Module 8: DDoS

Denial of Service

What is network DoS?

- Goal: take down 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):
    - TCP/UDP
    - Application
  - Generic DoS solutions [brief overview]
  - Network DoS solutions

- Sad truth:
  - Current Internet not designed to handle DDoS attacks

Why bother to do a DDoS

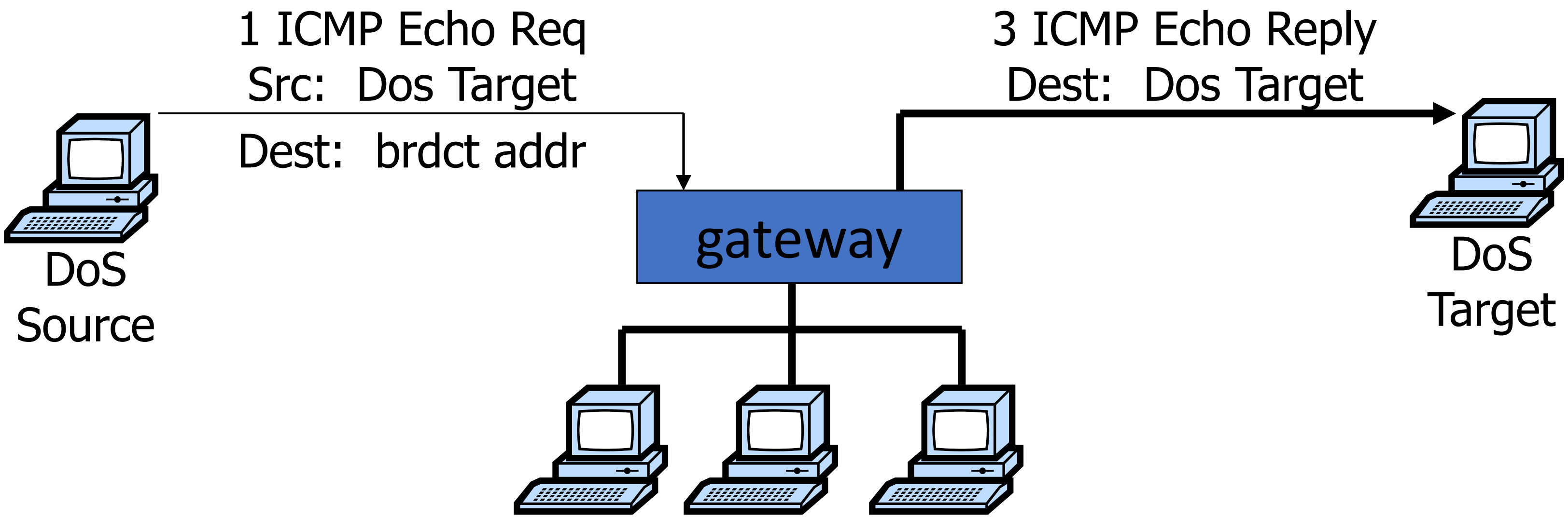
Politics

- Estonia (by Russia)
- GitHub (by China)
- Etc.

Money

- Blackmail website with DDoS threat
- Ransom in bitcoin (one thing bitcoin is good for)

Smurf amplification DoS attack

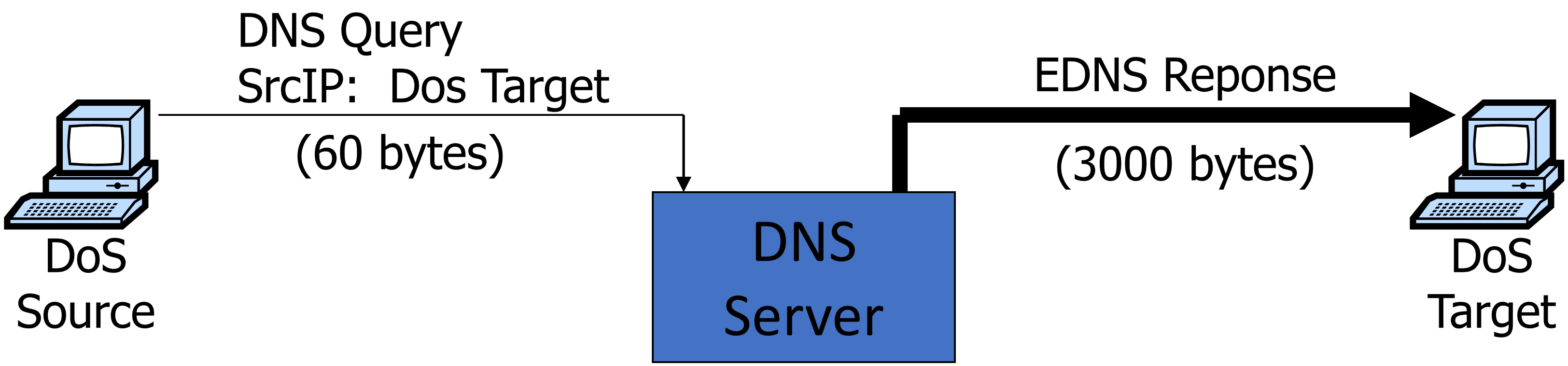


- Send ping request to broadcast addr (ICMP Echo Req)
- Lots of responses:
  - Every host on target network generates a ping reply (ICMP Echo Reply) to victim

Prevention: reject external packets to broadcast address

Modern day example (Mar ’13)

DNS Amplification attack: ($\times 50$ amplification)



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

2014: 28M open resolvers (openresolverproject.org)

$\Rightarrow$ 3/2013: DDoS attack generating 309 Gbps for 28 mins.

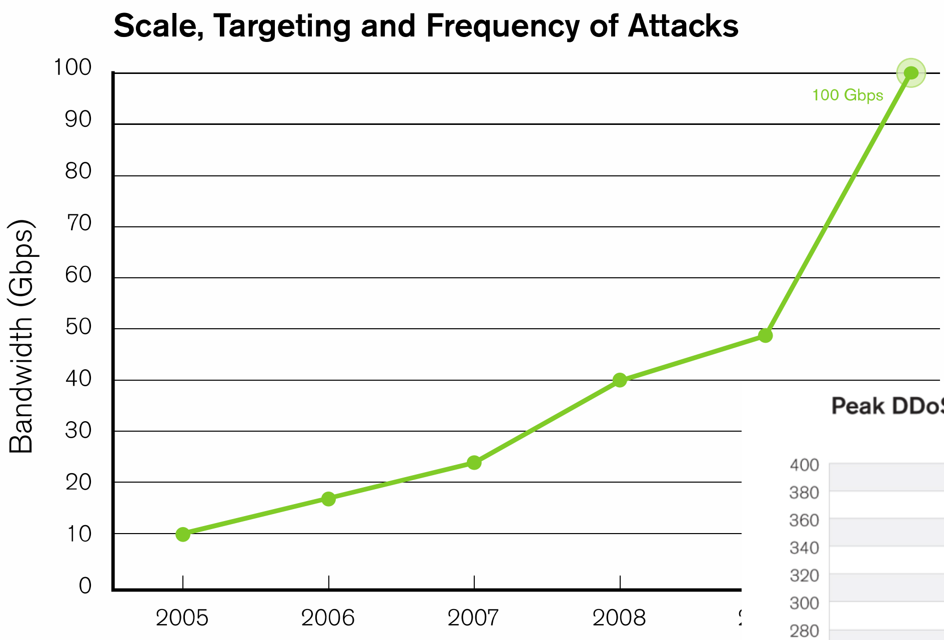
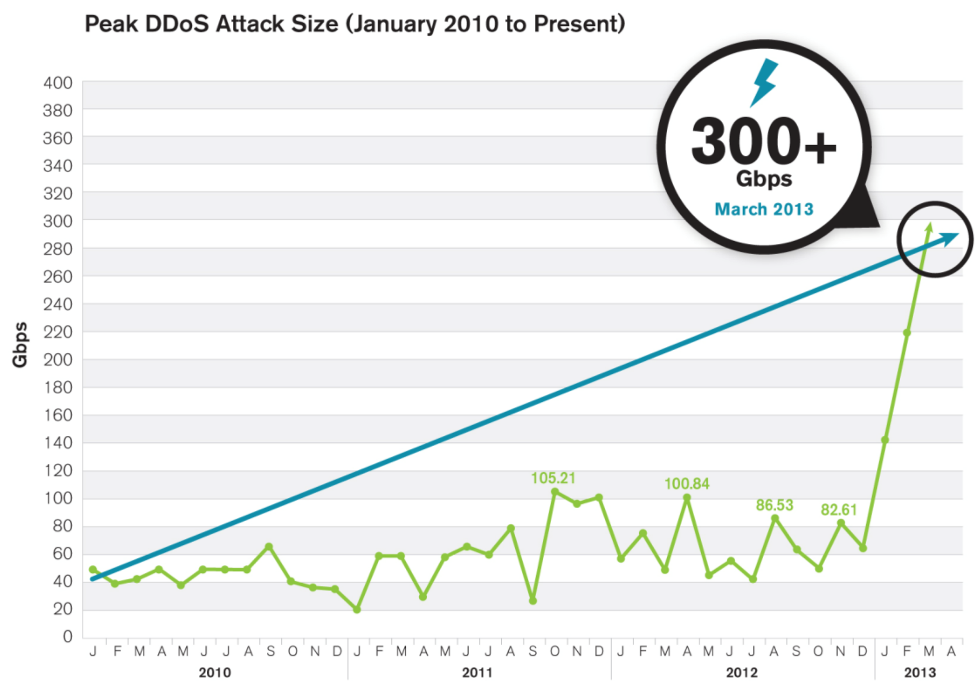


Figure 13

Source: Arbor Networks, Inc.

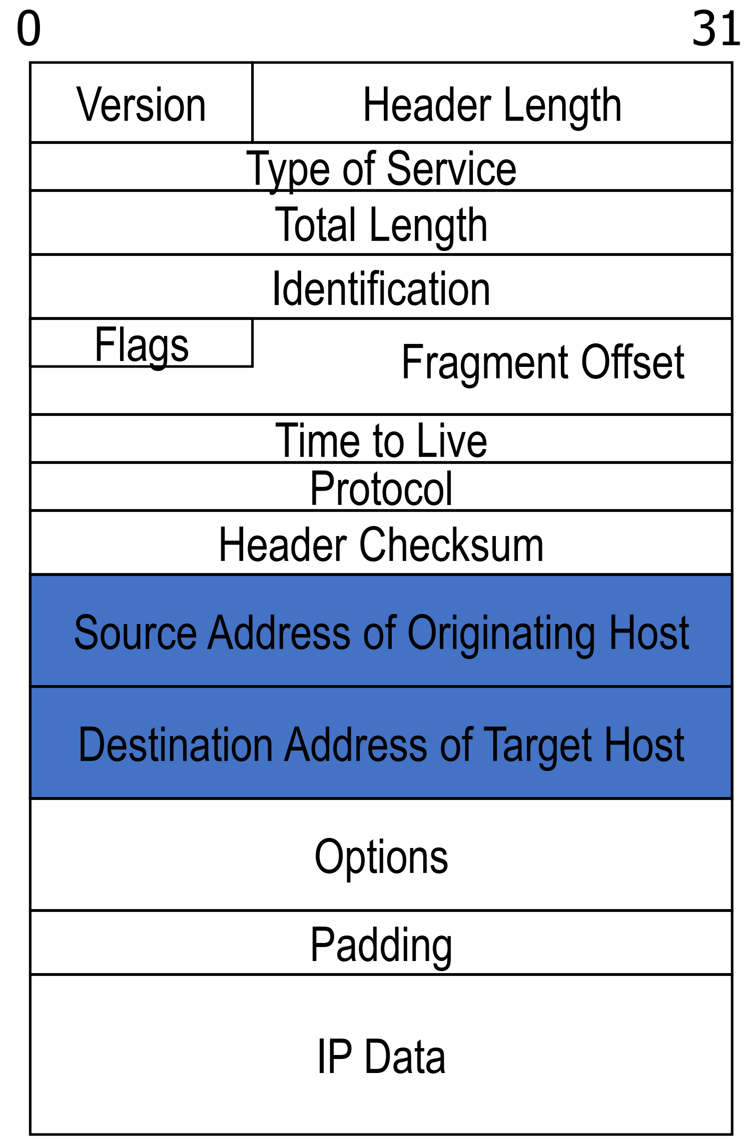


Source: Arbor Networks, Inc.

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

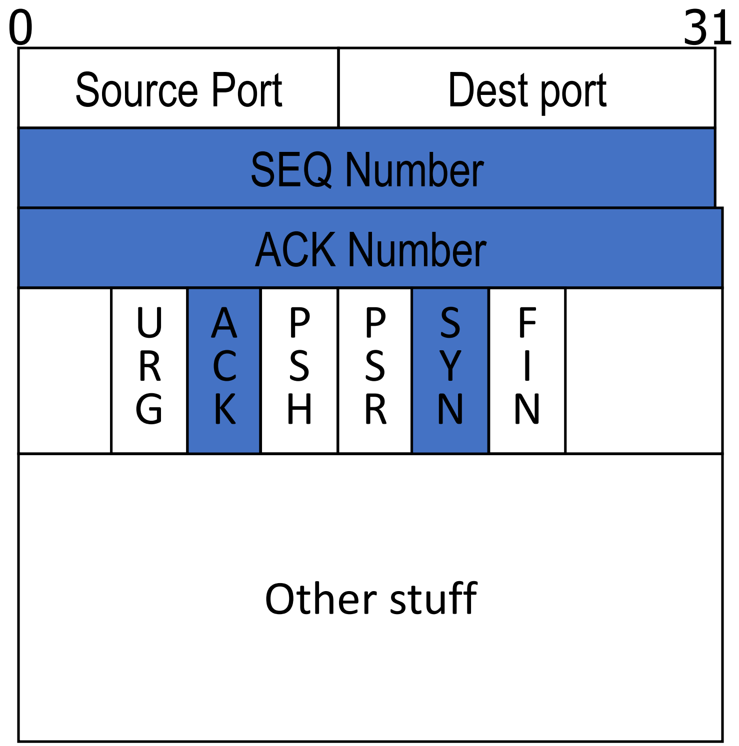
Review: IP Header format

- Connectionless
  - Unreliable
  - Best effort

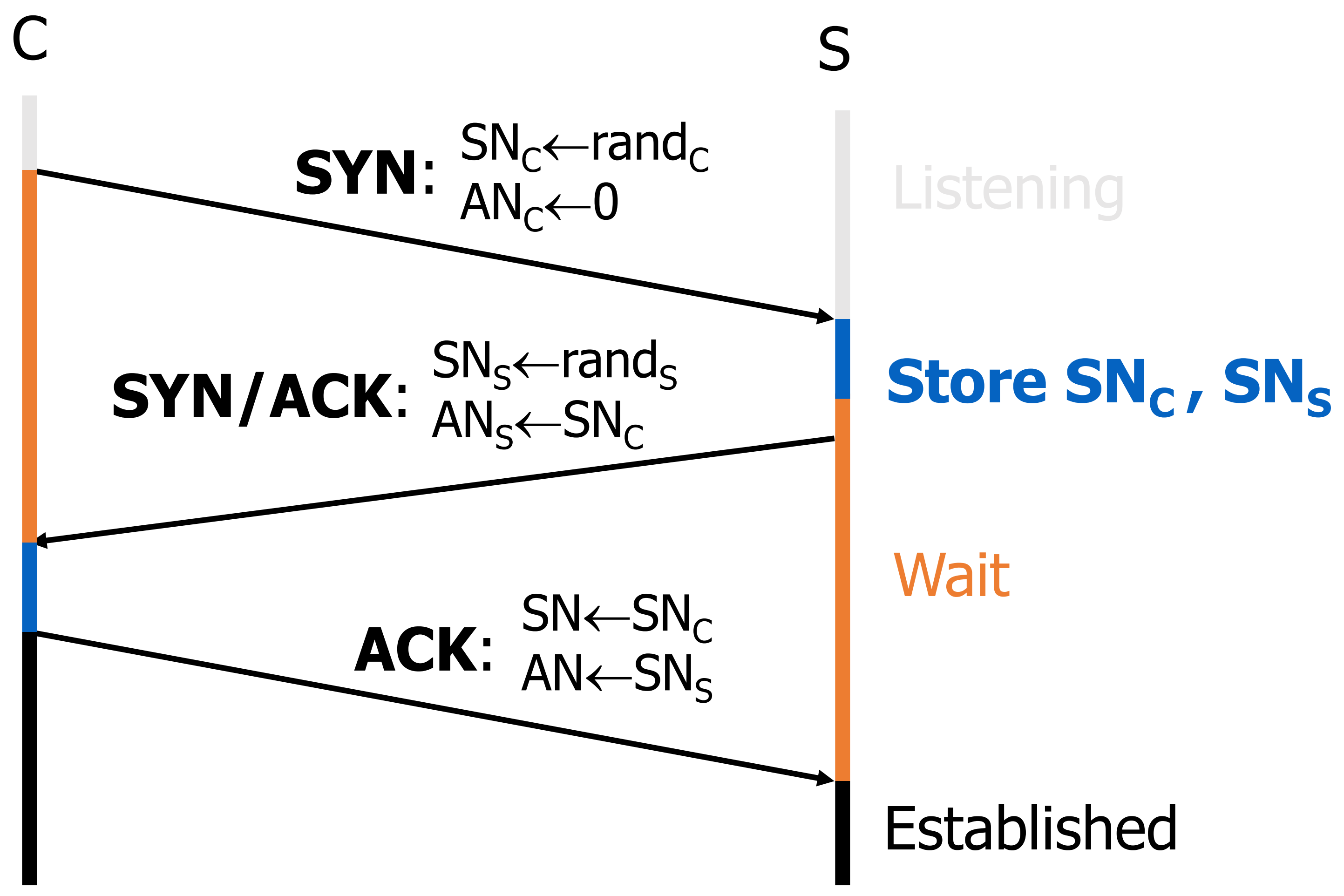


Review: TCP Header format

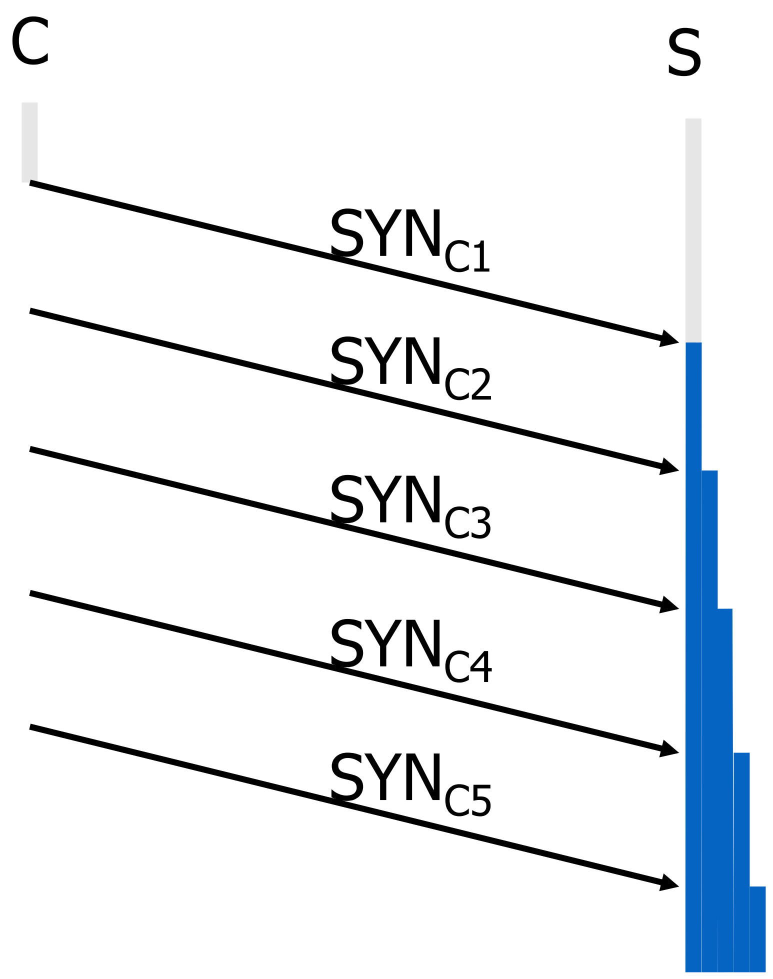
- TCP:
  - Session based
  - Congestion control
  - In order delivery



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

$\Rightarrow$ Attacker need only send 128 SYN packets every 3 minutes.

$\Rightarrow$ Low rate SYN flood

A classic SYN flood example

- MS Blaster worm   (2003)
  - Infected machines at noon on Aug 16th:
    - SYN flood on port 80 to **windowsupdate.com**
    - 50 SYN packets every second.
      - each packet is 40 bytes.
    - Spoofed source IP: a.b.X.Y where X,Y random.
- MS solution:
  - new name: windowsupdate.microsoft.com
  - Win update file delivered by Akamai

Low rate SYN flood defenses

- 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]

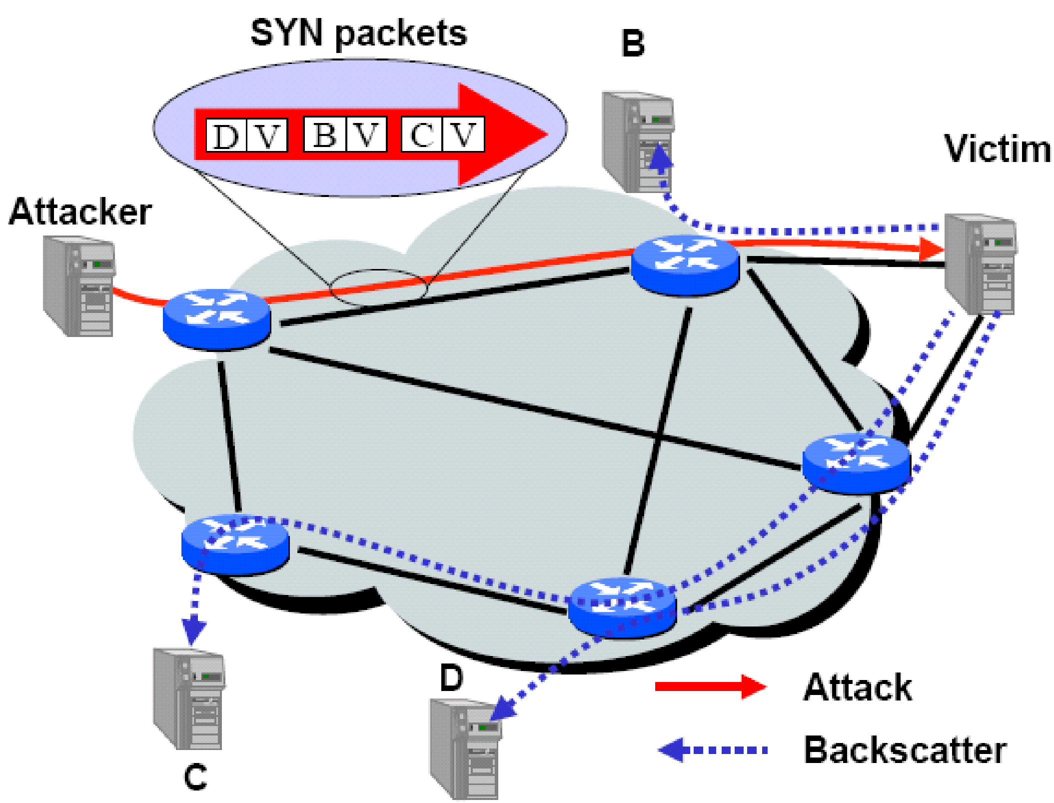
- Idea: use secret key and data in packet to gen. server SN

- 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

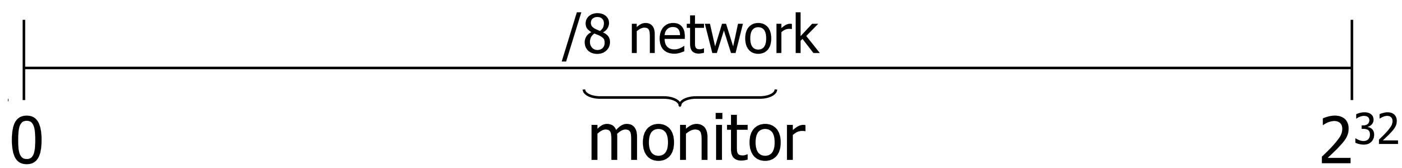
SYN floods: backscatter [MVS'01]

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



Backscatter measurement [MVS'01]

- 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

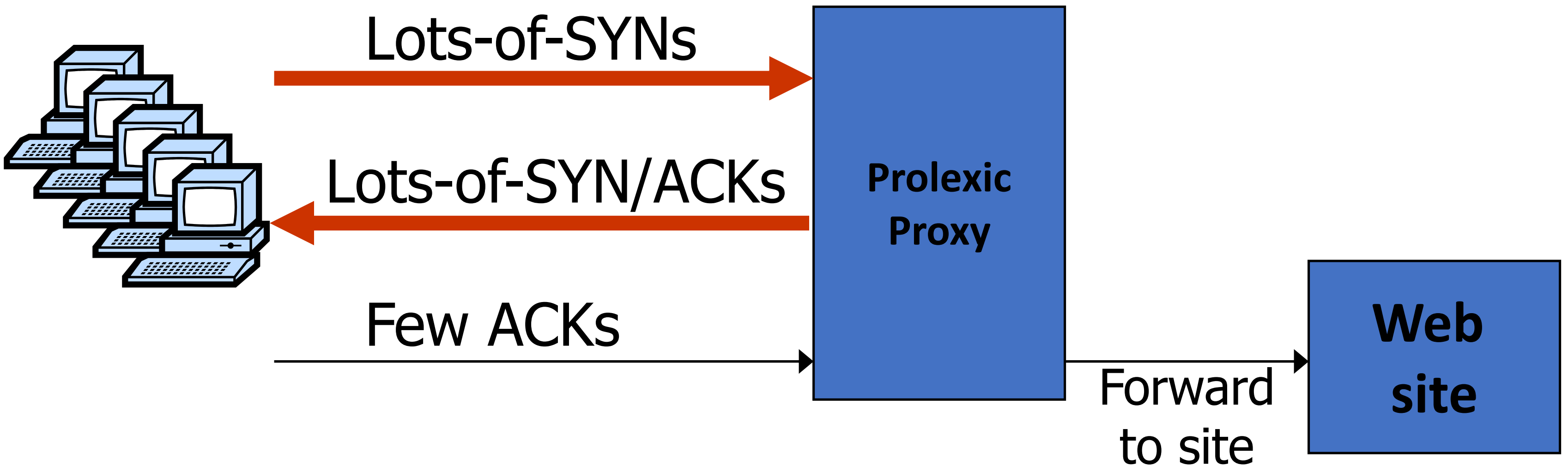
Estonia attack (ATLAS '07)

- 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: ISPs blocked all foreign traffic until attacks stopped

    => DoS attack had little impact inside Estonia

Prolexic / CloudFlare

- Idea: only forward established TCP connections to site



Other junk packets

Attack Packet	**Victim Response**	**Rate: attk/day [ATLAS 2013]**
TCP SYN to open port	TCP SYN/ACK	773
TCP SYN to closed port	TCP RST	
TCP ACK or TCP DATA	TCP RST	
TCP RST	No response	
TCP NULL	TCP RST	
ICMP ECHO Request	ICMP ECHO Response	**50**
UDP to closed port	ICMP Port unreachable	387

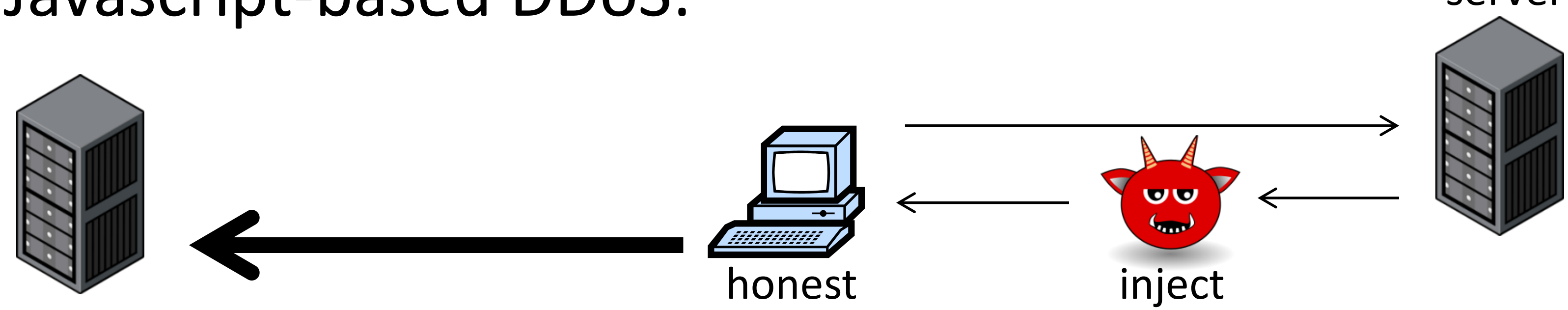
Proxy must keep floods of these away from web site

Stronger attacks: TCP con flood

- Command bot army to:
  - Complete TCP connection to web site
  - Send short HTTP HEAD 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:



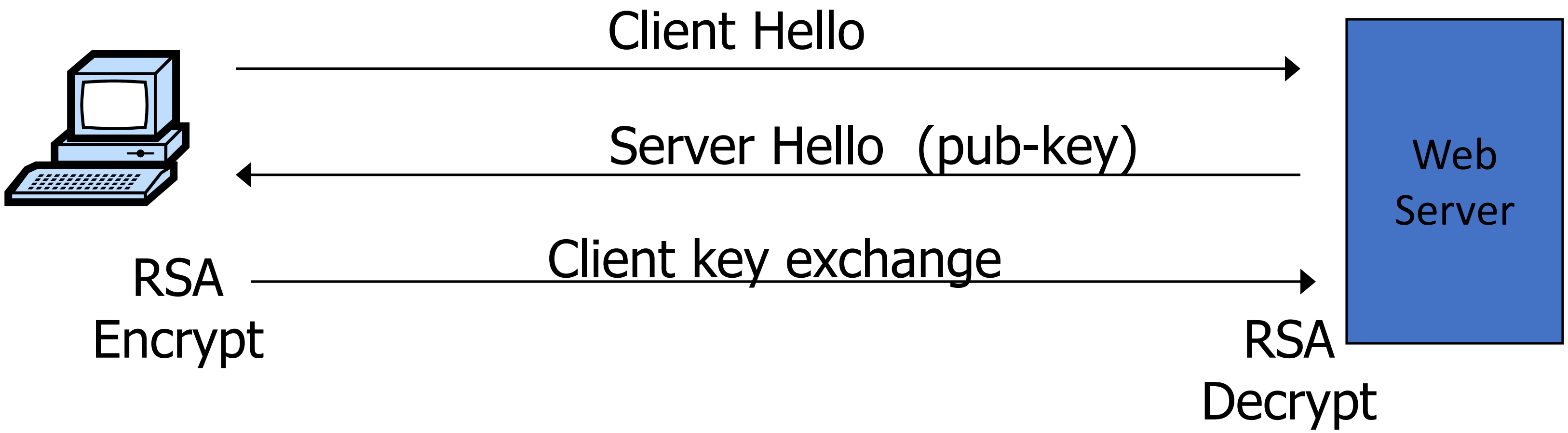
imageFlood.js

```
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?

DoS at higher layers

- SSL/TLS handshake [SD'03]



  - RSA-encrypt $\approx 10\times$ faster than RSA-decrypt

  $\Rightarrow$ Single machine can bring down ten web servers

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- Similar problem with application DoS:
  - Send HTTP request for some large PDF file

  $\Rightarrow$ Easy work for client, hard work for server.

DoS Mitigation

1. Client puzzles

- Idea: slow down attacker

- Moderately hard problem:
  - Given challenge C find X such that

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

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

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

Examples

- TCP connection 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.
- Same for application layer DoS and payment DoS.

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 cell phone = 8000

  $\Rightarrow$ Impossible to scale to hard puzzles

- Interesting observation:
  - Main memory access time ratio:
    - high end server / low end cell phone = 2

- Better puzzles:
  - 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.

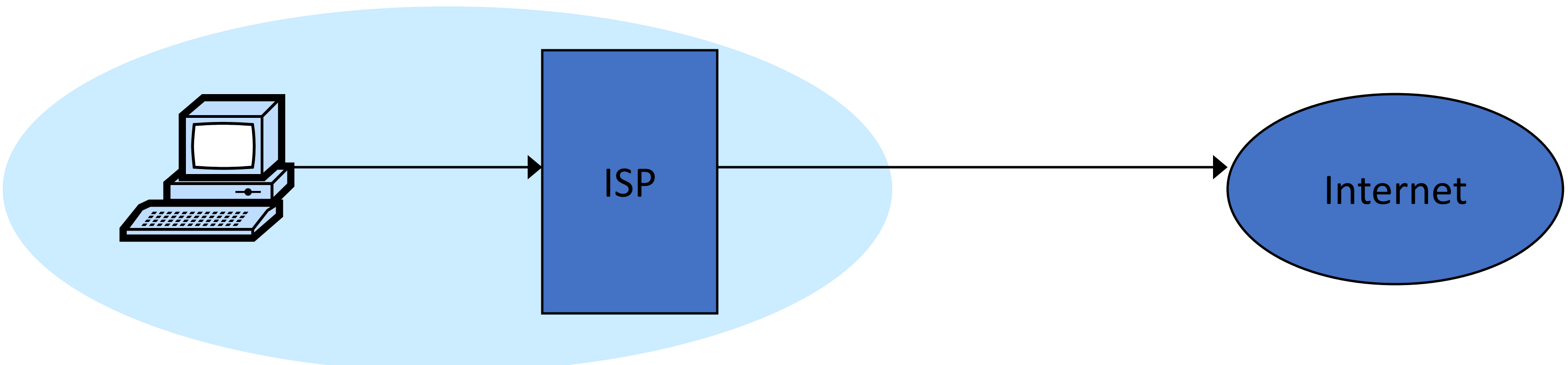
3. Source identification

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

Implementation problems

ALL ISPs must do this. Requires global trust.

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

2014:

- 23% of ASes are fully spoofable (spoofer.cmand.org)
- 16% 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

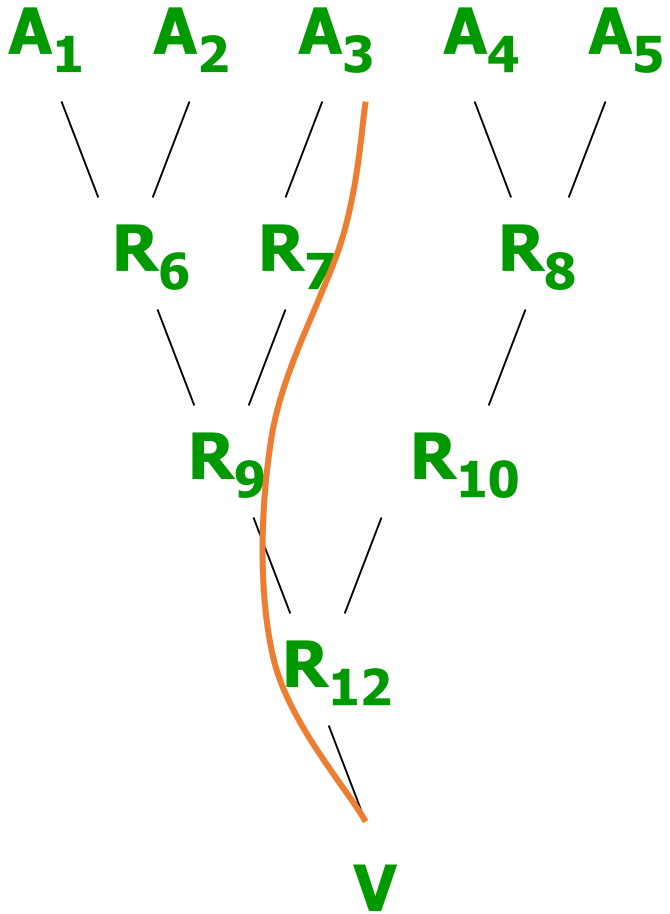
Simple method

- 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

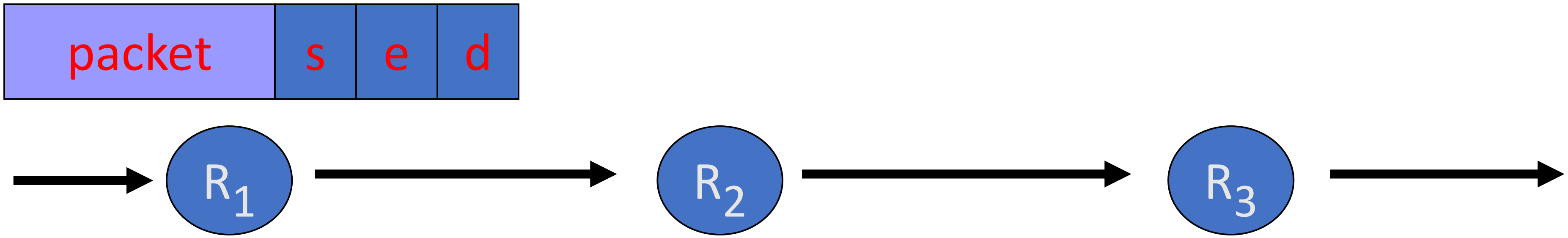
- Data fields written to packet:
  - Edge: *start* and *end* IP addresses
  - Distance: number of hops since edge stored

- 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
```

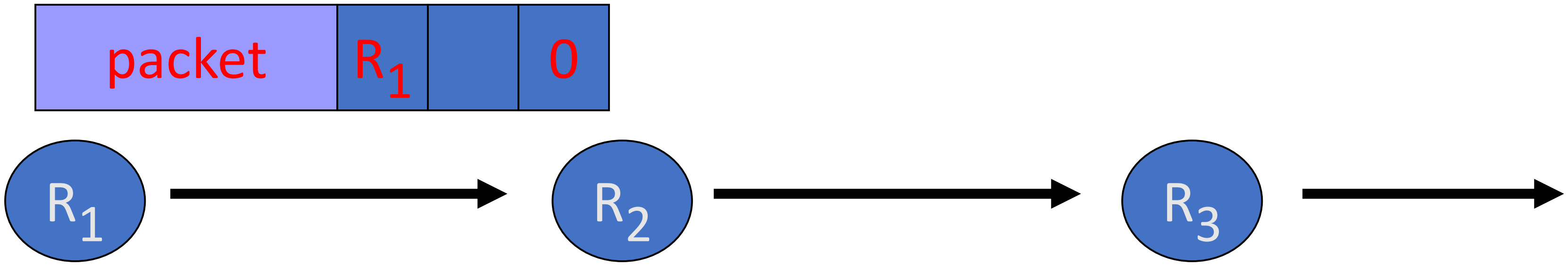
Edge Sampling: picture

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



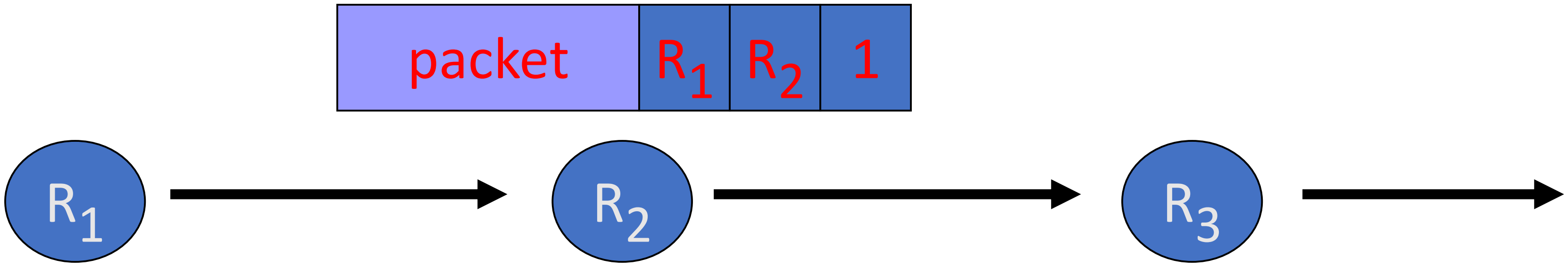
Edge Sampling: picture

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



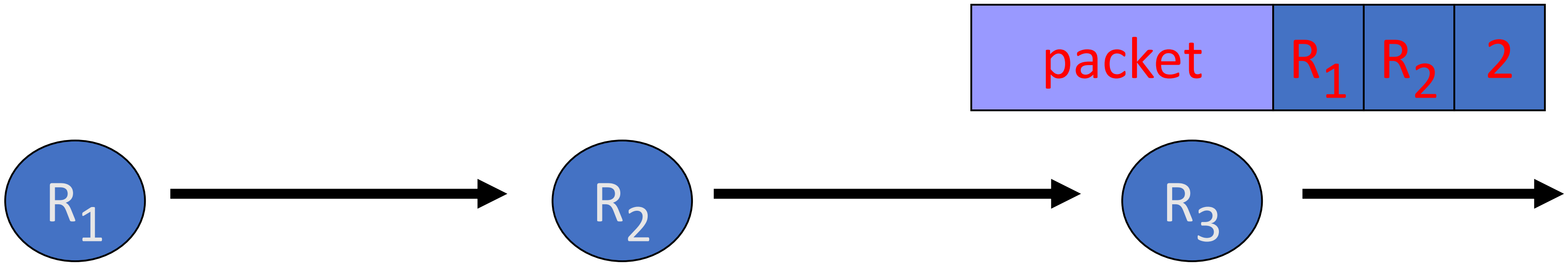
Edge Sampling

- 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

More traceback proposals

- Advanced and Authenticated Marking Schemes for IP Traceback
  - Song, Perrig.   IEEE Infocomm ’01
  - Reduces noisy data and time to reconstruct paths

- An algebraic approach to IP traceback
  - Stubblefield, Dean, Franklin.   NDSS ’02

- Hash-Based IP Traceback
  - Snoeren, Partridge, Sanchez, Jones, Tchakountio, Kent, Strayer.   SIGCOMM ‘01

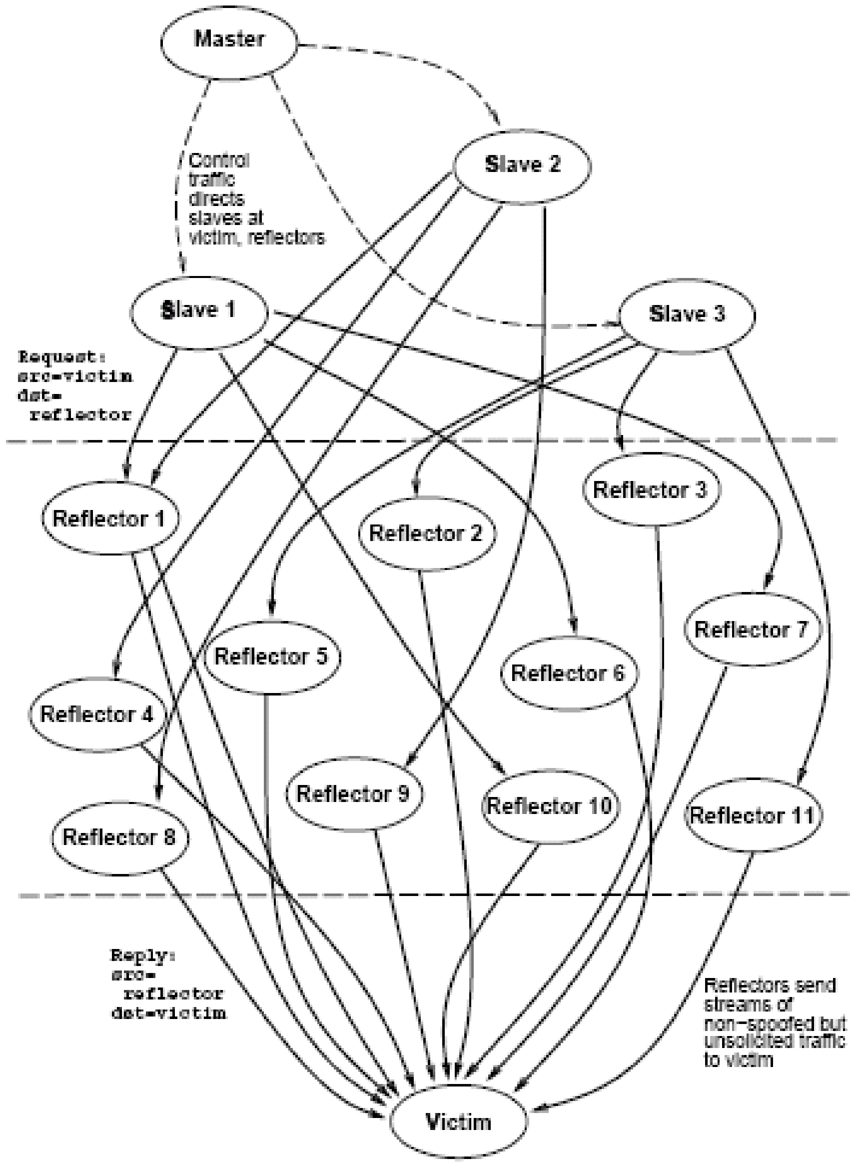
Problem: Reflector attacks [Paxson '01]

- **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
  - Gnutella 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

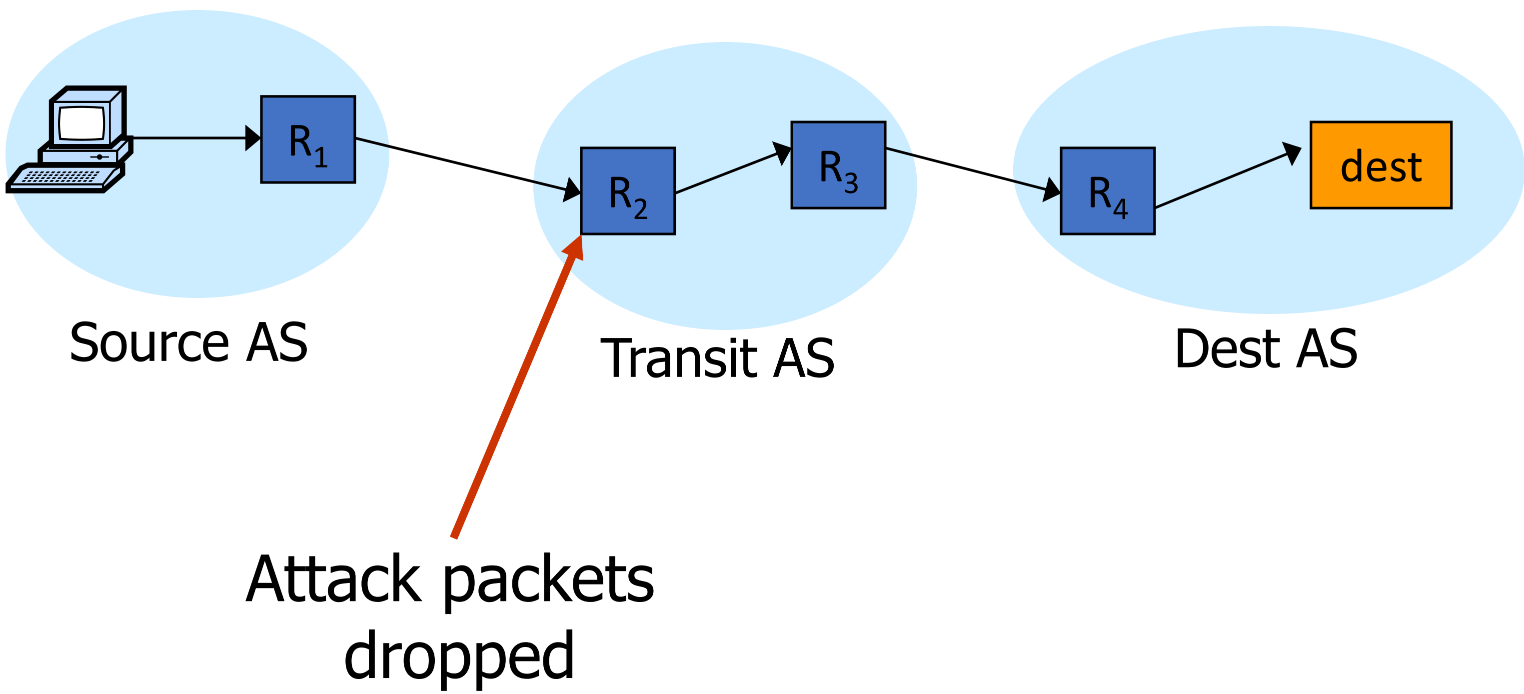
Capability based defense

- 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



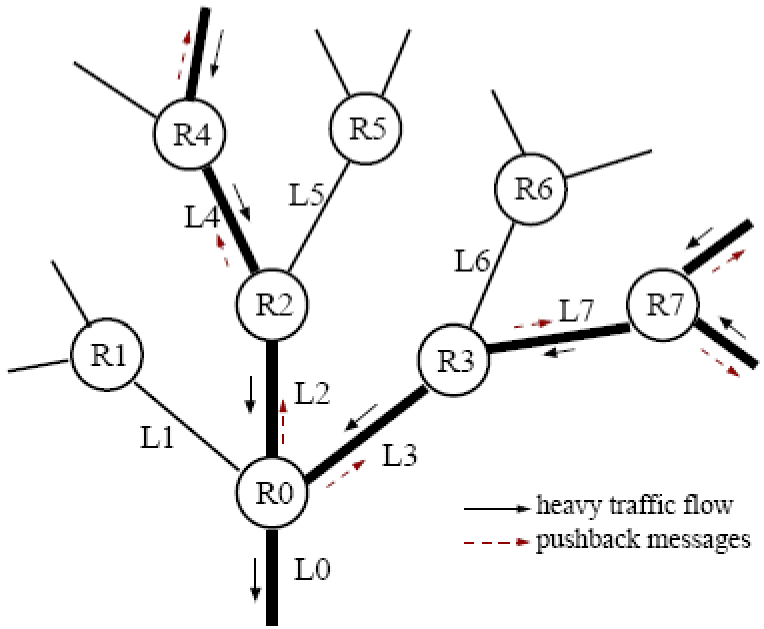
Pushback Traffic Filtering

Pushback filtering

- Mahajan, Bellovin, Floyd, Ioannidis, Paxson, Shenker. Controlling High Bandwidth Aggregates in the Network. *Computer Communications Review* ‘02.
- Ioannidis, Bellovin. Implementing Pushback: Router-Based Defense Against DoS Attacks. *NDSS* ’02
- Argyraki, Cheriton. Active Internet Traffic Filtering: Real-Time Response to Denial-of-Service Attacks. USENIX ‘05.

Pushback Traffic Filtering

- Assumption: DoS attack from few sources



- Iteratively block attacking network segments.

Overlay filtering

Overlay filtering

- Keromytis, Misra, Rubenstein.
  SOS: Secure Overlay Services. SIGCOMM ‘02.
- D. Andersen. Mayday.
  Distributed Filtering for Internet Services.
  Usenix USITS ‘03.
- Lakshminarayanan, Adkins, Perrig, Stoica.
  Taming IP Packet Flooding Attacks. HotNets ’03.

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
  - Commercial solutions: CloudFlare, Prolexic

- Many good proposals for core redesign.