Unwanted Traffic: Denial of Service Attacks

Dan Boneh

What is network DoS?

- Goal: take out a large site with little computing work
- How: **Amplification**
  - Small number of packets $\Rightarrow$ big effect
- Two types of amplification attacks:
  - DoS bug:
    - Design flaw allowing one machine to disrupt a service
  - DoS flood:
    - Command bot-net to generate flood of requests

DoS can happen at any layer

- This lecture:
  - Sample Dos at different layers (by order):
    - Link
    - TCP/UDP
    - Application
  - DoS mitigations
- Sad truth:
  - Current Internet not designed to handle DDoS attacks

Warm up: 802.11b DoS bugs

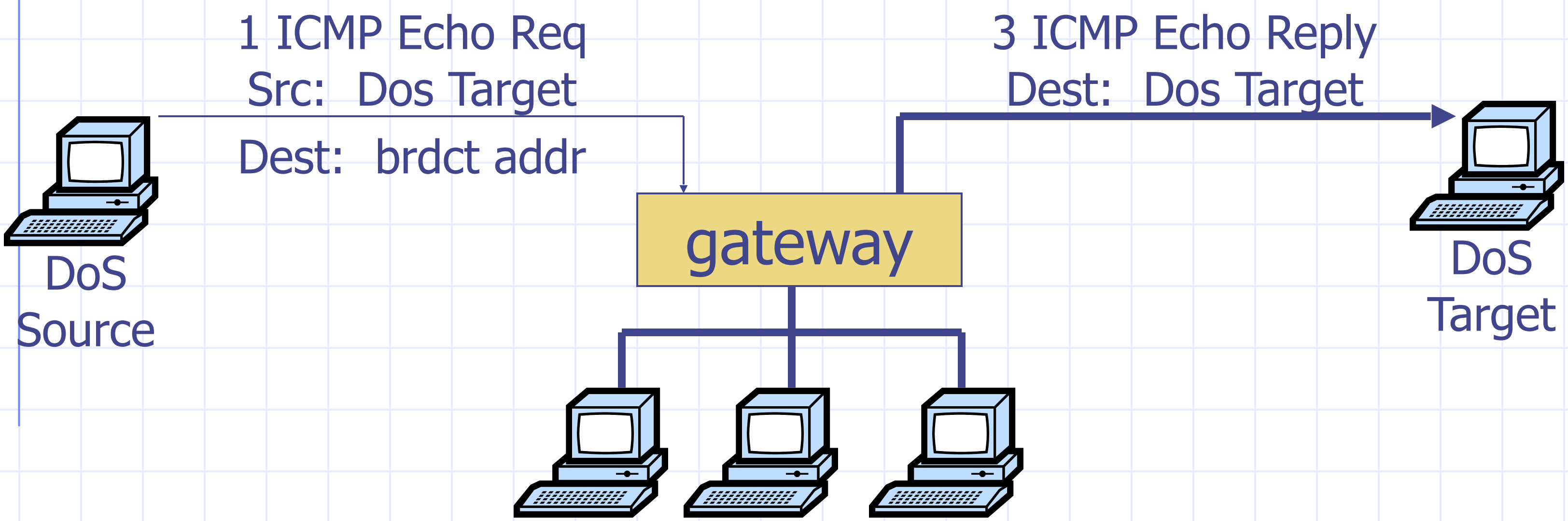
- Radio jamming attacks: trivial, not our focus.
- Protocol DoS bugs: [Bellardo, Savage, '03]
  - NAV (Network Allocation Vector):
    - 15-bit field. Max value: 32767
    - Any node can reserve channel for NAV seconds
    - No one else should transmit during NAV period

      … but not followed by most 802.11b cards

  - De-authentication bug:
    - Any node can send deauth packet to AP
    - Deauth packet unauthenticated

      $\Rightarrow$ attacker can repeatedly deauth anyone

Smurf amplification DoS attack

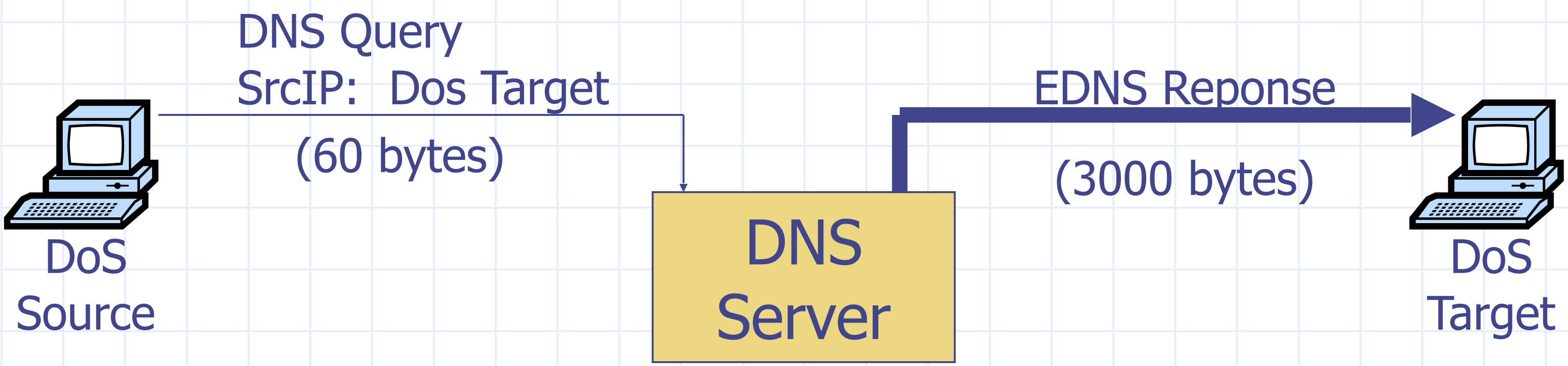


- Send ping request to broadcast addr (ICMP Echo Req)
- Lots of responses:
  - Every host on target network generates a ping reply (ICMP Echo Reply) to victim

Prevention: reject external packets to broadcast address

Modern day example (Mar ’13)

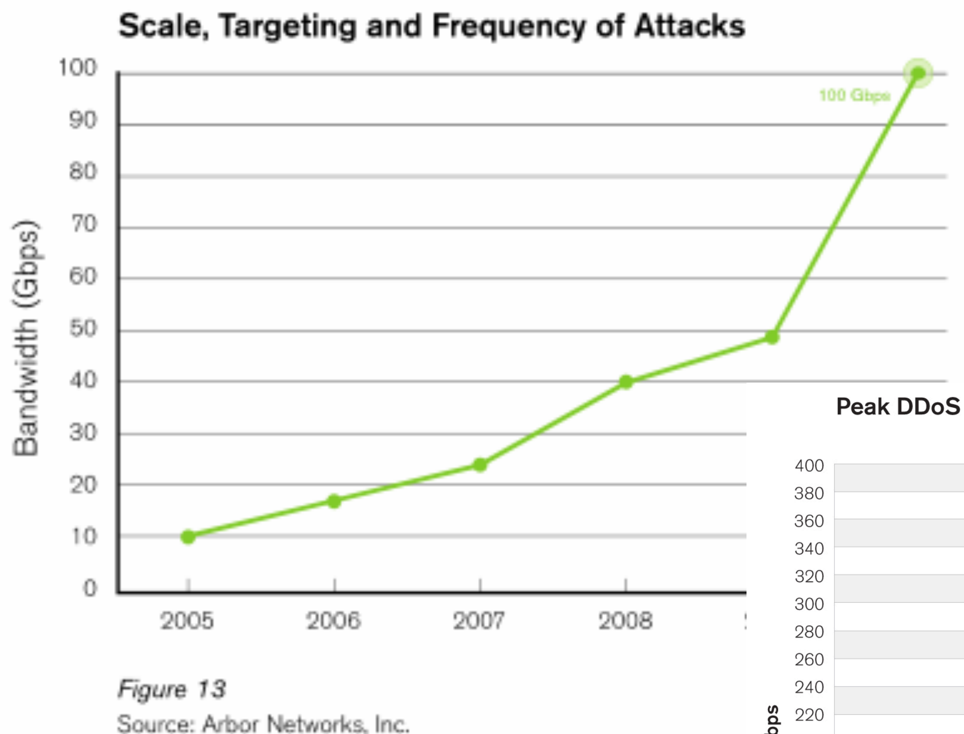
DNS Amplification attack: (×50 amplification)

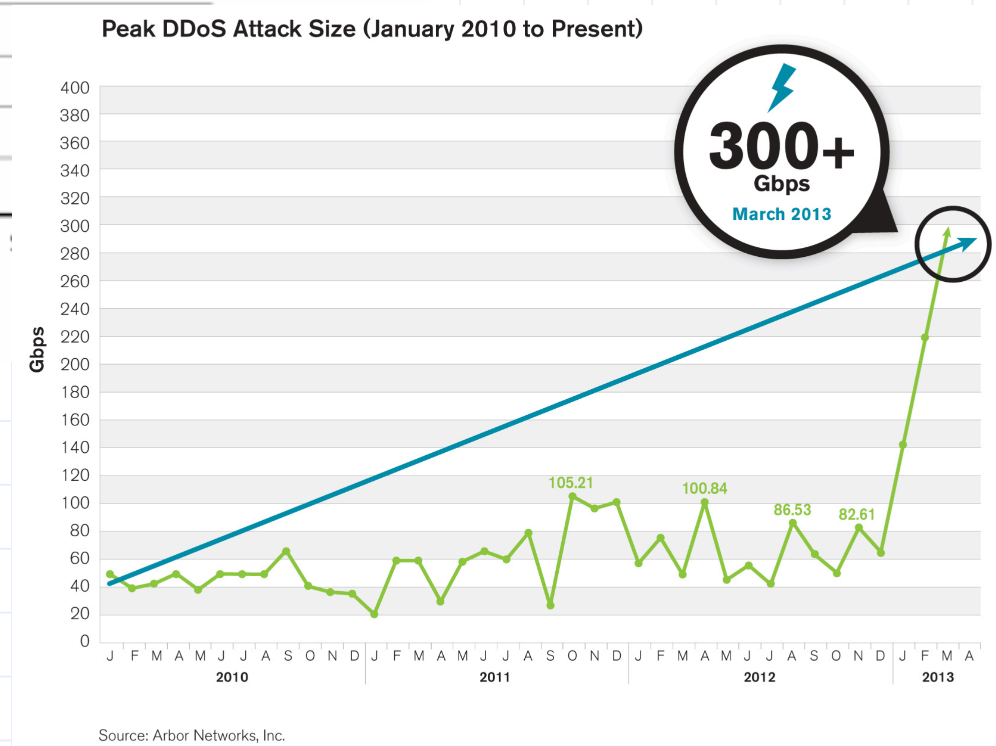


2006: 0.58M open resolvers on Internet (Kaminsky-Shiffman)

2017: 15M open resolvers (openresolverproject.org)

⇒ 3/2013: DDoS attack generating 309 Gbps for 28 mins.

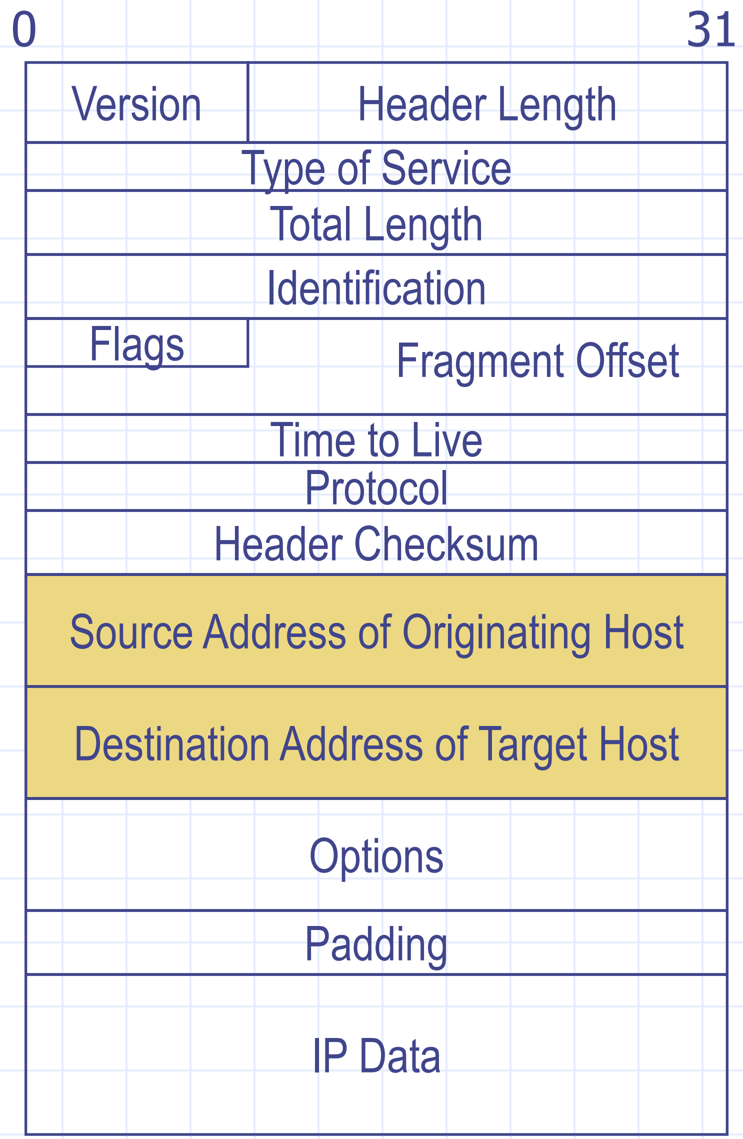




Feb. 2014: 400 Gbps via NTP amplification (4500 NTP servers)

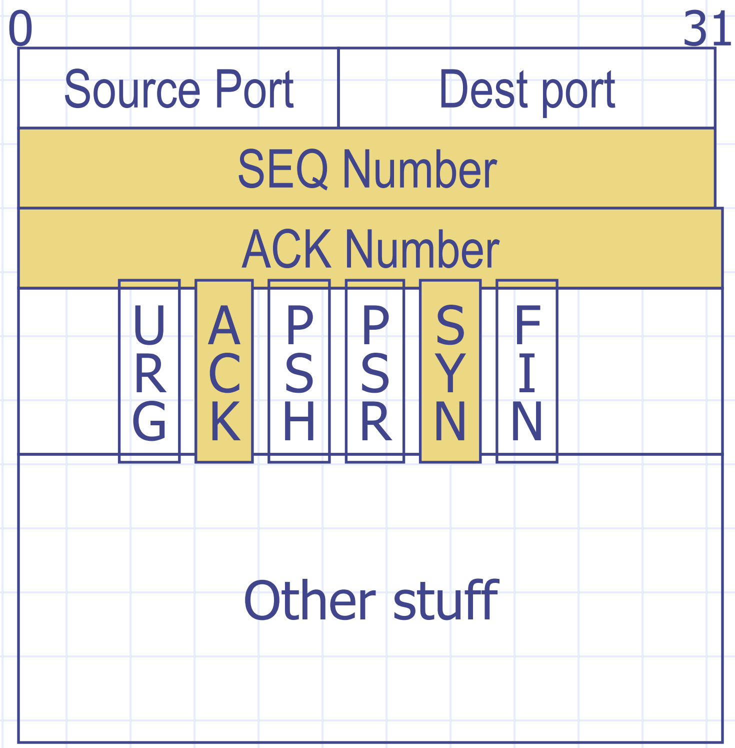
Review: IP Header format

- Connectionless
  - Unreliable
  - Best effort

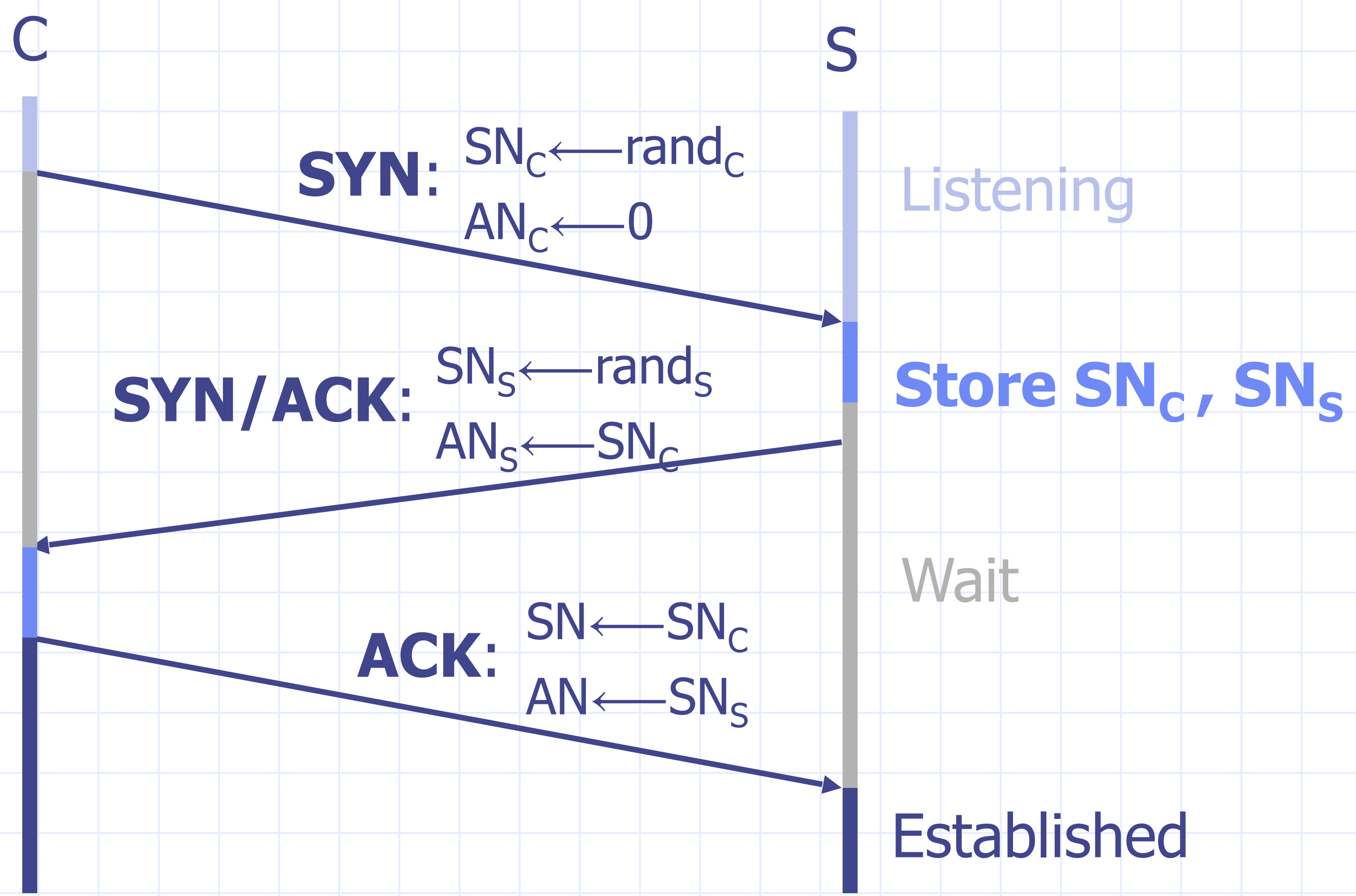


Review: TCP Header format

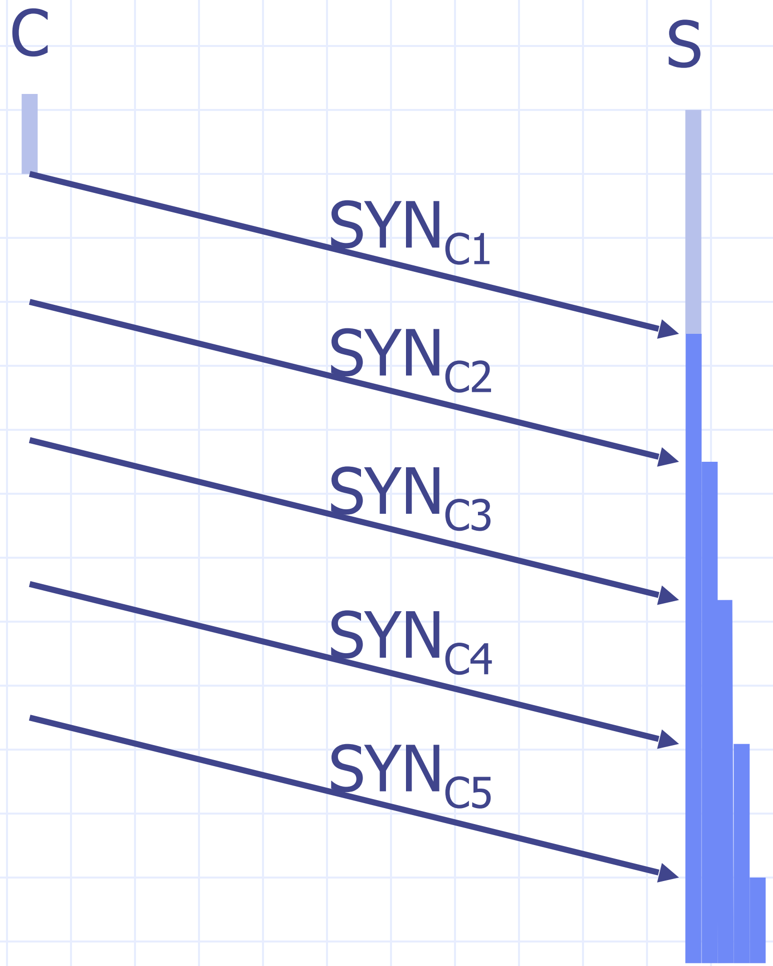
- TCP:
  - Session based
  - Congestion control
  - In order delivery



Review: TCP Handshake



TCP SYN Flood I: low rate (DoS bug)



Single machine:

- SYN Packets with **random source IP addresses**
- Fills up backlog queue on server
- No further connections possible

SYN Floods (phrack 48, no 13, 1996)

OS	Backlog queue size
Linux 1.2.x	10
FreeBSD 2.1.5	128
WinNT 4.0	6

Backlog timeout: 3 minutes

- Attacker needs only 128 SYN packets every 3 minutes
- Low rate SYN flood

Low rate SYN flood defenses

The problem:

- server commits resources (memory) before client responds

Non-solution:

- Increase backlog queue size or decrease timeout

Correct solution (when under attack) :

- **Syncookies**: remove state from server
- Small performance overhead

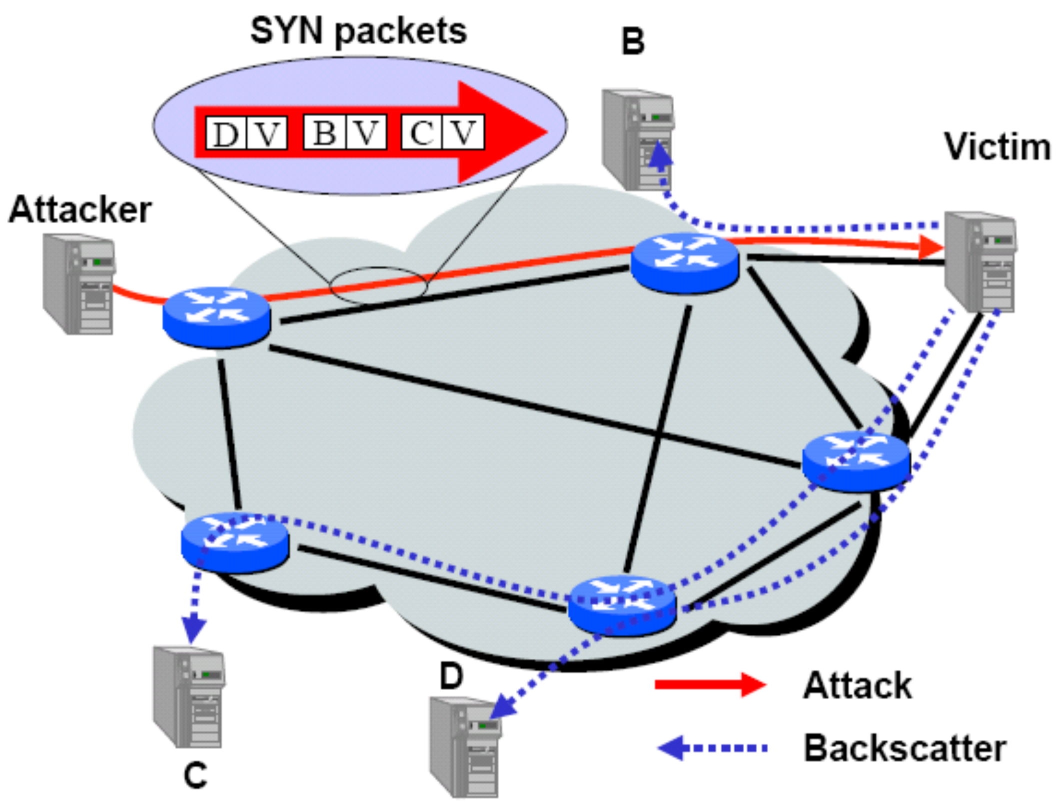
Syncookies

[Bernstein, Schenk]

- Idea: use secret key and data in packet to gen. server SN
- Server responds to Client with SYN-ACK cookie:
  - T = 5-bit counter incremented every 64 secs.
  - $L = MAC_{key}$ (SAddr, SPort, DAddr, DPort, SN_C, T) [24 bits]
    - key: picked at random during boot
  - SN_S = (T . mss . L) (|L| = 24 bits)
  - **Server does not save state** (other TCP options are lost)
- Honest client responds with ACK ($AN=SN_S$, $SN=SN_C+1$)
  - Server allocates space for socket only if valid SN_S

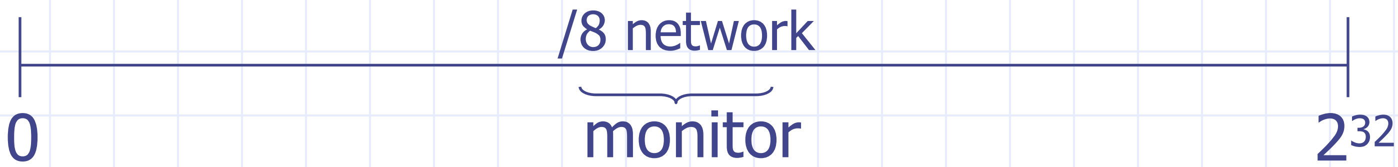
SYN floods: backscatter [MVS'01]

- SYN with forged source IP $\Rightarrow$ SYN/ACK to random host



Backscatter measurement

- Listen to unused IP addresss space (darknet)



- Lonely SYN/ACK packet likely to be result of SYN attack

- 2001: **400** SYN attacks/week
- 2013: **773** SYN attacks/24 hours (arbor networks ATLAS)

  - Larger experiments: (monitor many ISP darknets)
    - Arbor networks

Estonia attack (ATLAS '07)

- Attack types detected:
  - 115 ICMP floods, 4 TCP SYN floods
- Bandwidth:
  - 12 attacks: **70-95 Mbps for over 10 hours**
- All attack traffic was coming from outside Estonia
  - Estonia's solution:
    - Estonian ISPs blocked all foreign traffic until attacks stopped

      ⇒ DoS attack had little impact inside Estonia

Massive floods (e.g. Mirai 9/2016 on Krebs)

Command bot army to flood specific target: (DDoS)

- Flood with SYN, ACK, UDP, and GRE packets
- 623 Gbps (peak) from ≈100K compromised IoT devices
- At web site:
  - Saturates network uplink or network router
  - Random source IP ⇒

    attack SYNs look the same as real SYNs
- What to do ???

Country	% of Mirai botnet IPs
Vietnam	12.8%
Brazil	11.8%
United States	10.9%
China	8.8%
Mexico	8.4%
South Korea	6.2%
Taiwan	4.9%
Russia	4.0%
Romania	2.3%
Colombia	1.5%

Figure 3: Top countries of origin of Mirai DDoS attacks

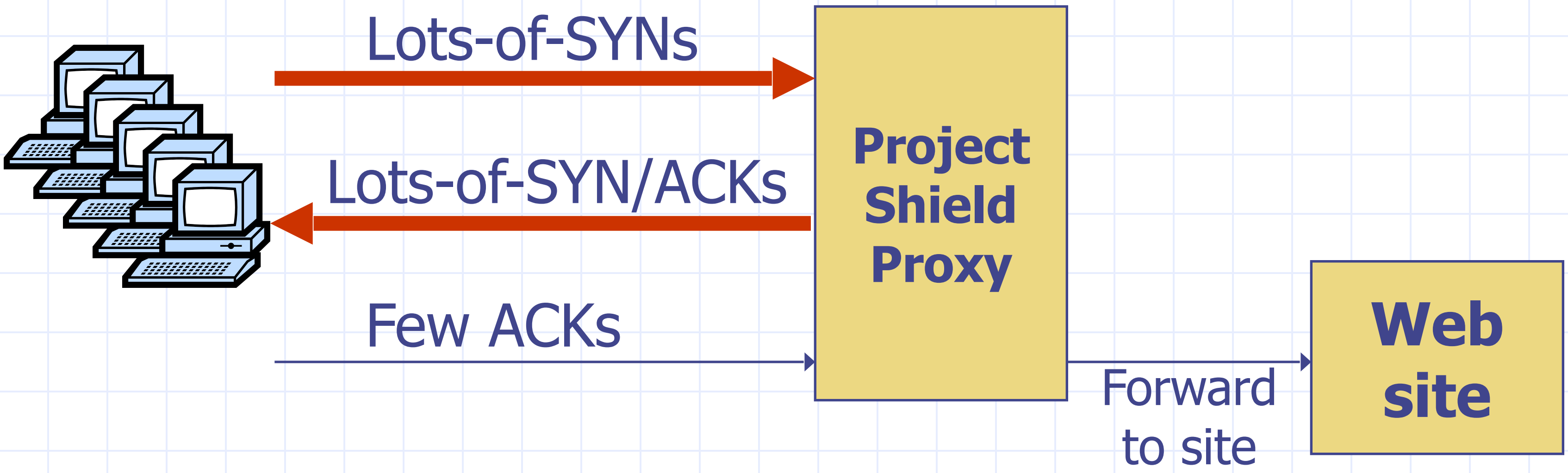
src: incapsula.com

Google project shield

Protecting news organizations.

(Commercial service: Akamai, Cloudlare, …)

Idea: only forward established TCP connections to site

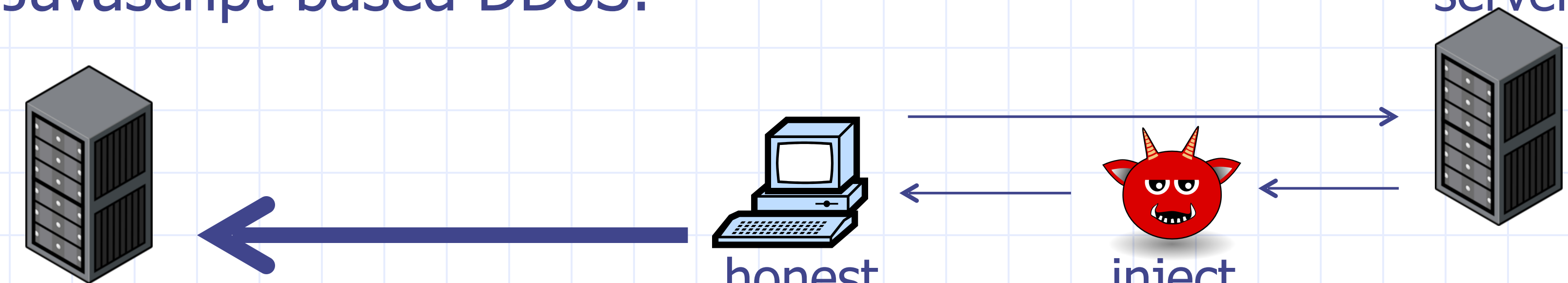


Stronger attacks: GET flood

- Command bot army to:
  - Complete TCP connection to web site
  - Send short HTTP GET request
  - Repeat
- Will bypass SYN flood protection proxy
- … but:
  - Attacker can no longer use random source IPs.
    - Reveals location of bot zombies
  - Proxy can now block or rate-limit bots.

A real-world example: GitHub (3/2015)

Javascript-based DDoS:



imageFlood.js

```
function imgflood() {
  var TARGET = 'victim-website.com/index.php?'
  var rand = Math.floor(Math.random() * 1000)
  var pic = new Image()
  pic.src = 'http://'+TARGET+rand+'=val'
}
setInterval(imgflood, 10)
```

Would HTTPS
prevent this DDoS?

DNS DoS Attacks (e.g. Dyn attack 10/2016)

DNS runs on UDP port 53

- DNS entry for victim.com hosted at DNSProvider.com

DDoS attack:

- flood DNSProvider.com with DNS queries
- **Random source IP address** in UDP packets
- Takes out entire DNS server (collateral damage)

Dyn attack: used some Mirai-based bots

- At least 100,000 malicious end points

$\Rightarrow$ Dyn cannot answer many legit DNS queries

$\Rightarrow$ Disrupted service at Netflix, Github, Twitter, …

DoS via route hijacking

- YouTube is 208.65.152.0/**22** (includes 2^{10} IP addr)

  youtube.com is 208.65.153.238, …

- Feb. 2008:
  - Pakistan telecom advertised a BGP path for

    208.65.153.0/**24** (includes 2^8 IP addr)
  - Routing decisions use most specific prefix
  - The entire Internet now thinks

    208.65.153.238 is in Pakistan

- Outage resolved within two hours

  … but demonstrates huge DoS vuln. with no solution!

DoS Mitigation

1. Client puzzles

- Idea: slow down attacker

- <u>Moderately hard problem</u>:
  - Given challenge C find X such that

$$LSB_n\big(\,SHA\text{-}1(\;C \;\|\; X\;)\,\big) = 0^n$$

  - Assumption: takes expected 2^n time to solve
  - For n=16 takes about .3sec on 1GhZ machine
  - Main point: checking puzzle solution is easy.

- <u>During DoS attack</u>:
  - Everyone must submit puzzle solution with requests
  - When no attack: do not require puzzle solution

Examples

- GET floods (RSA '99)
  - Example challenge: C = TCP server-seq-num
  - First data packet must contain puzzle solution
    - Otherwise TCP connection is closed

- SSL handshake DoS: (SD'03)
  - Challenge C based on TLS session ID
  - Server: check puzzle solution before RSA decrypt.

Benefits and limitations

- Hardness of challenge: n
  - Decided based on DoS attack volume.
- Limitations:
  - Requires changes to both clients and servers
  - Hurts low power legitimate clients during attack:
    - Clients on cell phones and tablets cannot connect

Memory-bound functions

- CPU power ratio:
  - high end server / low-end IoT device = 8000

    $\Rightarrow$ Impossible to scale to hard puzzles

- <u>Interesting observation</u>:
  - Main memory access time ratio:
    - high end server / low-end IoT device = 2

- <u>Better puzzles</u>:
  - Solution requires many main memory accesses
    - Dwork-Goldberg-Naor, Crypto '03
    - Abadi-Burrows-Manasse-Wobber, ACM ToIT '05

2. CAPTCHAs

- Idea: verify that connection is from a human

- Applies to application layer DDoS [Killbots '05]
  - During attack: generate CAPTCHAs and process request only if valid solution
  - Present one CAPTCHA per source IP address.

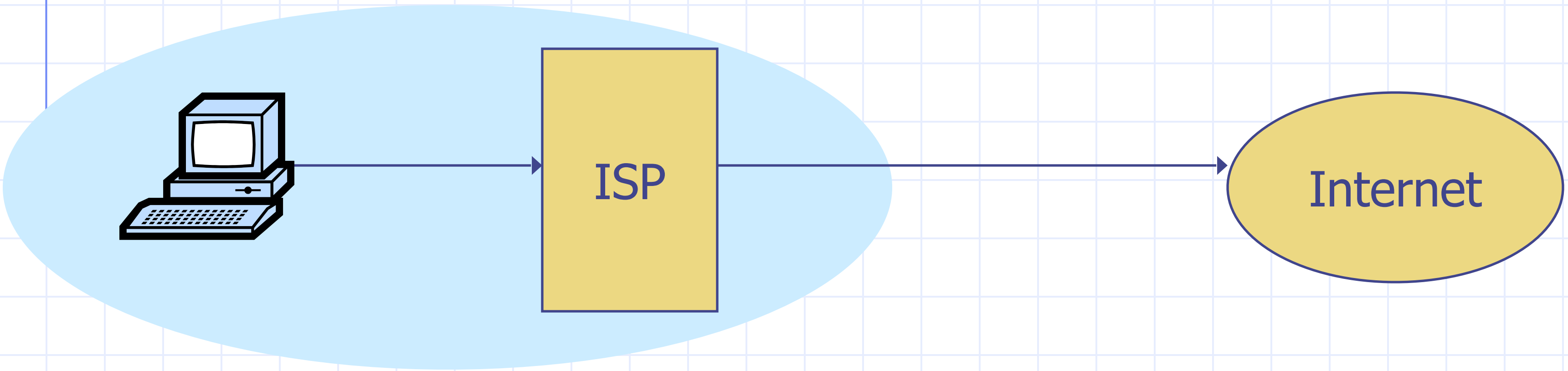
3. Source identification

Goal: identify packet source

Ultimate goal: block attack at the source

1. Ingress filtering (RFC 2827, 3704)

- Big problem: DDoS with spoofed source IPs



- Ingress filtering policy: ISP only forwards packets with legitimate source IP (see also SAVE protocol)

Implementation problems

ALL ISPs must do this. Requires global trust.

- If 10% of ISPs do not implement $\Rightarrow$ no defense
- No incentive for deployment

2017:

- 33% of Auto. Systems are fully spoofable
  (spoofer.caida.org)
- 23% of announced IP address space is spoofable

Recall: 309 Gbps attack used only 3 networks (3/2013)

2. Traceback [Savage et al. '00]

- Goal:
  - Given set of attack packets
  - Determine path to source

- How: change routers to record info in packets

- Assumptions:
  - Most routers remain uncompromised
  - Attacker sends many packets
  - Route from attacker to victim remains relatively stable

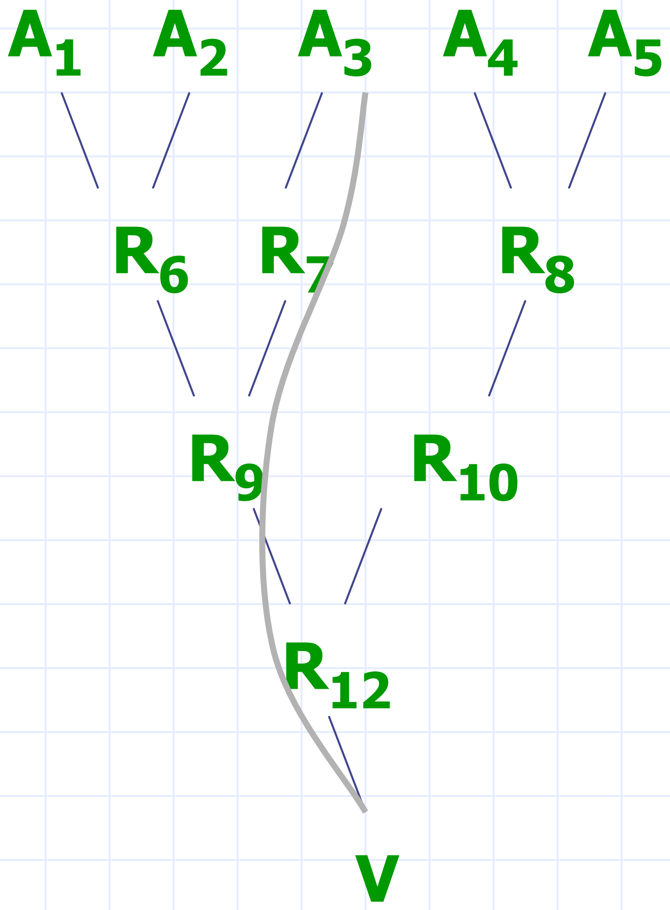
Simple method

- Write path into network packet
  - Each router adds its own IP address to packet
  - Victim reads path from packet

- Problem:
  - Requires space in packet
    - Path can be long
    - No extra fields in current IP format
      - Changes to packet format too much to expect

Better idea

- DDoS involves many packets on same path
- Store one link in each packet
  - Each router probabilistically stores own address
  - Fixed space regardless of path length



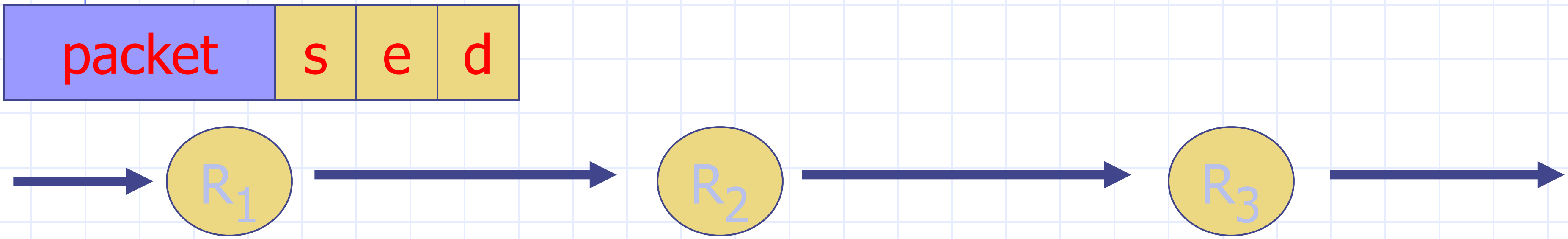
Edge Sampling

- Data fields written to packet:
  - Edge: start and end IP addresses
  - Distance: number of hops since edge stored
- Marking procedure for router R

if coin turns up heads (with probability p) then
write R into start address
write 0 into distance field
else
if distance == 0 write R into end field
increment distance field

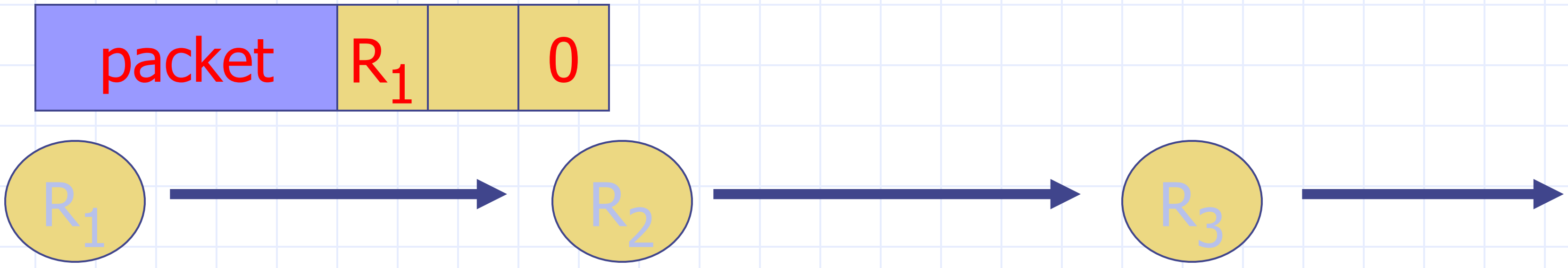
Edge Sampling: picture

- Packet received
  - R_1 receives packet from source or another router
  - Packet contains space for start, end, distance



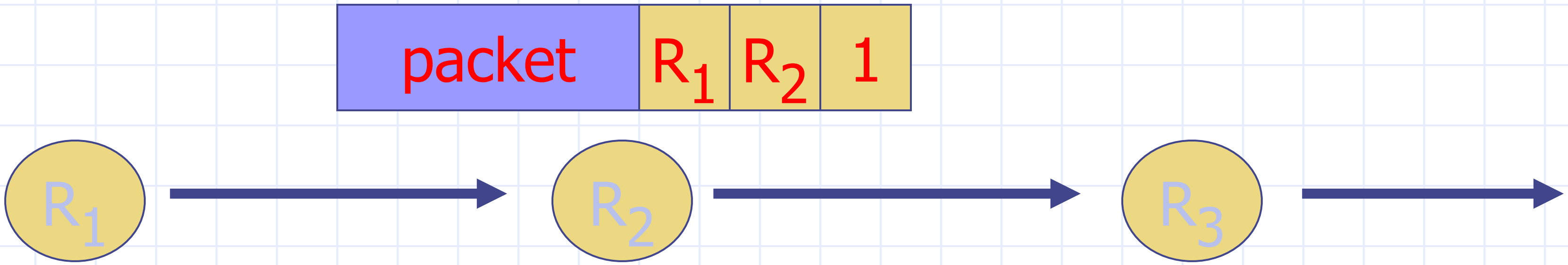
Edge Sampling: picture

- Begin writing edge
  - R_1 chooses to write start of edge
  - Sets distance to 0



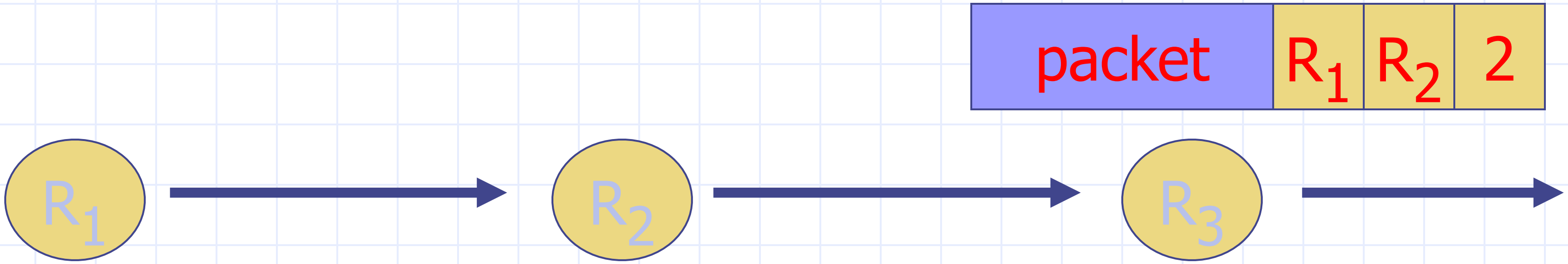
Edge Sampling

- Finish writing edge
  - R_2 chooses not to overwrite edge
  - Distance is 0
    - Write end of edge, increment distance to 1



Edge Sampling

- Increment distance
  - R_3 chooses not to overwrite edge
  - Distance >0
    - Increment distance to 2



Path reconstruction

- Extract information from attack packets
- Build graph rooted at victim
  - Each (start,end,distance) tuple provides an edge
- # packets needed to reconstruct path

$$E(X) < \frac{\ln(d)}{p(1-p)^{d-1}}$$

where p is marking probability, d is length of path

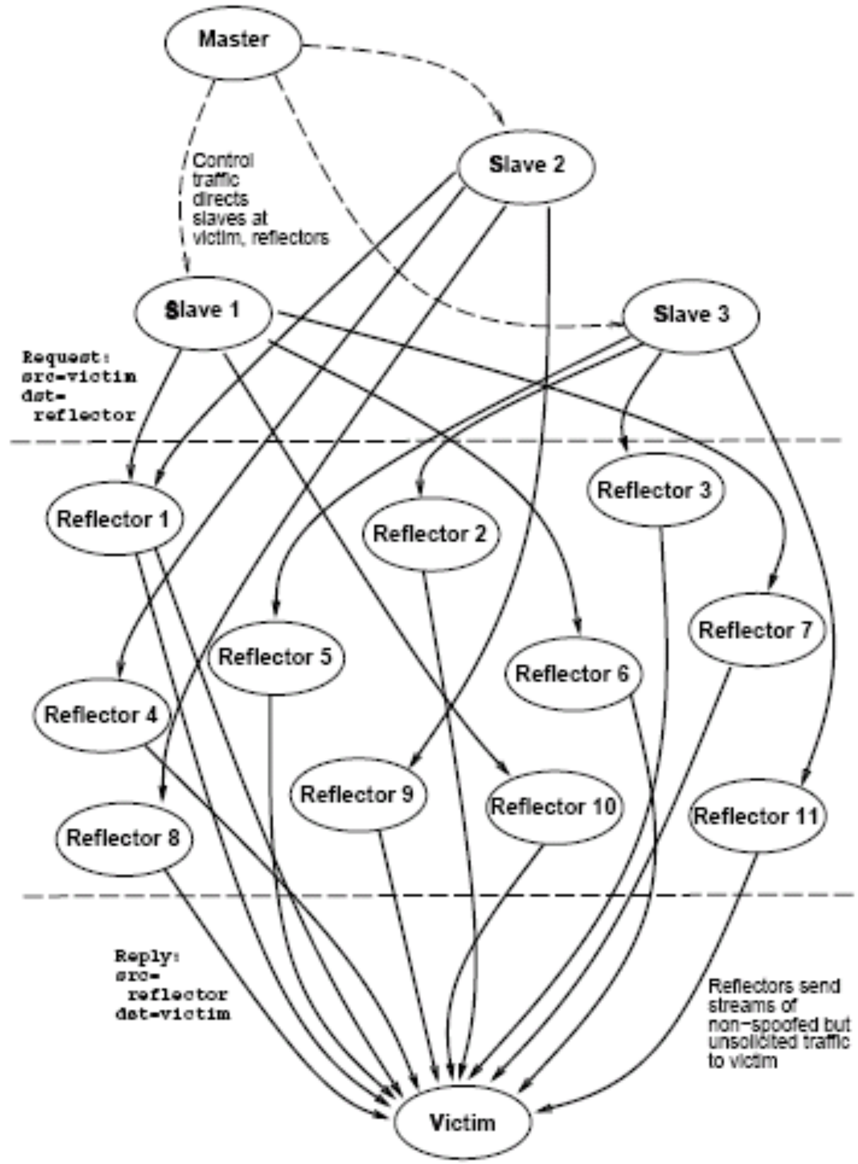
Problem: Reflector attacks [Paxson '01]

- **Reflector**:
  - A network component that responds to packets
  - Response sent to victim (spoofed source IP)

- Examples:
  - DNS Resolvers: UDP 53 with victim.com source
    - At victim: DNS response
  - Web servers: TCP SYN 80 with victim.com source
    - At victim: TCP SYN ACK packet
  - NTP servers

DoS Attack

- Single Master
- Many bots to generate flood
- Zillions of reflectors to hide bots
  - Kills traceback and pushback methods



Capability based defense

Capability based defense

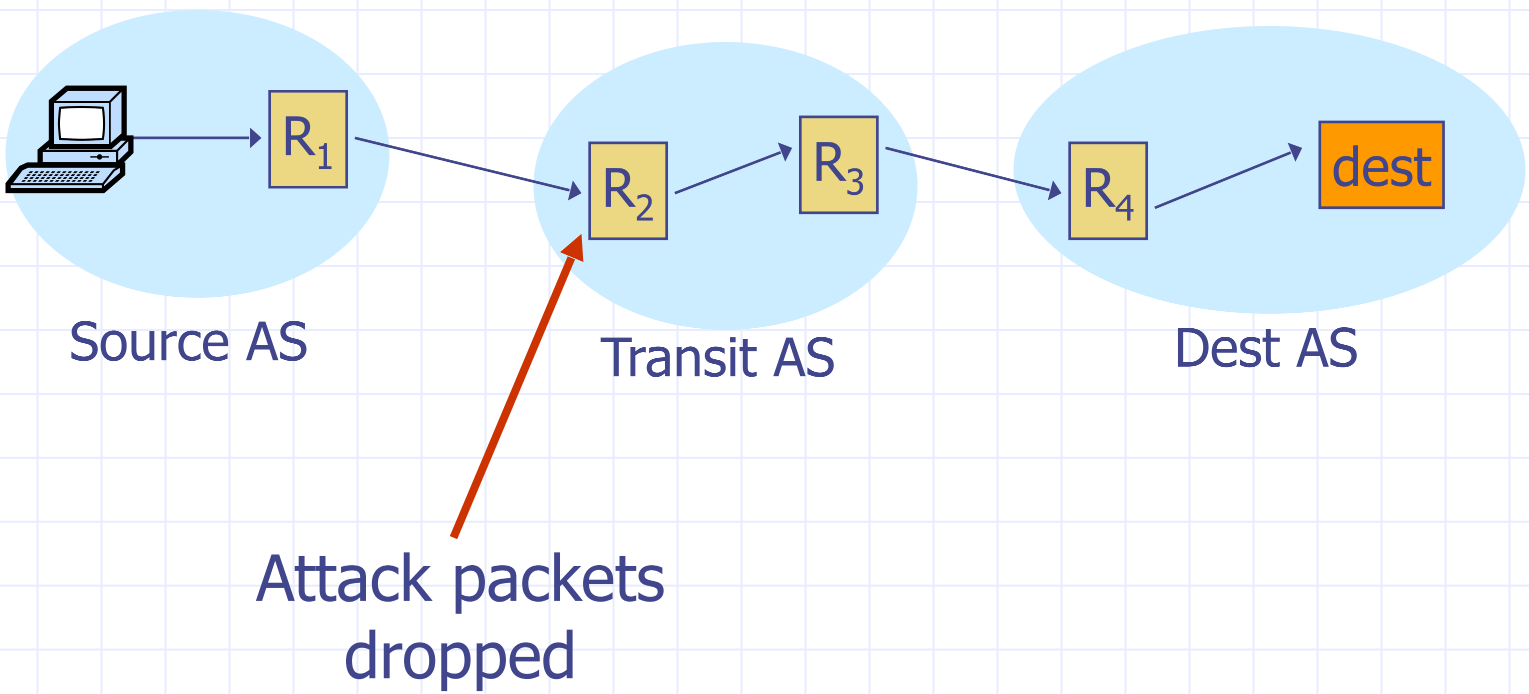
- Anderson, Roscoe, Wetherall.
  - Preventing internet denial-of-service with capabilities. SIGCOMM ‘04.
- Yaar, Perrig, and Song.
  - Siff: A stateless internet flow filter to mitigate DDoS flooding attacks. IEEE S&P ’04.
- Yang, Wetherall, Anderson.
  - A DoS-limiting network architecture. SIGCOMM ’05

Capability based defense

- Basic idea:
  - Receivers can specify what packets they want
- How:
  - Sender requests capability in SYN packet
    - Path identifier used to limit # reqs from one source
  - Receiver responds with capability
  - Sender includes capability in all future packets
  - **Main point**: Routers only forward:
    - Request packets, and
    - Packets with valid capability

Capability based defense

- Capabilities can be revoked if source is attacking
  - Blocks attack packets close to source



Take home message:

- Denial of Service attacks are real:
  Must be considered at design time
- Sad truth:
  - Internet is ill-equipped to handle DDoS attacks
  - Many commercial solutions: CloudFlare, Akamai, …
- Many proposals for core redesign

THE END