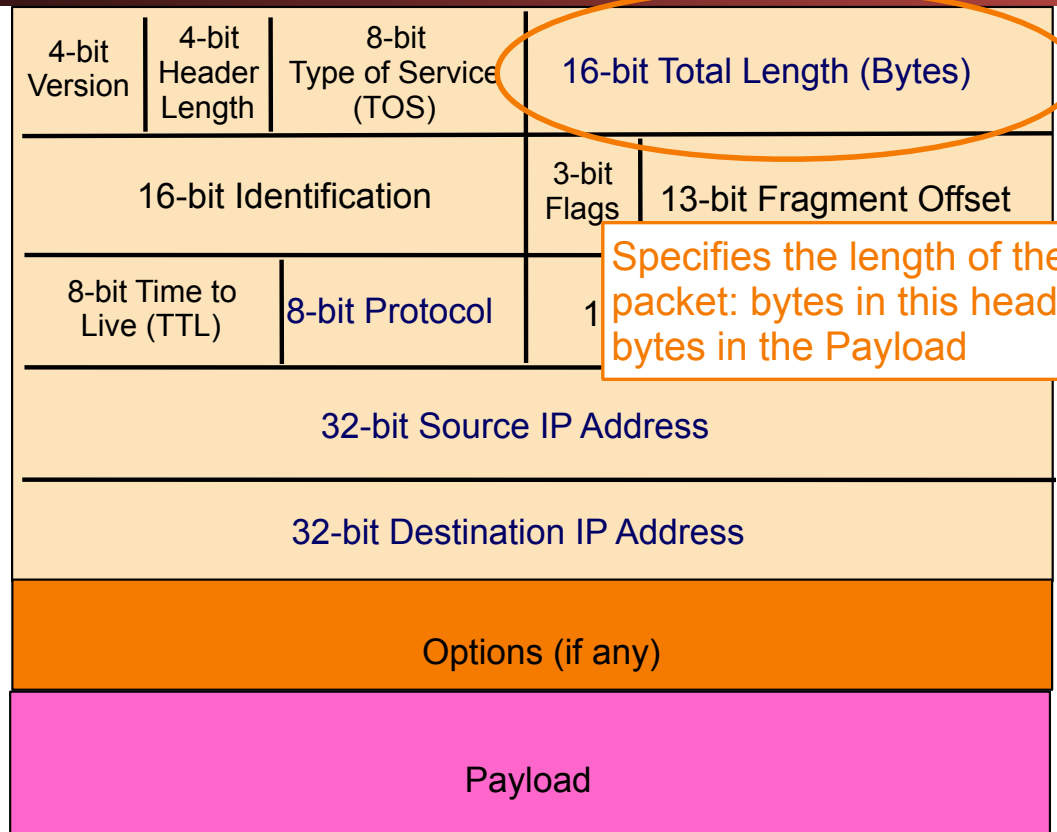
The Internet

- How the Internet routes IP packets
 - Distributed trust through Autonomous Systems
- How TCP works
- Denial of Service Attacks
- (If time) the Firewall #1

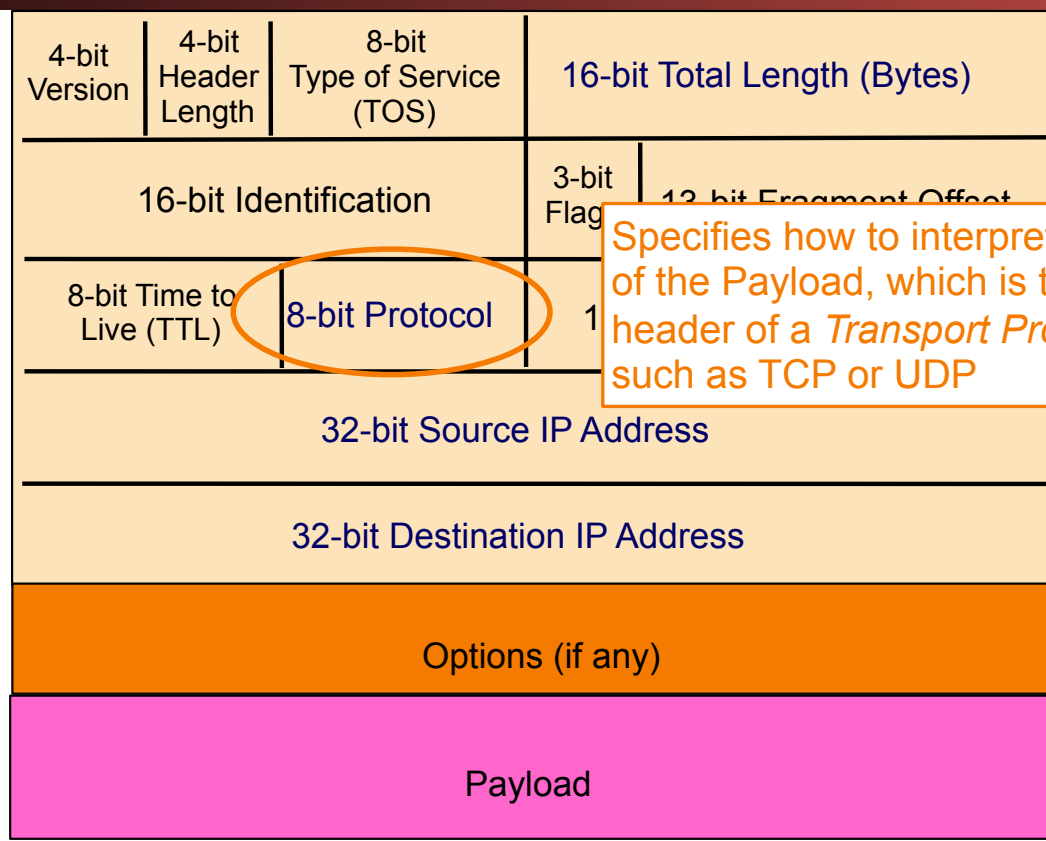
IP Packet Structure



IP Packet Structure

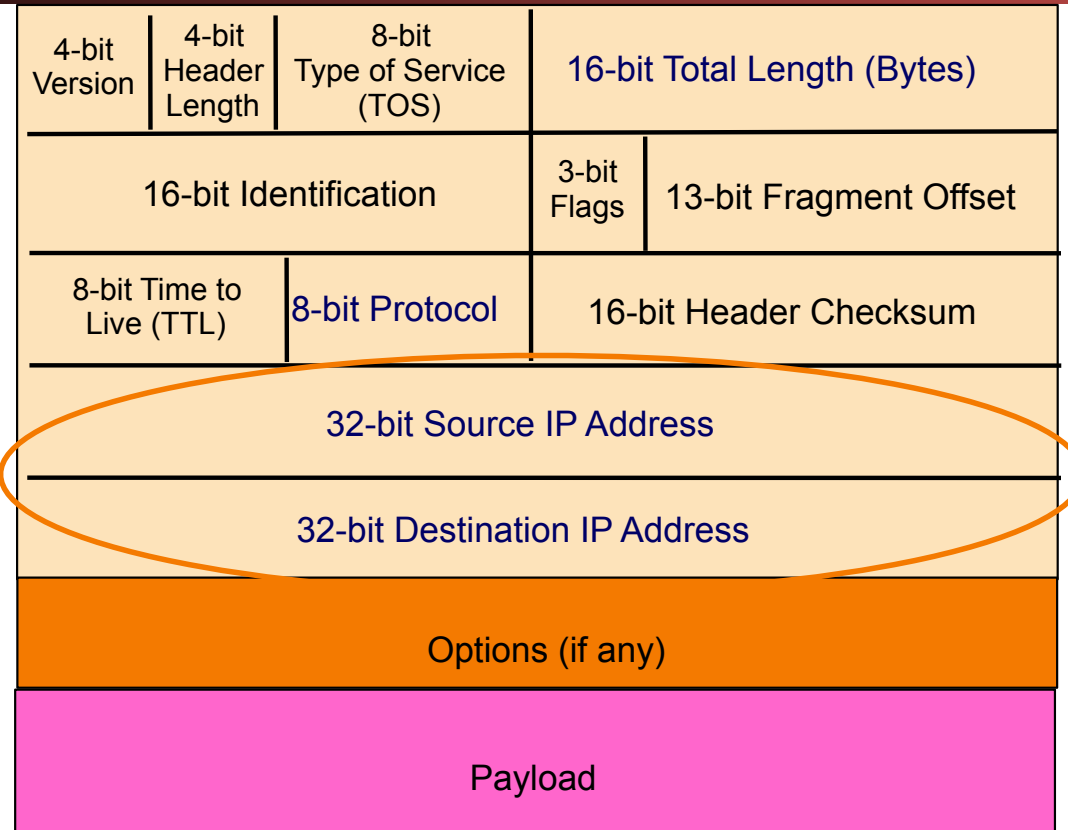


IP Packet Structure

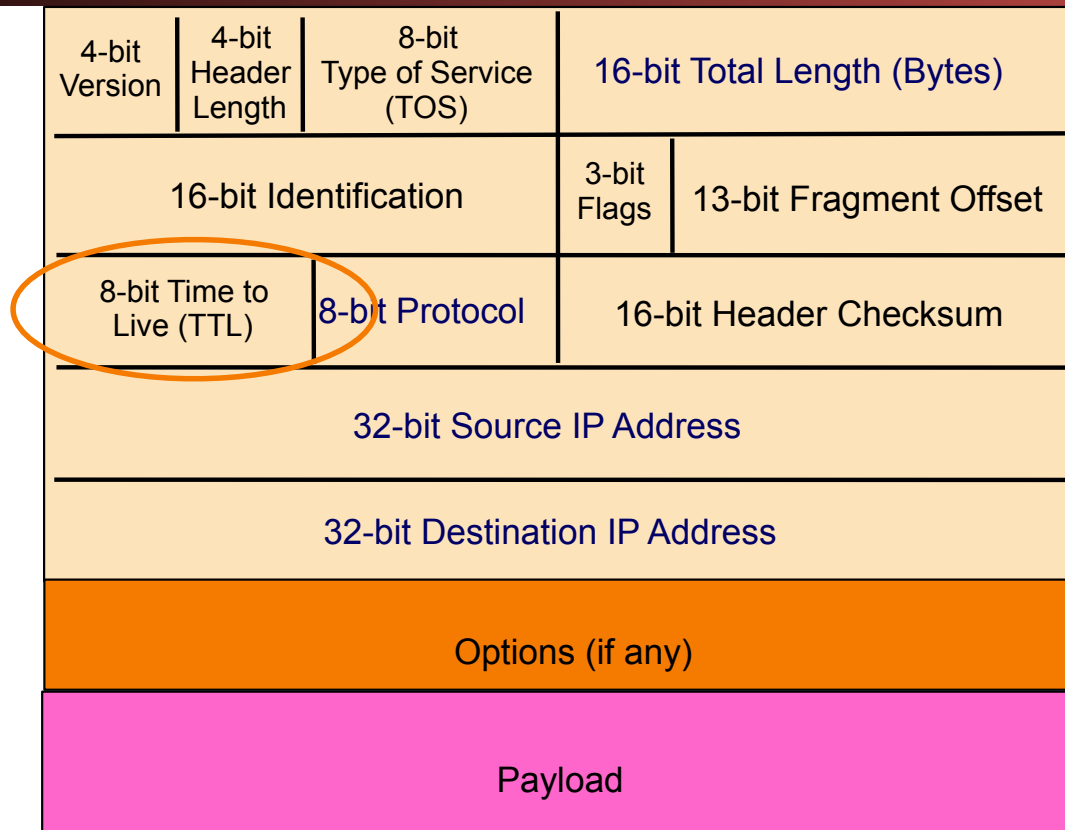


Specifies how to interpret the start of the Payload, which is the header of a *Transport Protocol* such as TCP or UDP

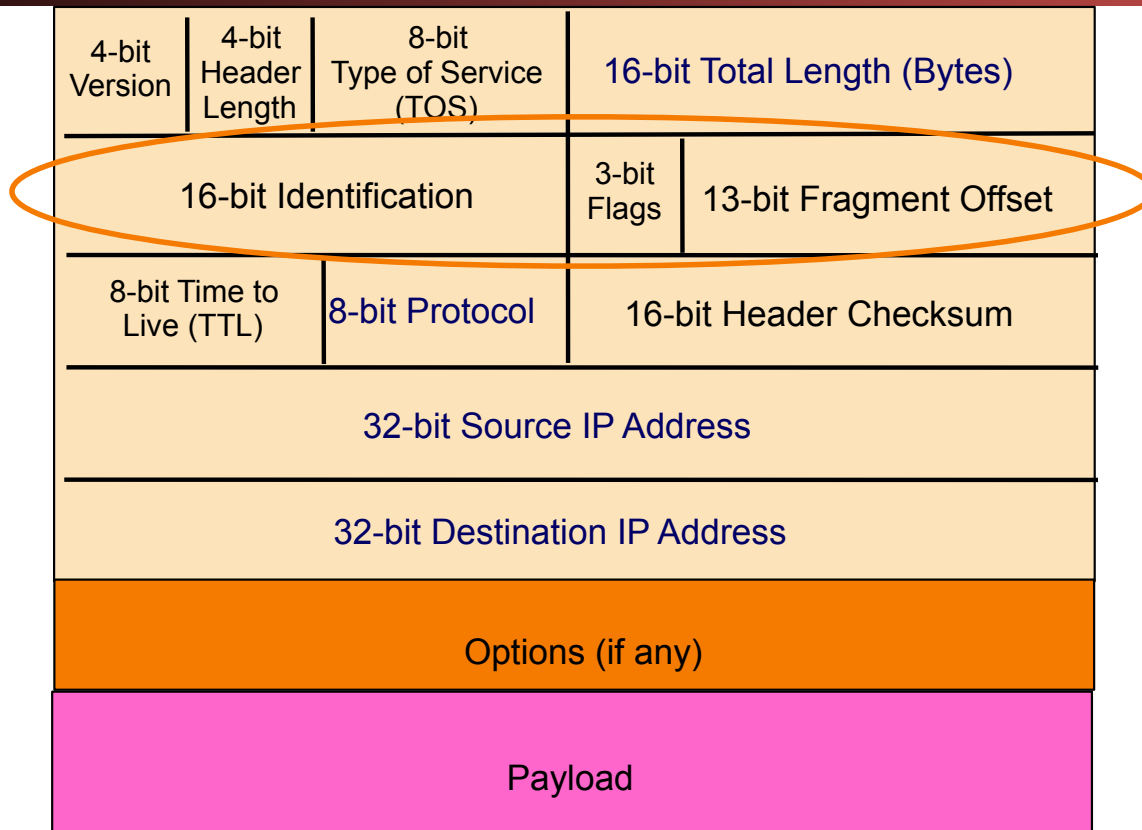
IP Packet Structure



IP Packet Structure



IP Packet Structure

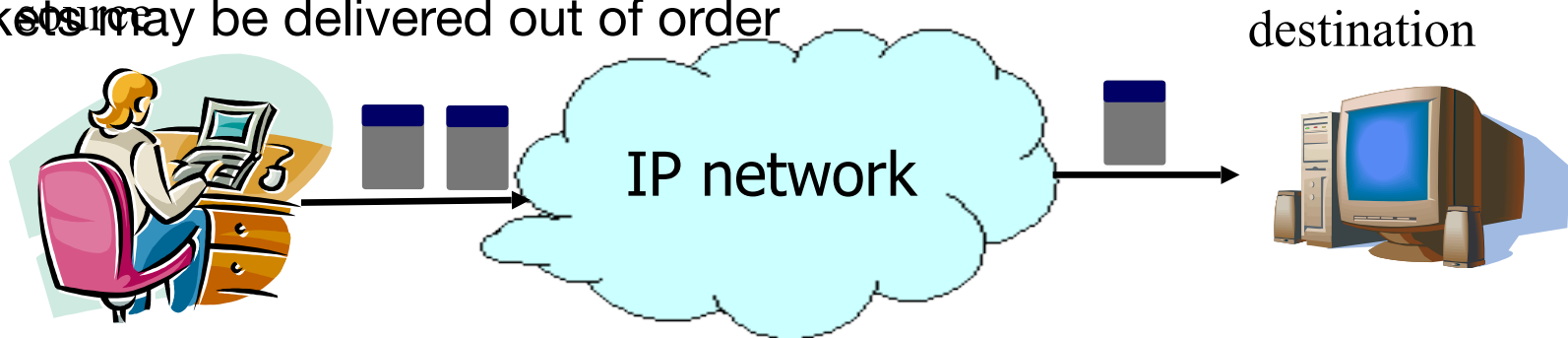


IP Packet Header (Continued)

- 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

IP: “Best Effort ” Packet Delivery

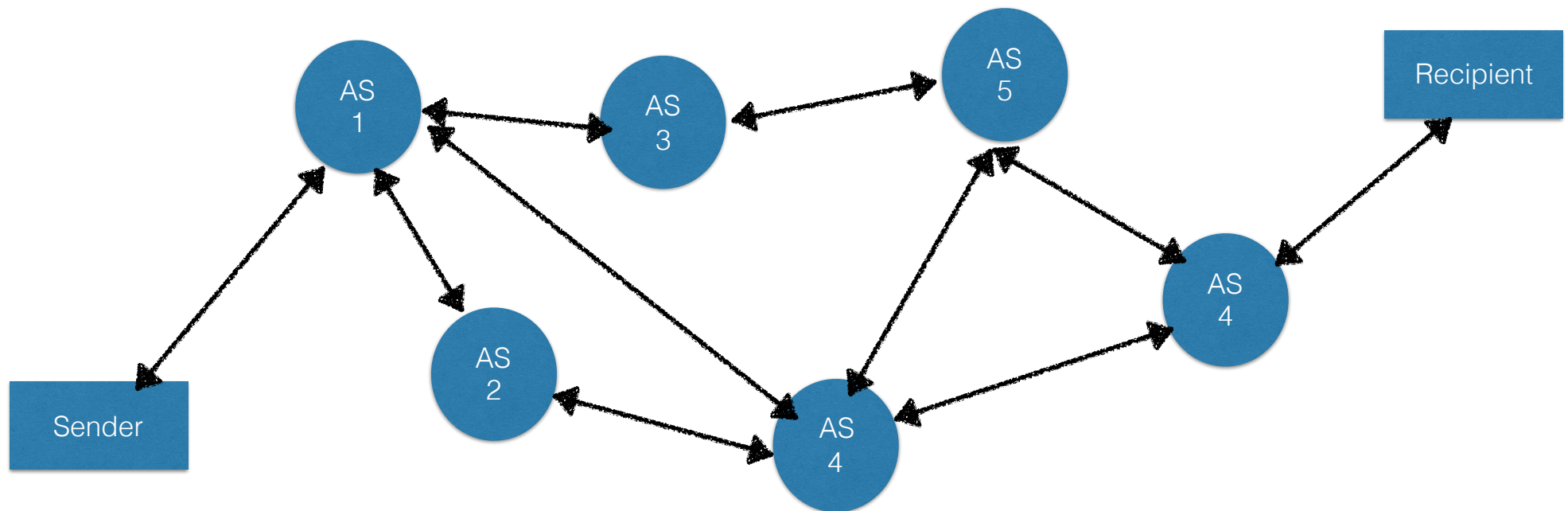
- Routers inspect destination address, locate “next hop” in forwarding table
- Address = ~unique **identifier/locator** for the receiving host
- Only provides a “*I’ll give it a try*” delivery service:
 - Packets may be lost
 - Packets may be corrupted
 - Packets may be delivered out of order



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

Packet Routing on the Internet



Remarks

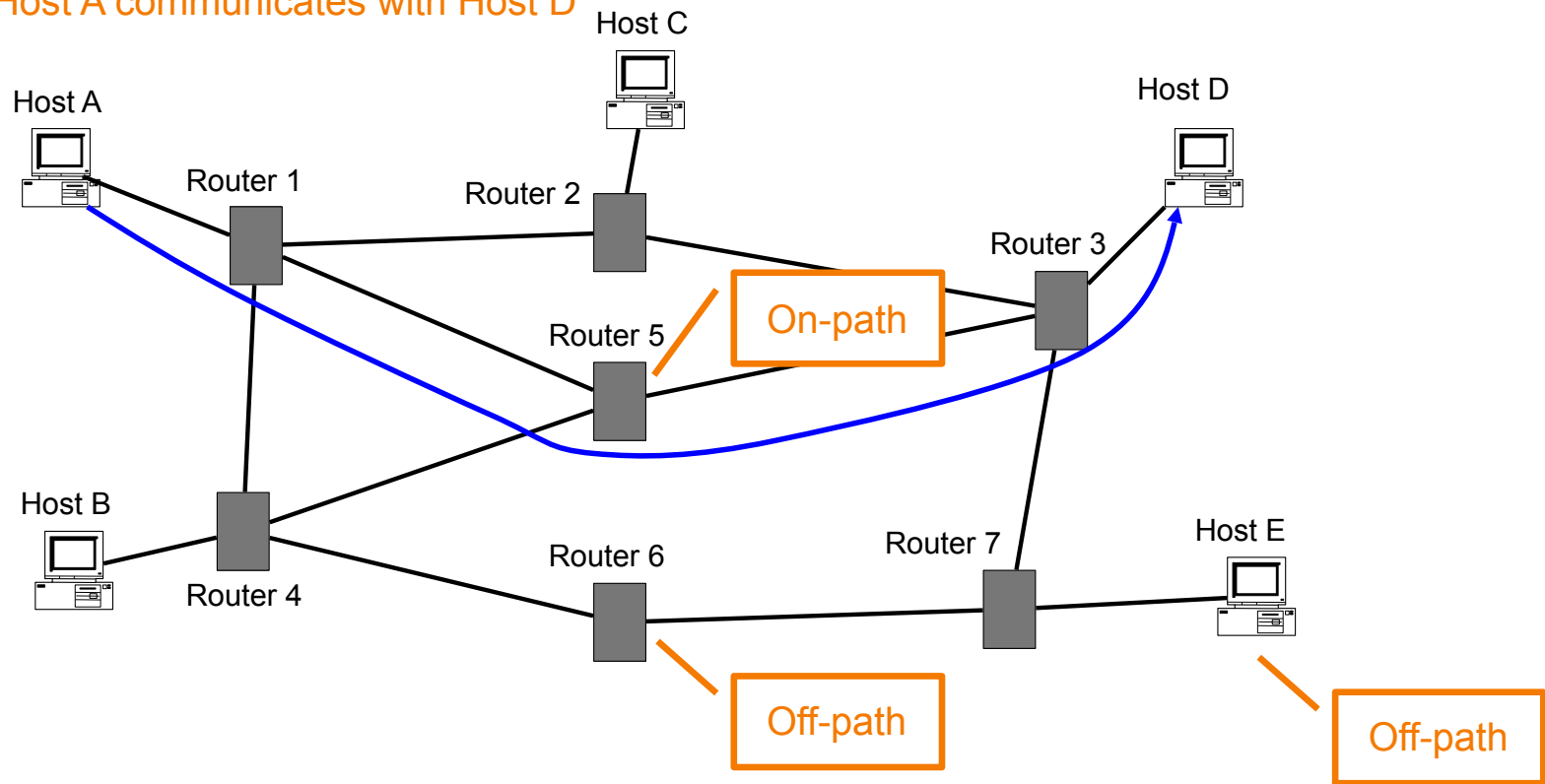
- This is a network of networks
 - Its designed with failures in mind:
Links can go down and the system will recover
 - But it also generally trust-based
 - A system can lie about what networks it can route to!
- Each hop decrements the TTL
 - Prevents a "routing loop" from happening
- Routing can be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

IP Spoofing And Autonomous Systems

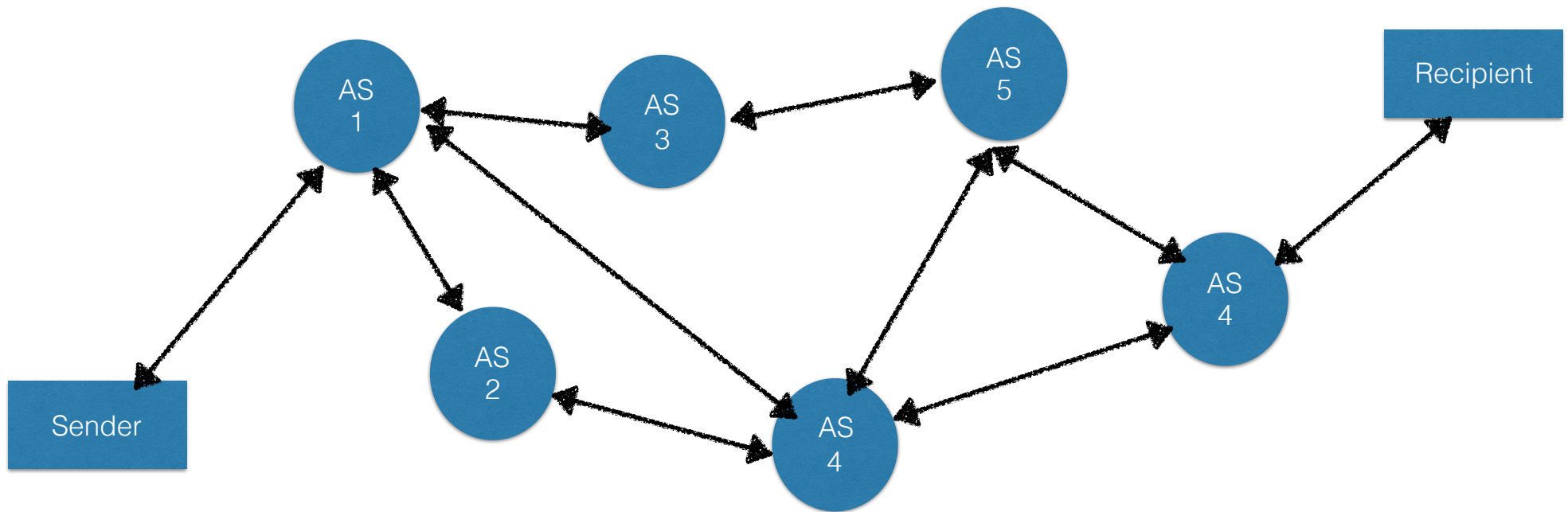
- The edge-AS where a user connects ***should*** restrict packet spoofing
 - Sending a packet with a different sender IP address
- But about 25% of them don't...
 - So a system can simply lie and say it comes from someplace else
- This enables blind-spoofing attacks
 - Such as the Kaminski attack on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

On-path Injection vs Off-path Spoofing

Host A communicates with Host D



Lying in BGP



“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

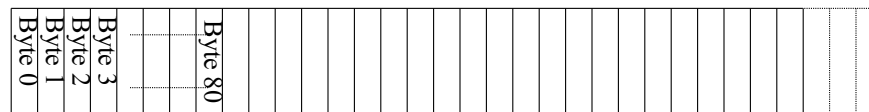
TCP “Bytestream” Service

Process A on host H1



Processes don't ever see packet boundaries, lost or corrupted packets, retransmissions, etc.

Process B on host H2



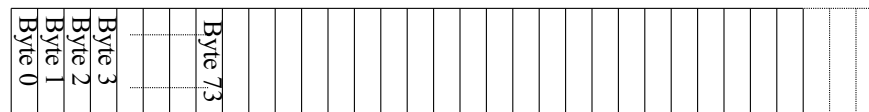
Bidirectional communication:

Process B on host H2

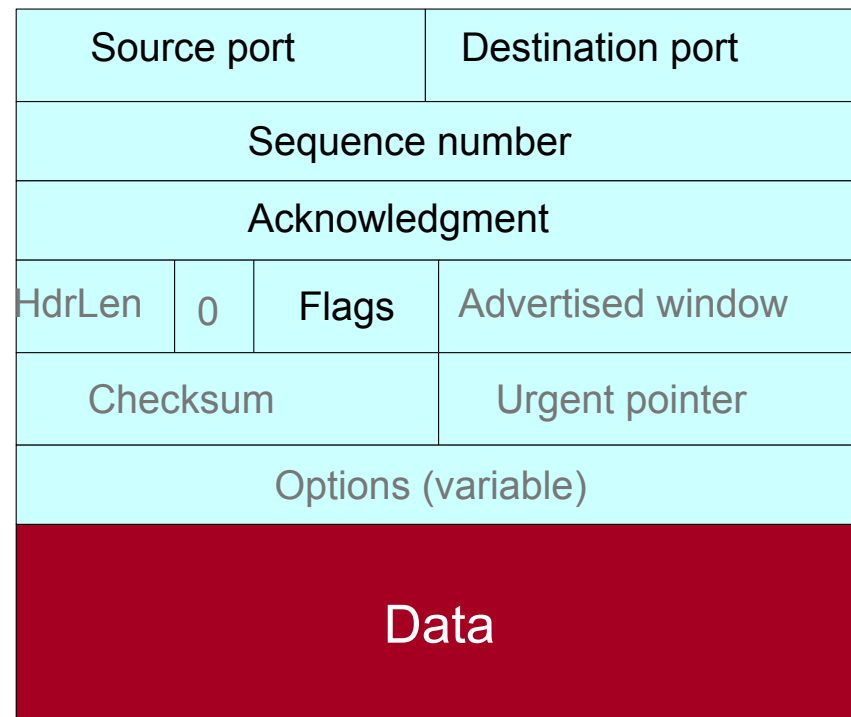
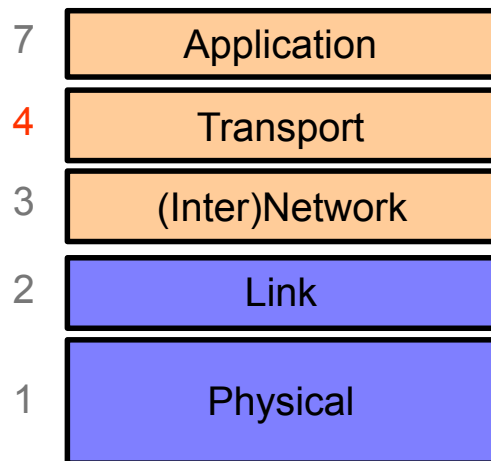


There are two separate **bytestreams**, one in each direction

Process A
on host H1

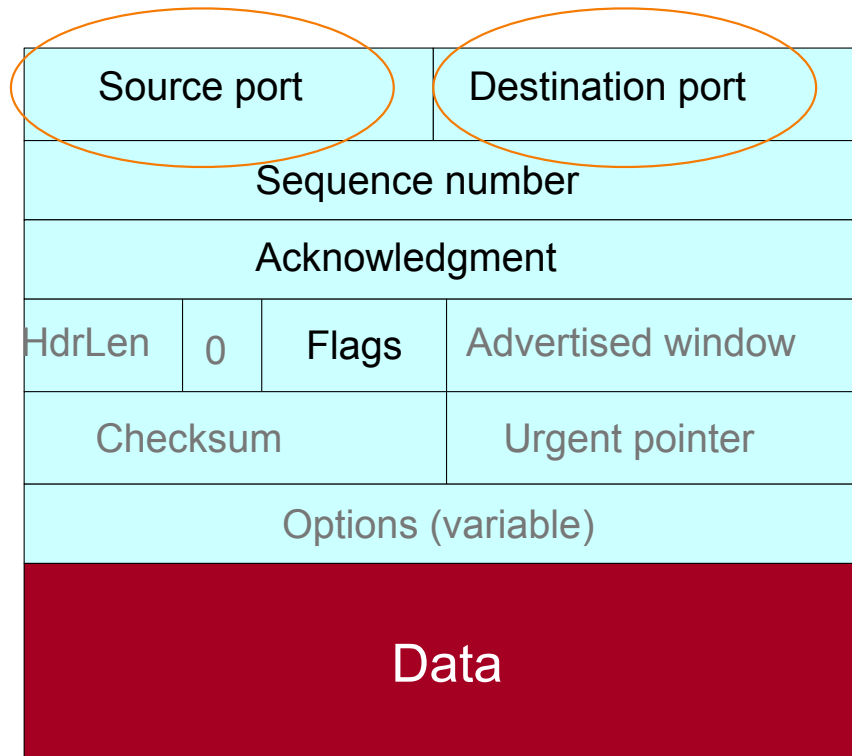


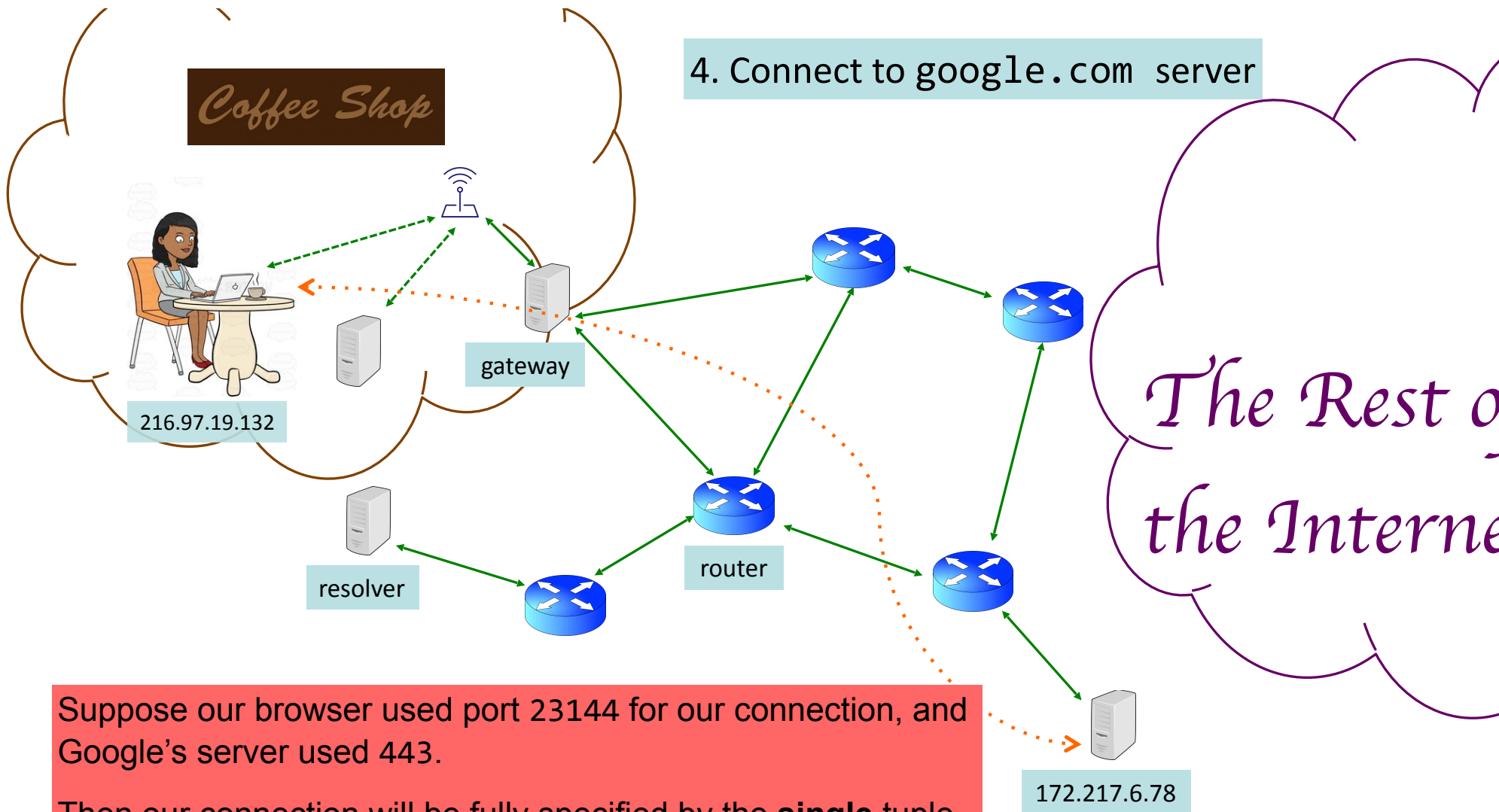
TCP



TCP

These plus IP addresses define
a given connection



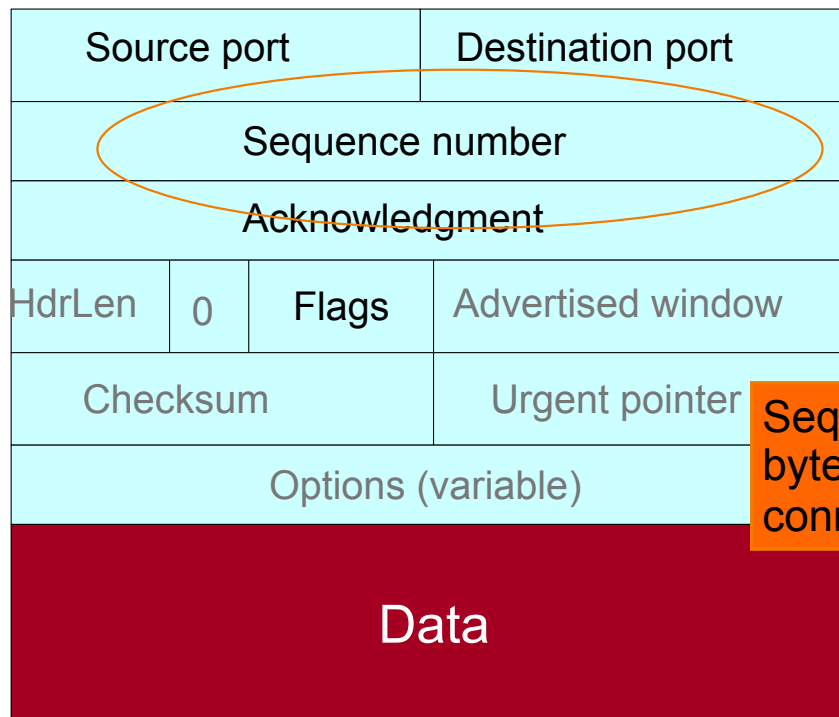


Suppose our browser used port 23144 for our connection, and Google's server used 443.

Then our connection will be fully specified by the **single** tuple $\langle 216.97.19.132, 23144, 172.217.6.78, 443, \text{TCP} \rangle$

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

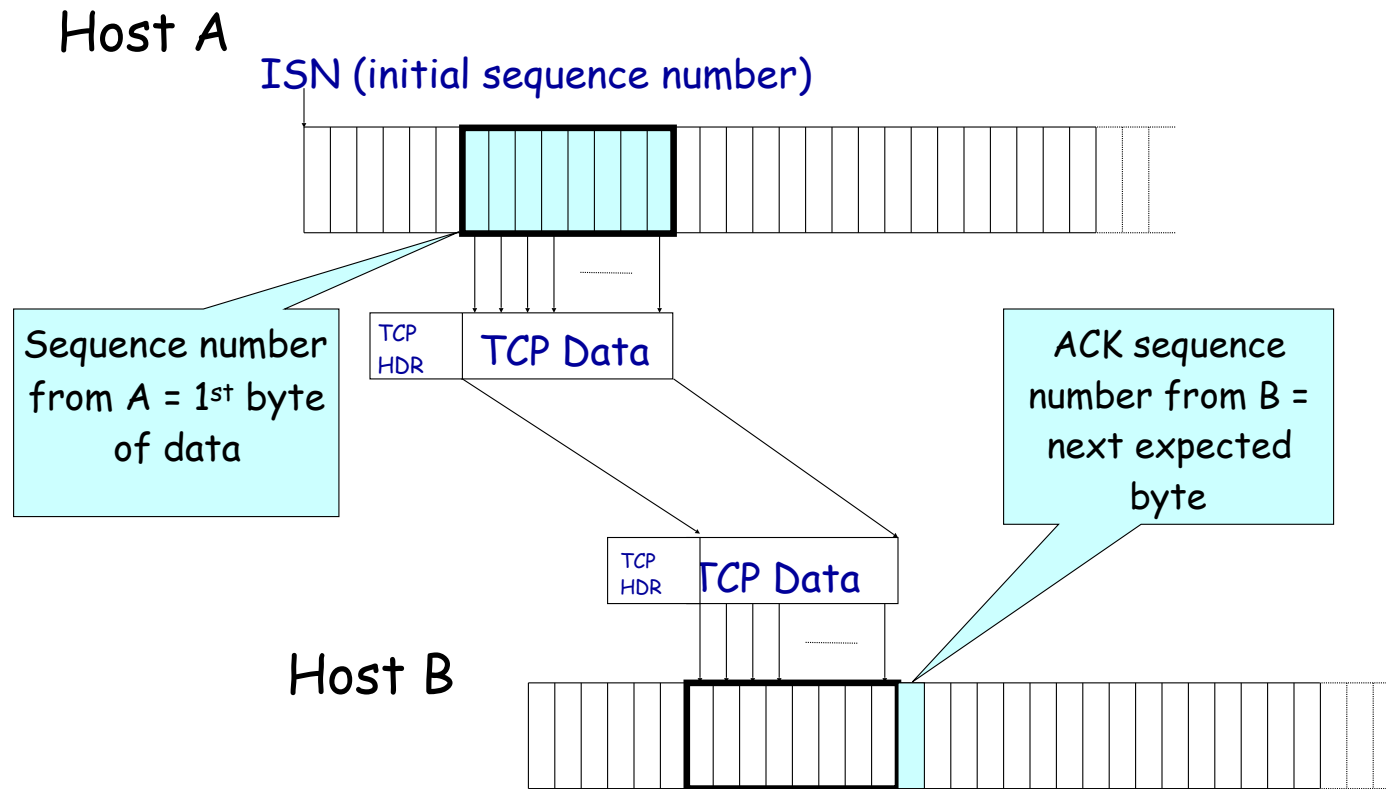
Used to say how much data has been received

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

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

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

Flags have different meaning:

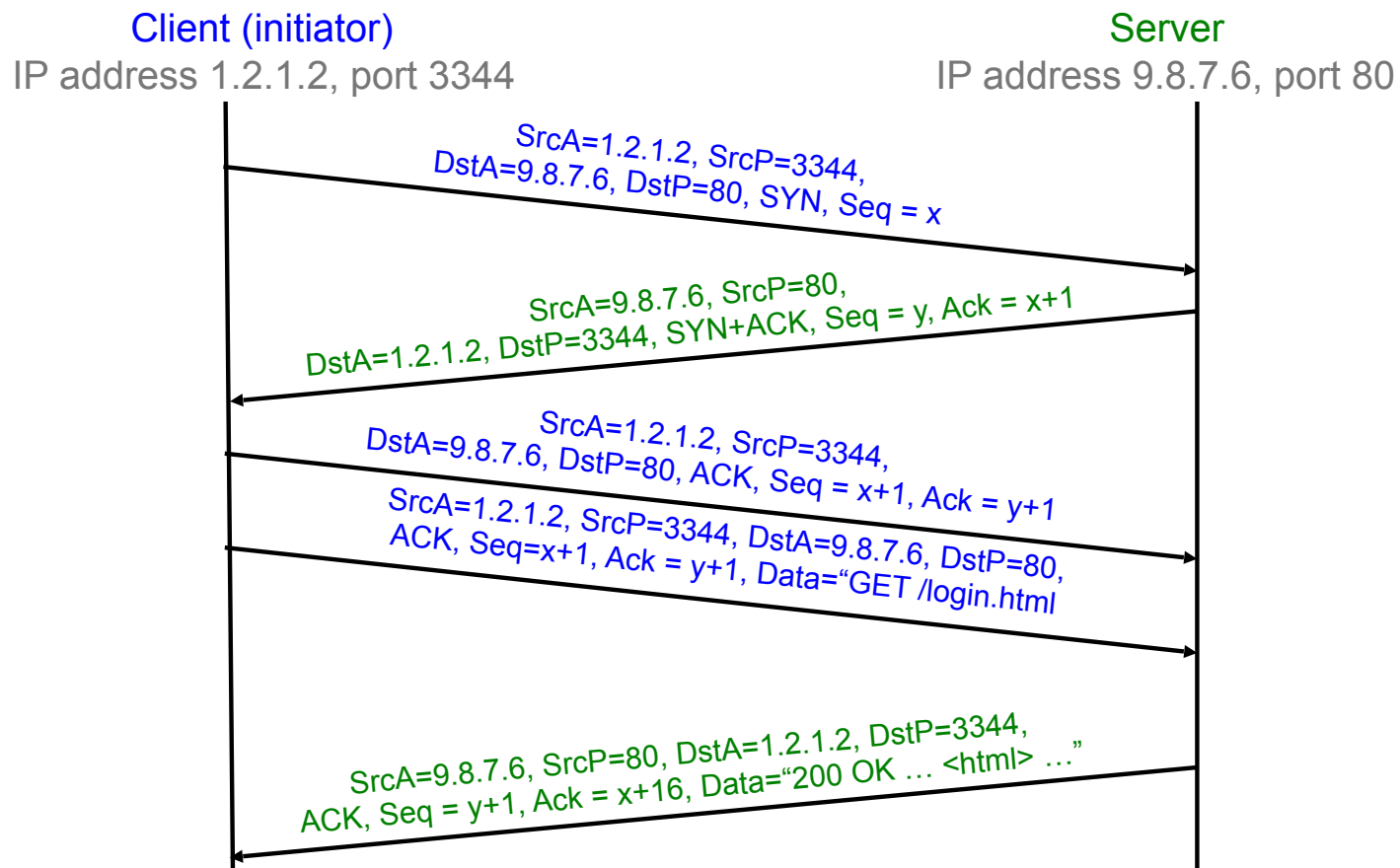
SYN: Synchronize, used to initiate a connection

ACK: Acknowledge, used to indicate acknowledgement of data

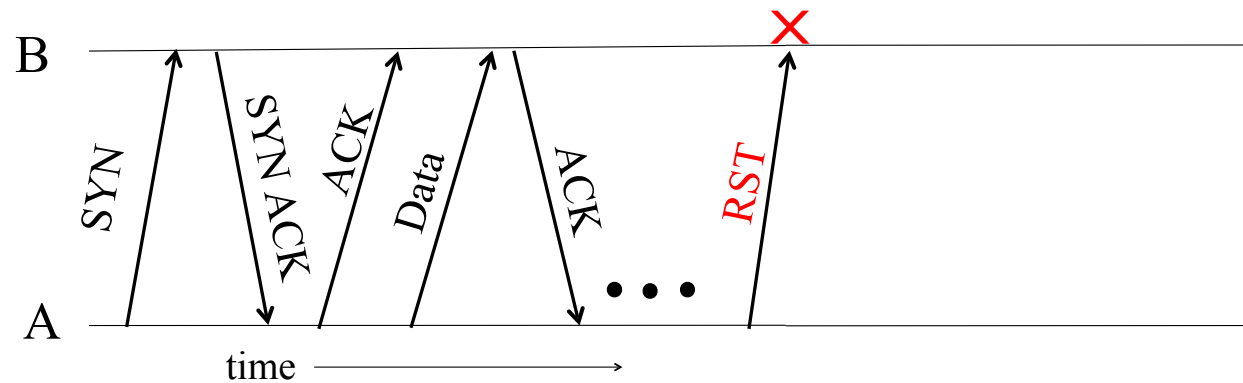
FIN: Finish, used to indicate no more data will be sent (but can still receive and acknowledge data)

RST: Reset, used to terminate the connection completely

TCP Conn. Setup & Data Exchange



Abrupt Termination



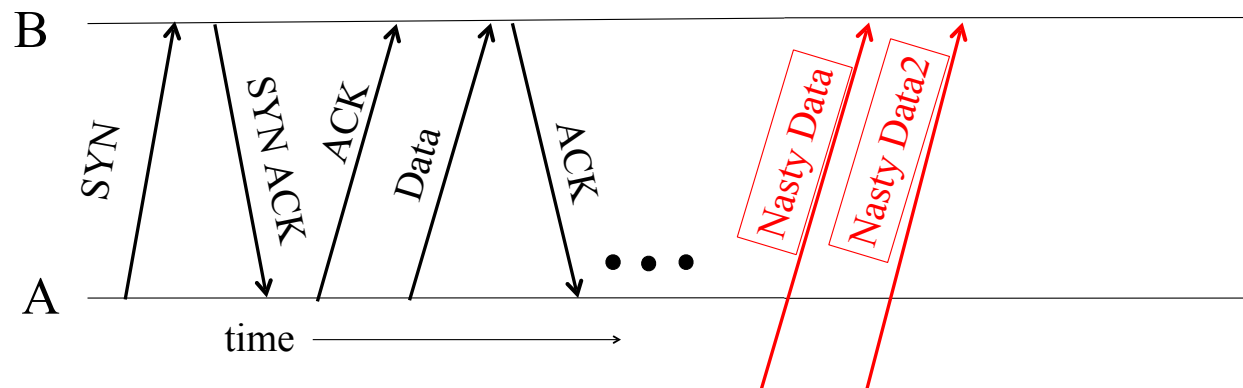
- A sends a TCP packet with RESET (**RST**) flag to B
 - E.g., because app. process on A **crashed**
 - (Could instead be that B sends a RST to A)
- Assuming that the sequence numbers in the **RST** fit with what B expects, **That's It:**
 - B's user-level process receives: **ECONNRESET**
 - No further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

Disruption

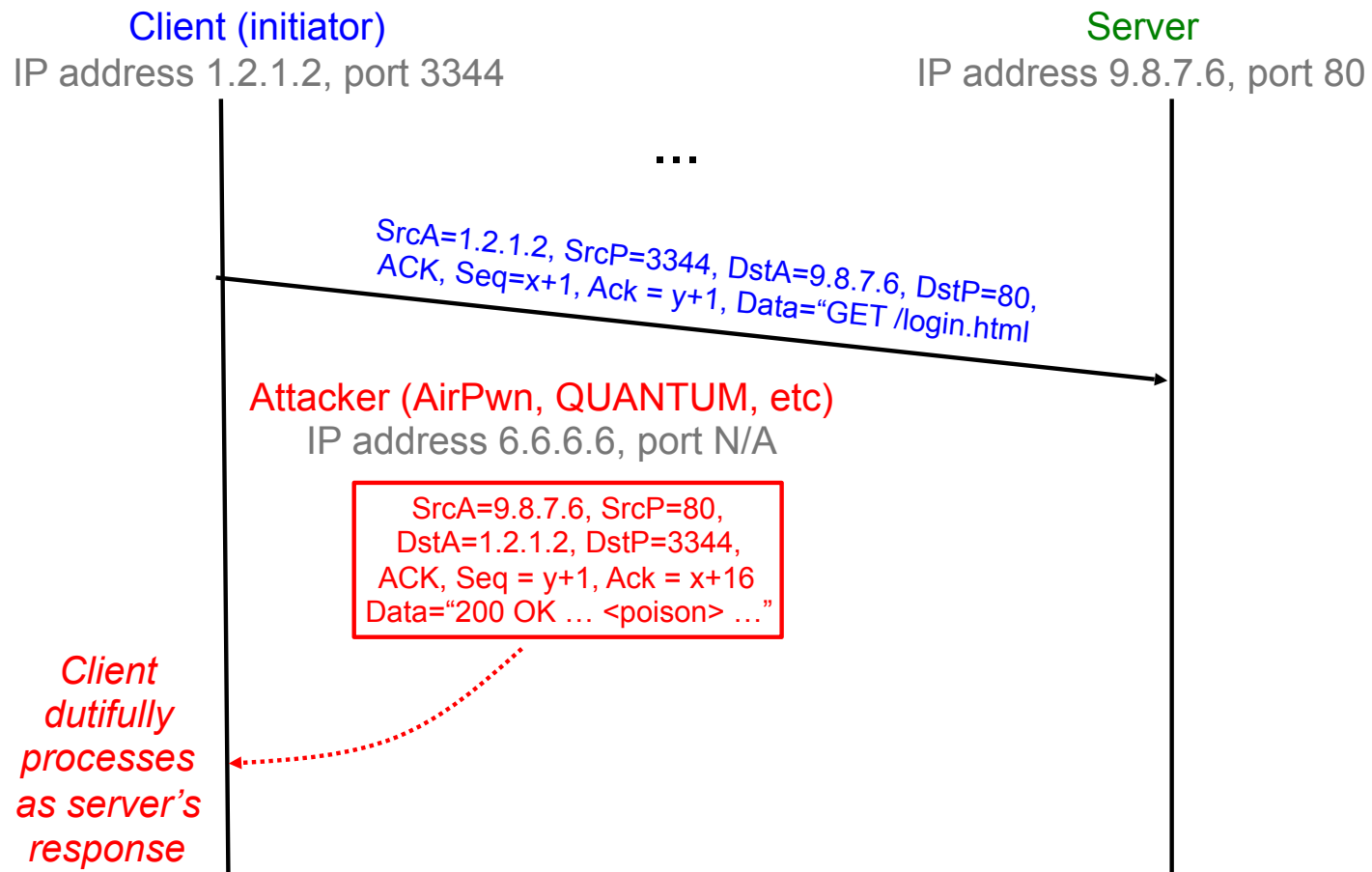
- Normally, TCP finishes (“closes”) a connection by each side sending a FIN control message
 - Reliably delivered, since other side must ack
- But: if a TCP endpoint finds unable to continue (process dies; info from other “peer” is inconsistent), it abruptly **terminates** by sending a **RST** control 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 (initiator)

IP address 1.2.1.2, port 3344

Server

IP address 9.8.7.6, port 80

...

SrcA=1.2.1.2, SrcP=3344, DstA=9.8.7.6, DstP=80,
ACK, Seq=x+1, Ack = y+1, Data="GET /login.html"

Attacker

IP address 6.6.6.6, port N/A

SrcA=9.8.7.6, SrcP=80,
DstA=1.2.1.2, DstP=3344,
ACK, Seq = y+1, Ack = x+16
Data="200 OK ... <poison> ..."

SrcA=9.8.7.6, SrcP=80, DstA=1.2.1.2, DstP=3344,
ACK, Seq = y+1, Ack = x+16, Data="200 OK ... <html> ..."

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

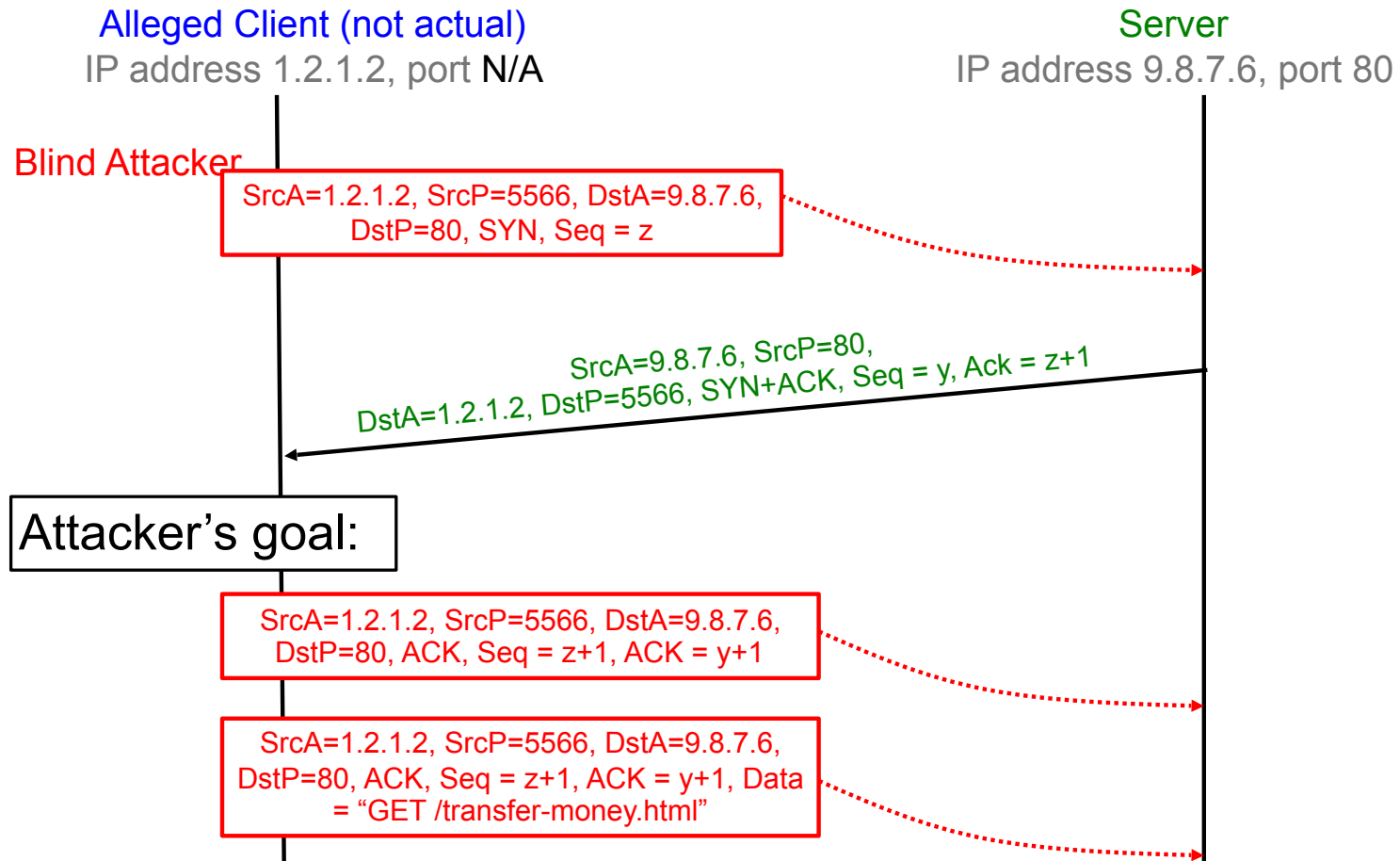
TCP Threat: Blind Hijacking

- 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

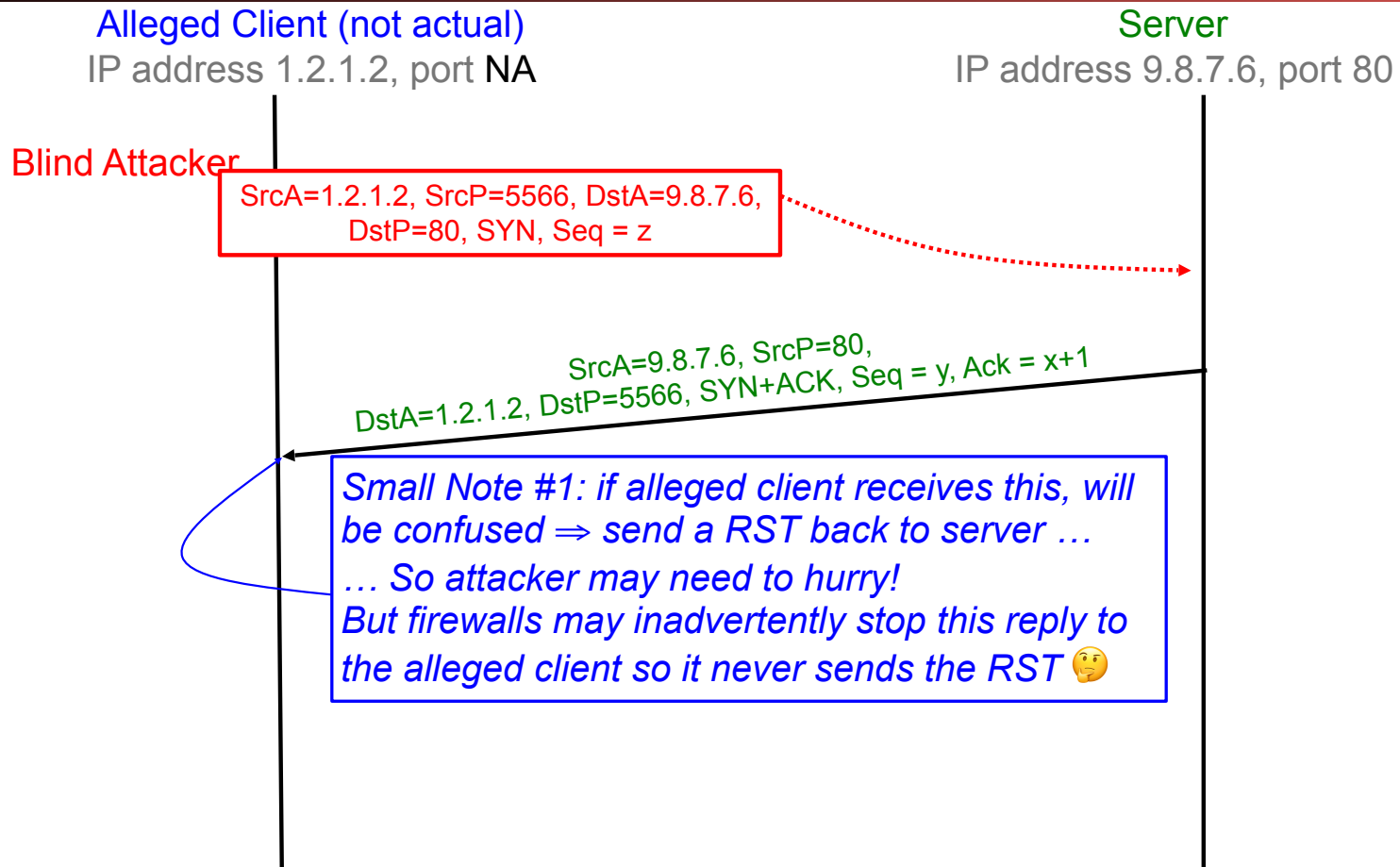
TCP Threat: Blind Spoofing

- 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

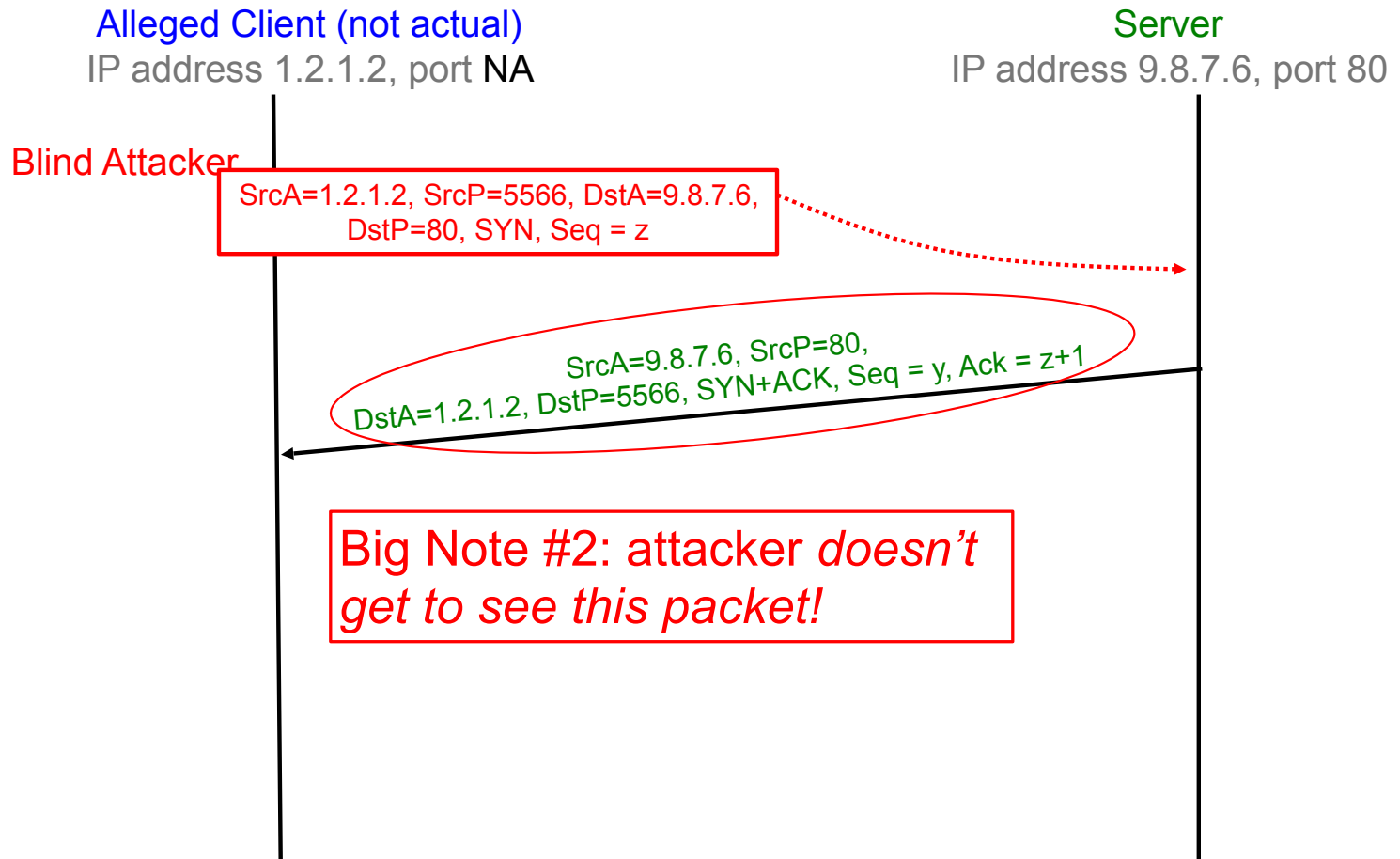
Blind Spoofing on TCP Handshake



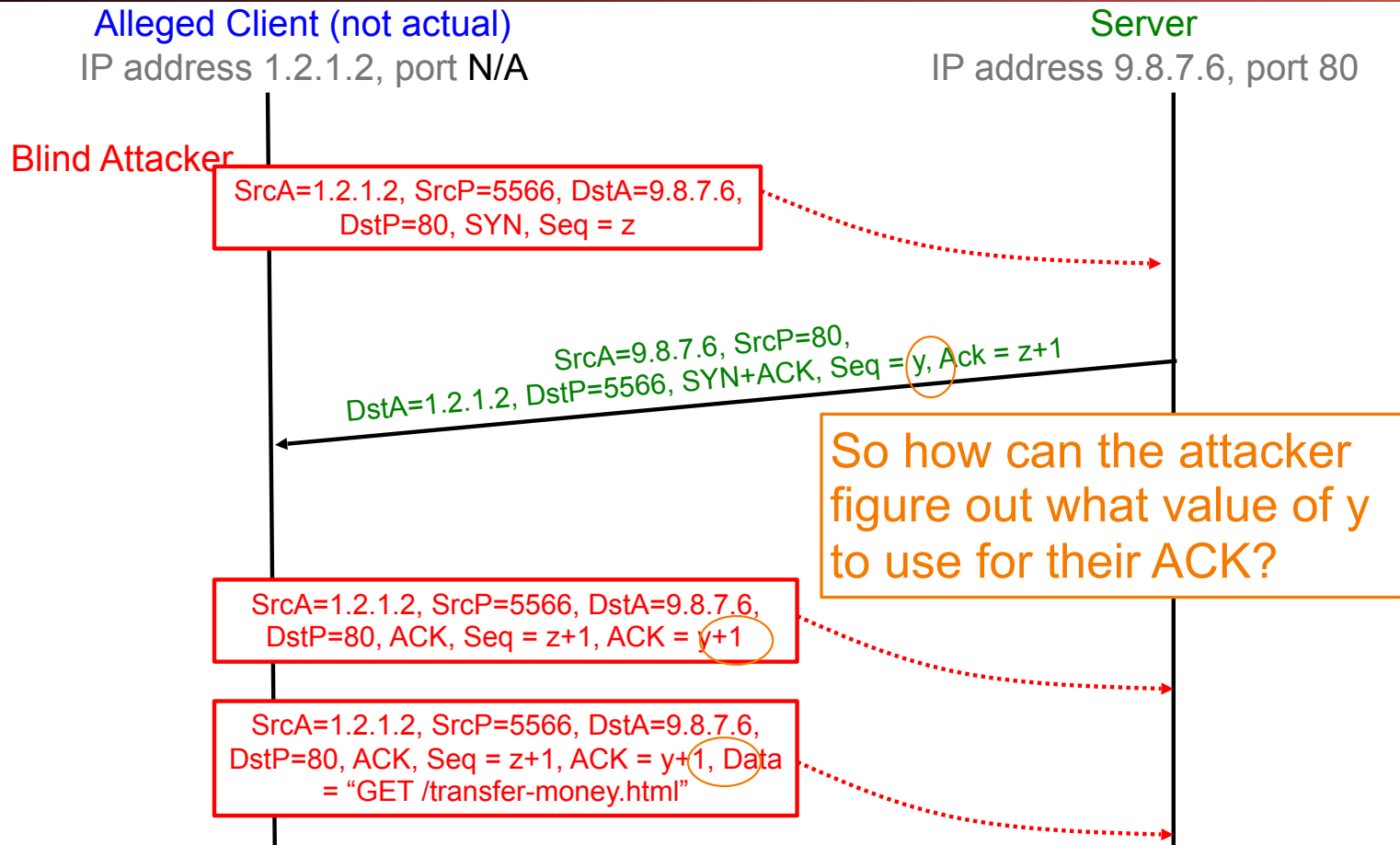
Blind Spoofing on TCP Handshake



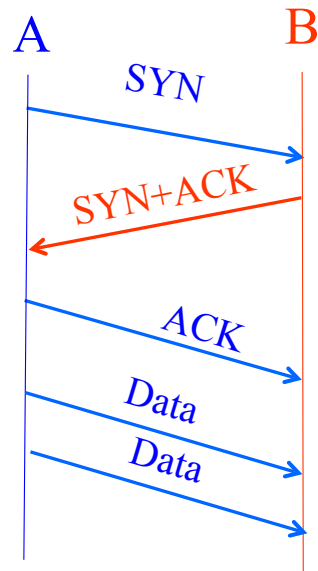
Blind Spoofing on TCP Handshake



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
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 - 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)

The Bane of the Internet: The (distributed) Denial of Service Attack

- Lets say you've run afoul of a bad guy...
 - And he don't like your web page
 - He hires some other bad guy to launch a "Denial of Service" attack
- This other bad guys controls a lot of machines on the Internet
 - These days a million systems is not unheard of
- The bad guy just instructs those machines to make a **lot** of requests to your server...
 - Blowing it off the network with traffic

And the Firewall...

- Attackers can't attack what they can't talk to!
 - If you don't accept **any** communication from an attacker, you can't be exploited
- The firewall is a network device (or software filter on the end host) that restricts communication
 - Primarily just by IP/Port or network/Port
- Default deny:
 - By default, disallow any contact to this host on any port
- Default allow:
 - By default, allow any contact to this host on any port
- More when we discuss Intrusion Detection next week