Denial-of-Service (DoS), continued

CS 161: Computer Security

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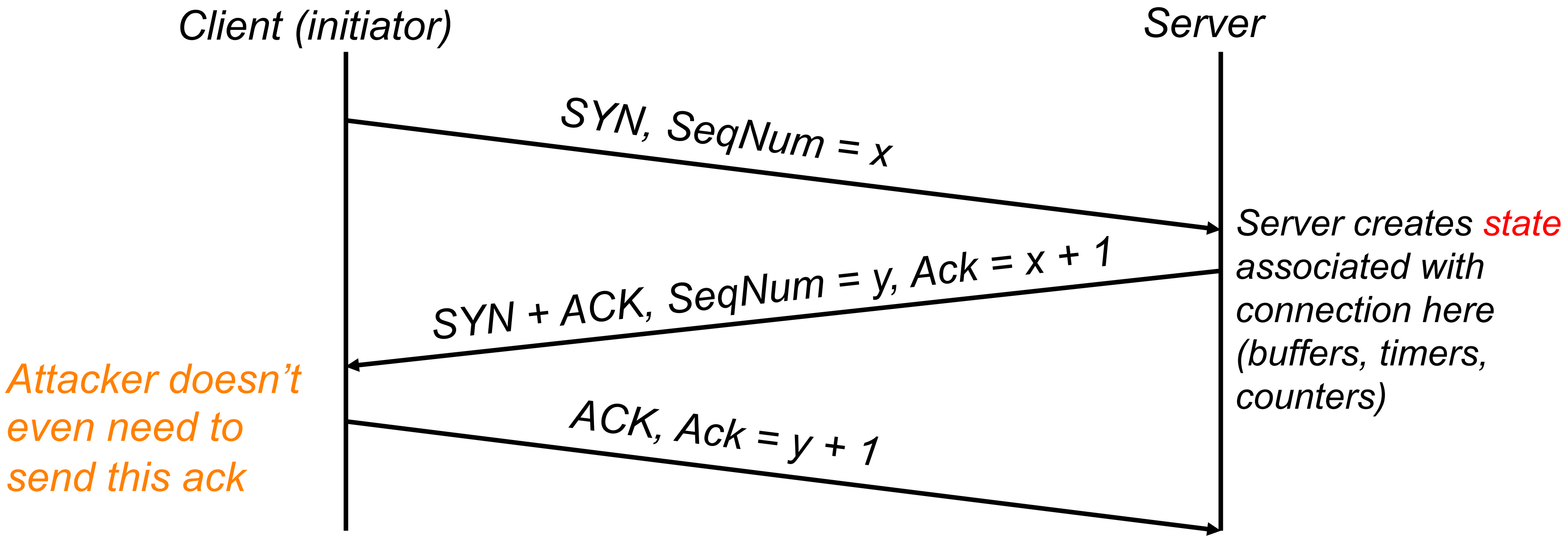
April 4, 2016

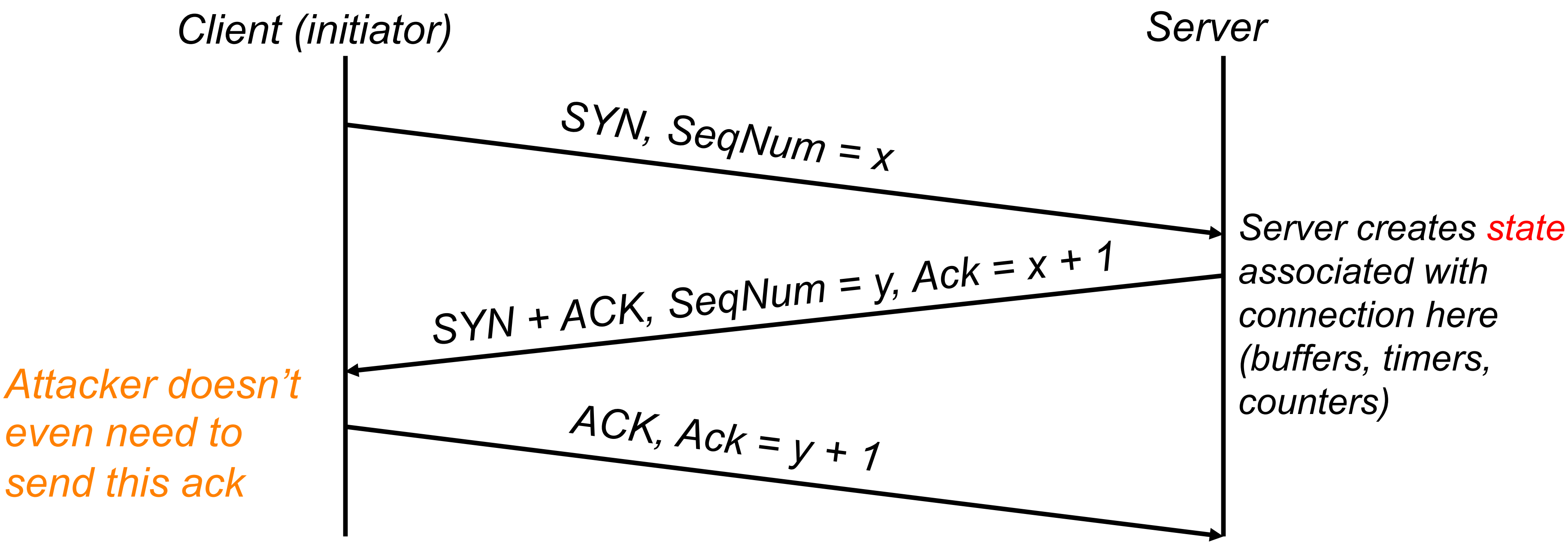
Transport-Level Denial-of-Service

- Recall TCP's 3-way connection establishment handshake
  - Goal: agree on initial sequence numbers



Transport-Level Denial-of-Service

- Recall TCP's 3-way connection establishment handshake
  - Goal: agree on initial sequence numbers
- So a single SYN from an attacker suffices to force the server to *spend some memory*



TCP *SYN Flooding*

- Attacker targets *memory* rather than network capacity
- Every (unique) SYN that the attacker sends burdens the target
- What should target do when it has no more memory for a new connection?
- No good answer!
  - *Refuse* new connection?
    - Legit new users can’t access service
  - *Evict* old connections to make room?
    - Legit old users get kicked off

TCP SYN Flooding Defenses

- How can the target defend itself?

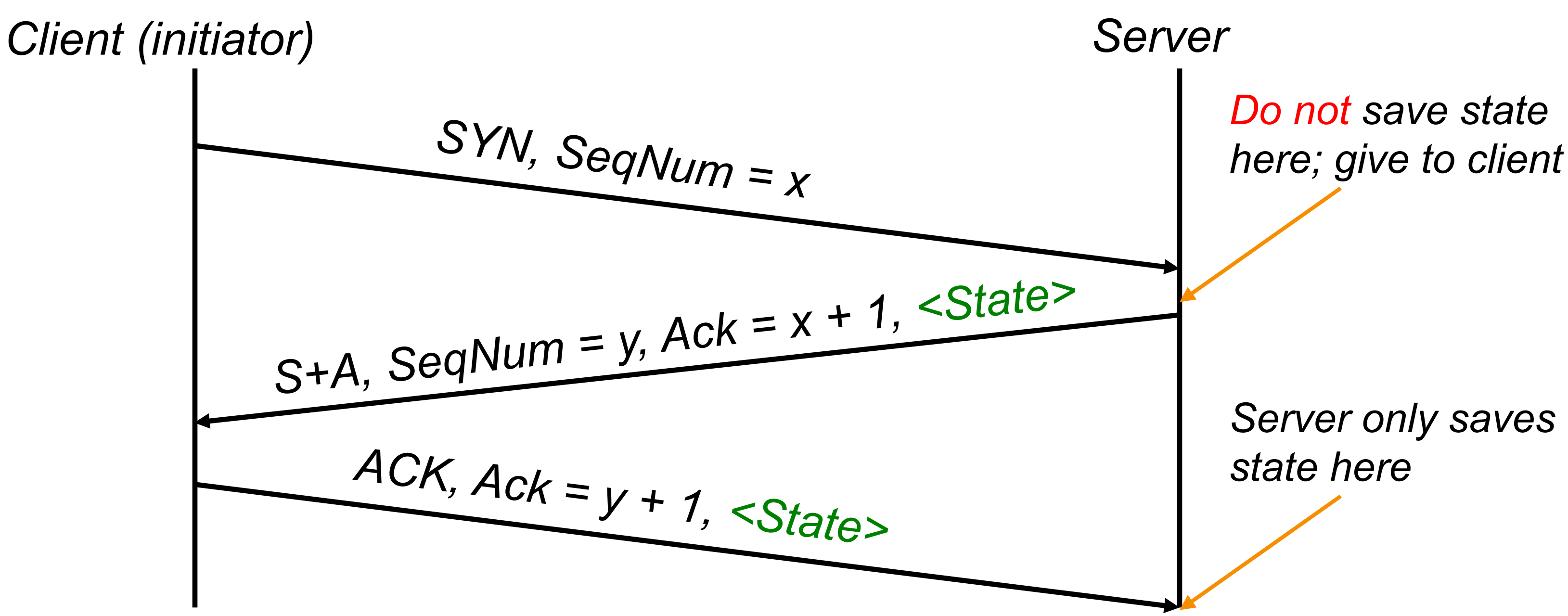
- Approach #1: make sure they have **tons of memory!**
  - How much is enough?
  - Depends on resources attacker can bring to bear (threat model), which might be hard to know

TCP SYN Flooding Defenses

- Approach #2: identify bad actors & refuse their connections
  - Hard because only way to identify them is based on IP address
    - We can't for example require them to send a password because doing so requires we have an established connection!
  - For a public Internet service, who knows which addresses customers might come from?
  - Plus: attacker can spoof addresses since they don't need to complete TCP 3-way handshake
- Approach #3: don't keep state! ("*SYN cookies*"; *only works for spoofed SYN flooding*)

SYN Flooding Defense: *Idealized*

- Server: when SYN arrives, rather than keeping state locally, *send it to the client* …
- Client needs to *return the state* in order to established connection



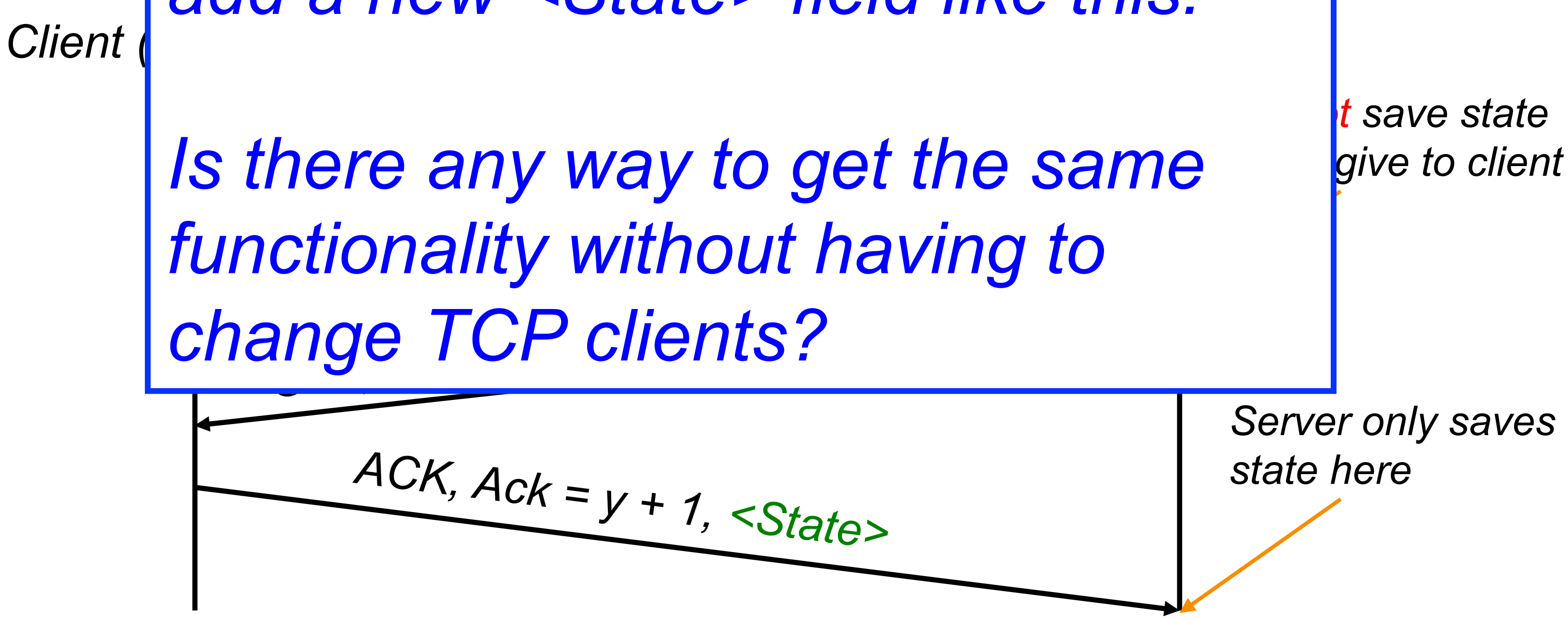
SYN Flooding Defense: *Idealized*

- Server: when SYN arrives, rather than keeping state locally, *send it to the client* …
- Client
  establ

Problem: the world isn't so ideal!

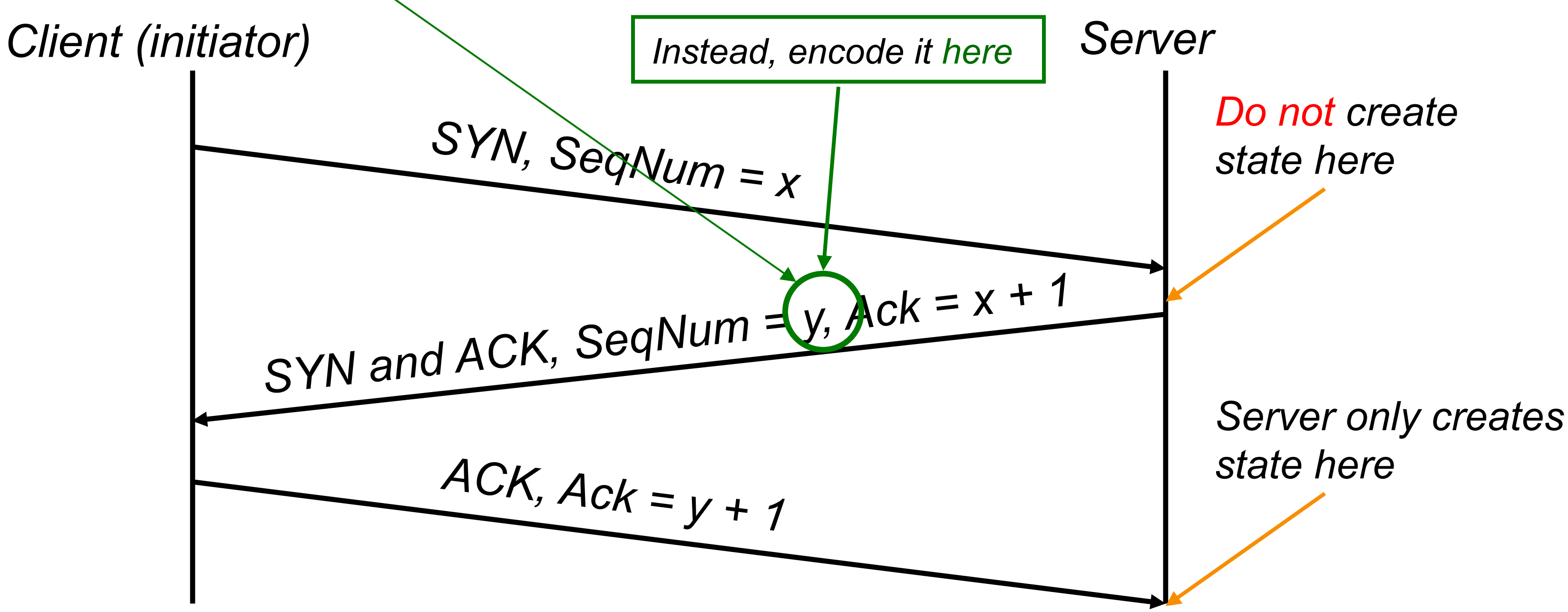
TCP doesn't include an easy way to add a new <State> field like this.

Is there any way to get the same functionality without having to change TCP clients?



Practical Defense: *SYN Cookies*

- Server: when SYN arrives, encode connection state entirely within SYN-ACK's sequence # y
  - y = *encoding* of state, MAC'ed using server secret
- When ACK of SYN-ACK arrives, server only creates state ***if*** MAC is valid



SYN Cookies: Discussion

- Illustrates general strategy: rather than *holding* state, *encode* it so that it is returned when needed. Use crypto to prevent tampering.
- For SYN cookies, attacker must complete 3-way handshake in order to burden server
  - *Can't use spoofed source addresses*
- Note #1: strategy requires that you have enough bits to encode all the state
  - (This is just barely the case for SYN cookies)
- Note #2: if it's expensive to generate *or check* the cookie, then it's not a win

Application-Layer DoS

- Rather than exhausting network or memory resources, attacker can overwhelm a service's processing capacity

- There are many ways to do so, often at little expense to attacker compared to target (*asymmetry*)

The link sends a request to the web server that requires heavy processing by its "backend database".

Algorithmic complexity attacks

- Attacker can try to trigger worst-case complexity of algorithms / data structures
- Example: You have a hash table.
  Expected time: O(1). Worst-case: O(n).
- Attacker picks inputs that cause hash collisions.
  Time per lookup: O(n).
  Total time to do n operations: O(n^2).
- Solution? Use algorithms with good worst-case running time.
  - E.g., universal hash function guarantees that $Pr[h_k(x)=h_k(y)] = 1/2^b$, so hash collisions will be rare.

Application-Layer DoS

- Rather than exhausting network or memory resources, attacker can overwhelm a service's processing capacity
- There are many ways to do so, often at little expense to attacker compared to target (asymmetry)
- Defenses against such attacks?
- Approach #1: Only let legit users issue expensive requests
  - Relies on being able to identify/authenticate them
  - Note: that *this itself might be expensive*!
- Approach #2: Force legit users to "burn" cash
- Approach #3: massive over-provisioning ($$$)

DoS Defense in General Terms

- Defending against program flaws requires:
  - Careful design and coding/testing/review
  - Consideration of behavior of defense mechanisms
    - E.g. buffer overflow detector that when triggered halts execution to prevent code injection ⇒ denial-of-service
- Defending resources from exhaustion can be **really** hard. Requires:
  - *Isolation and scheduling mechanisms*
    - Keep adversary's consumption from affecting others
  - *Reliable identification* of different users
- Watch out for amplification attacks

Firewalls

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Controlling Networks … On The Cheap

- Motivation: How do you harden a set of systems against external attack?
  - *Key Observation:*
    - *The more network services your machines run, the greater the risk*
  - Due to larger attack surface
- One approach: on each system, turn off unnecessary network services
  - But you have to know ***all*** the services that are running
  - And sometimes some trusted remote users still require access

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- One approach: on each system, turn off unnecessary network services
  - But you have to know ***all*** the services that are running
  - And sometimes some trusted remote users still require access
- Plus key question of scaling
  - What happens when you have to secure 100s/1000s of systems?
  - Which may have different OSs, hardware & users …
  - Which may in fact not all even be identified …

Taming Management Complexity

- Possibly more scalable defense: Reduce risk by blocking *in the network* outsiders from having unwanted access your network services
  - Interpose a **firewall** the traffic to/from the outside must traverse
  - Chokepoint can cover thousands of hosts
    - Where in everyday experience do we see such chokepoints?

Selecting a Security Policy

- Firewall enforces an (access control) policy:
  - *Who is allowed to talk to whom, accessing what service?*
- Distinguish between inbound & outbound connections
  - Inbound: attempts by external users to connect to services on internal machines
  - Outbound: internal users to external services
  - Why? Because fits with a common ***threat model***. There are thousands of internal users (and we've vetted them). There are billions of outsiders.
- Conceptually simple *access control policy*:
  - Permit inside users to connect to any service
  - External users restricted:
    - Permit connections to services meant to be externally visible
    - Deny connections to services not meant for external access

How To Treat Traffic Not Mentioned in Policy?

- **Default Allow**: start off permitting external access to services
  - Shut them off as problems recognized

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- **Default Allow**: start off permitting external access to services
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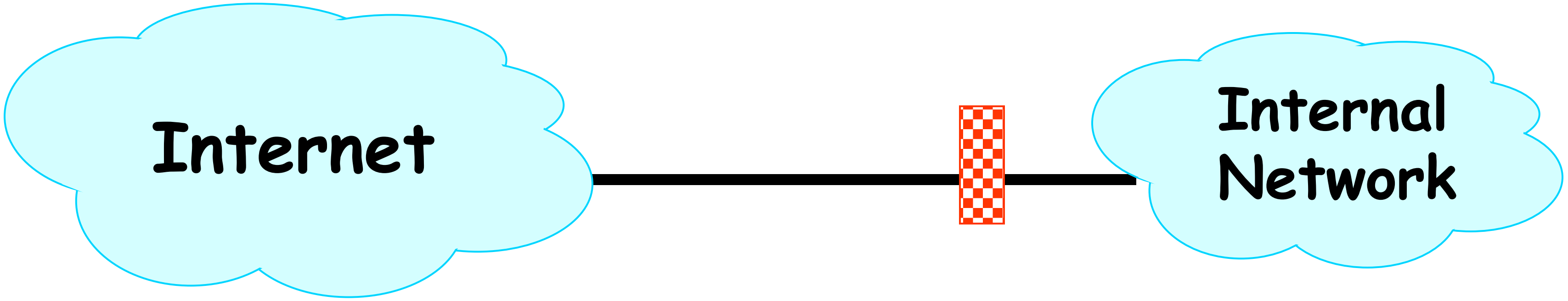
How To Treat Traffic Not Mentioned in Policy?

- **Default Allow**: start off permitting external access to services
  - Shut them off as problems recognized
- **Default Deny**: ✓ rt off permitting just a few known, well-secured services
  - Add more when users complain (and mgt. approves)
- Pros & Cons?
  - Flexibility vs. conservative design
  - Flaws in Default Deny get noticed more quickly / less painfully

In general, use Default Deny

Stateful Packet Filter

- Stateful packet filter is a router that checks each packet against security rules and decides to forward or drop it
  - Firewall keeps track of all connections (inbound/outbound)
  - Each rule specifies which connections are allowed/denied (*access control policy*)
  - A packet is forwarded if it is part of an allowed connection



Example Rule

```
allow tcp connection 4.5.5.4:* -> 3.1.1.2:80
```

- Firewall should **permit** TCP connection that's:
  - Initiated by host with Internet address `4.5.5.4` **and**
  - Connecting to port `80` of host with IP address `3.1.1.2`
- Firewall should permit any packet associated with this connection

- Thus, firewall keeps a table of (allowed) active connections. When firewall sees a packet, it checks whether it is part of one of those active connections. If yes, forward it; if no, drop it.

Example Rule

```
allow tcp connection *:*/int -> 3.1.1.2:80/ext
```

- Firewall should **permit** TCP connection that's:
  - Initiated by host with any internal host **and**
  - Connecting to port `80` of host with IP address `3.1.1.2` on external Internet
- Firewall should permit any packet associated with this connection
- The `/int` indicates the network interface.

Example Ruleset

```
allow tcp connection *:*/int -> *:*/ext
allow tcp connection *:*/ext -> 1.2.2.3:80/int
```

- Firewall should permit outbound TCP connections (i.e., those that are initiated by internal hosts)
- Firewall should permit inbound TCP connection to our public webserver at IP address 1.2.2.3

Stateful Filtering

Discussion question:

Suppose you want to allow inbound connection to a FTP server, but block any attempts to login as “root”. How would you build a stateful packet filter to do that? In particular, what state would it keep, for each connection?

Discuss with a partner.

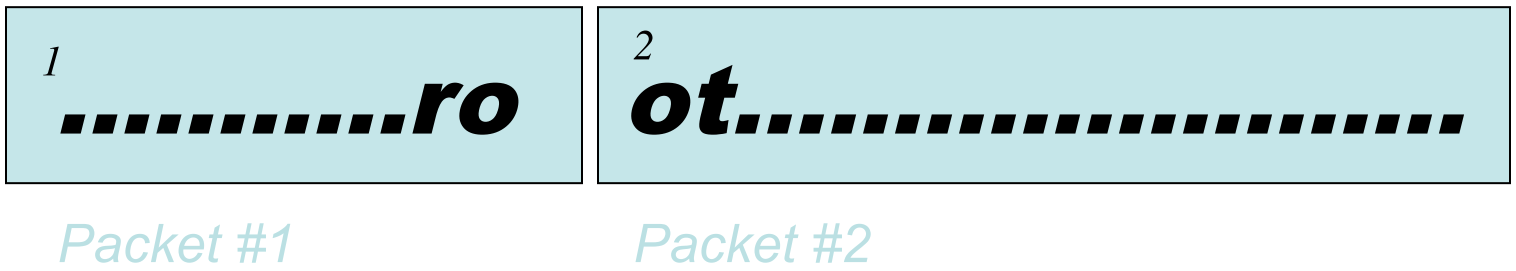
State Kept

- No state – just drop any packet with root in them

- Is it a FTP connection?
- Where in FTP state (e.g. command, what command)
- Src ip addr, dst ip addr, src port, dst port
- Inbound/outbound connection
- Keep piece of login command until it's completed – only first 5 bytes of username

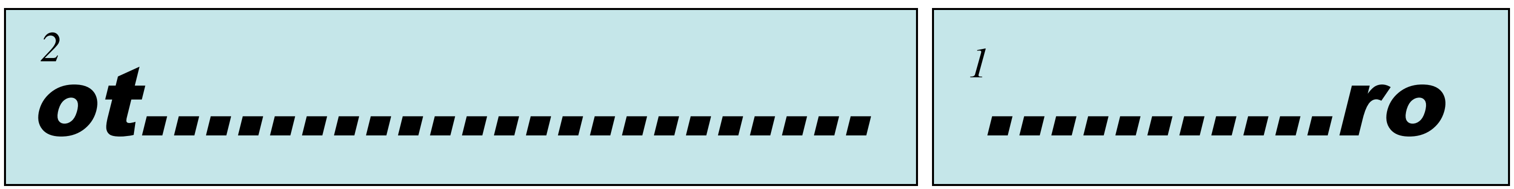
Beware!

- Sender might be malicious and trying to sneak through firewall
- “root” might span packet boundaries



Beware!

- Packets might be re-ordered



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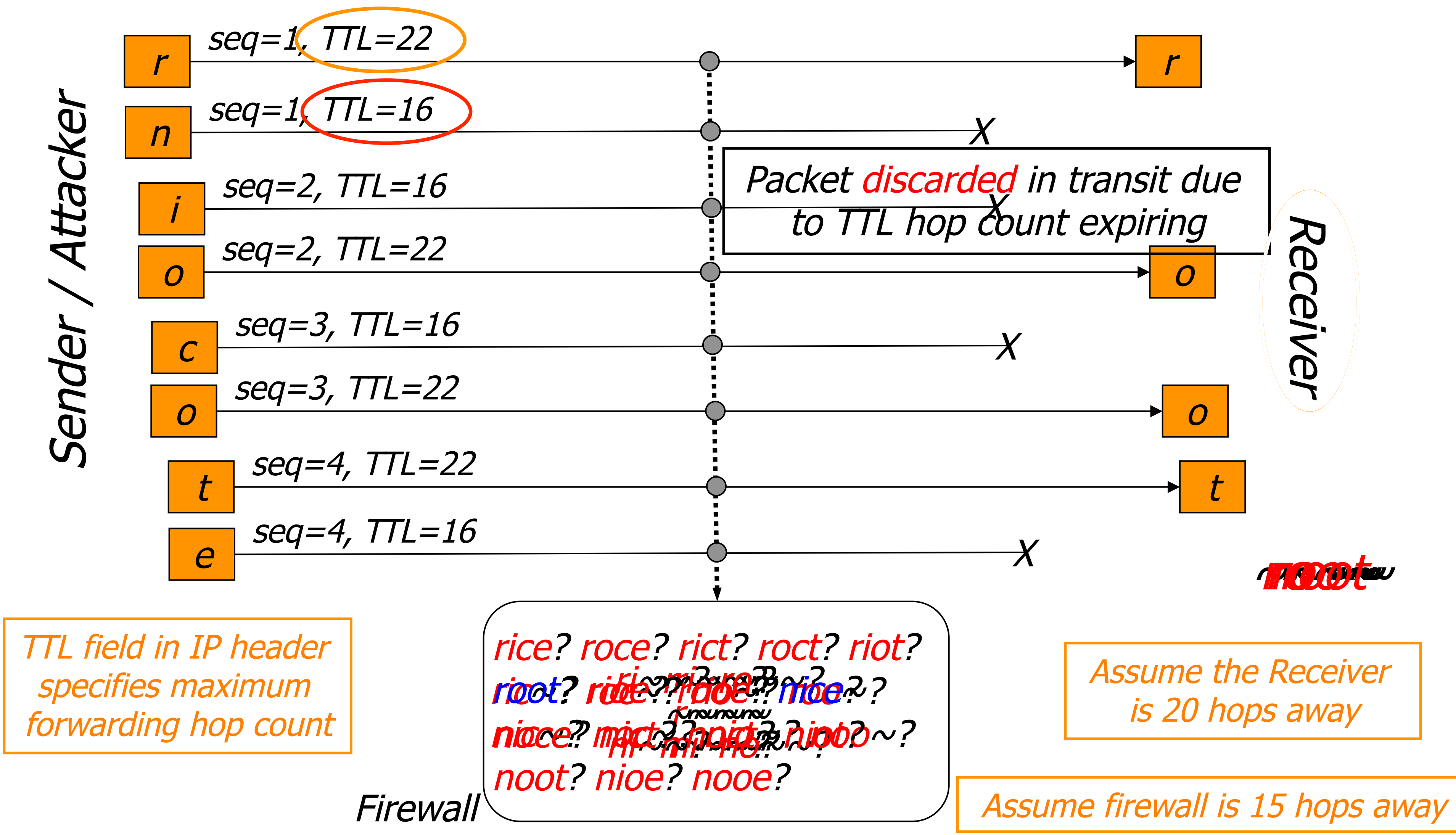
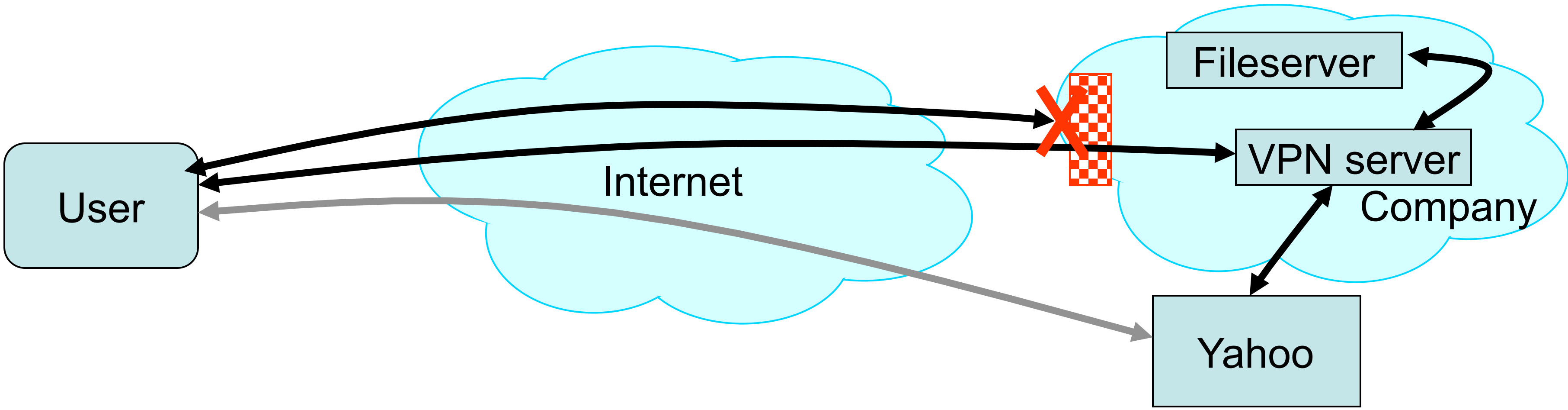


Sender / Attacker
Receiver
r
seq=1, TTL=22
r
n
seq=1, TTL=16
X
Packet discarded in transit due to TTL hop count expiring
i
seq=2, TTL=16
X
o
seq=2, TTL=22
o
c
seq=3, TTL=16
X
o
seq=3, TTL=22
o
t
seq=4, TTL=22
t
e
seq=4, TTL=16
X
Firewall
rice? roce? rict? roct? riot?
noot? nioe? nooe?
TTL field in IP header specifies maximum forwarding hop count
Assume the Receiver is 20 hops away
Assume firewall is 15 hops away

Other Kinds of Firewalls

- Stateless packet filter
  - No state in the packet filter. Rules specify whether to drop packet, without history.
  - Problem: requires hacks to handle TCP connections (e.g., an inbound packet is OK if it is associated with a TCP connection initiated by an inside host to an outside host).
- Application-level firewall
  - Firewall acts as a proxy. TCP connection from client to firewall, which then makes a second TCP connection from firewall to server.
  - Only modest benefits over stateful packet filter.

Secure External Access to Inside Machines



- Often need to provide secure remote access to a network protected by a firewall
  - Remote access, telecommuting, branch offices, …
- Create secure channel (*Virtual Private Network*, or **VPN**) to tunnel traffic from outside host/network to inside network
  - Provides Authentication, Confidentiality, Integrity
  - However, also raises *perimeter issues*

    (Try it yourself at http://www.net.berkeley.edu/vpn/)

Why Have Firewalls Been Successful?

- *Central control – easy administration and update*
  - Single point of control: update one config to change security policies
  - Potentially allows rapid response
- *Easy to deploy – transparent to end users*
  - Easy incremental/total deployment to protect 1000's
- *Addresses an important problem*
  - Security vulnerabilities in network services are rampant
  - Easier to use firewall than to directly secure code …

Attacks Firewalls Don't Stop?

Discussion question:

Suppose you wanted to attack a company protected by a firewall. What attacks might you try?

Discuss with a partner.

Attacks Firewalls Don’t Stop

- tbd

Firewall Disadvantages?

Discussion question:

What are the limitations of firewalls?
Why have firewalls become less effective over time?

Discuss with a partner.

Firewall Disadvantages

- *Functionality loss – less connectivity, less risk*
  - May reduce network's usefulness
  - Some applications don't work with firewalls
    - Two peer-to-peer users behind different firewalls
- *The malicious insider problem*
  - Assume insiders are trusted
    - Malicious insider (or anyone gaining control of internal machine) can wreak havoc
- Firewalls establish a *security perimeter*
  - Like *Eskimo Pies*: "hard crunchy exterior, soft creamy center"
  - Threat from travelers with laptops, cell phones, …

Takeaways on Firewalls

- Firewalls: Reference monitors and access control all over again, but at the network level
- Attack surface reduction
- Centralized control