Unwanted Traffic: Denial of Service Attacks

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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

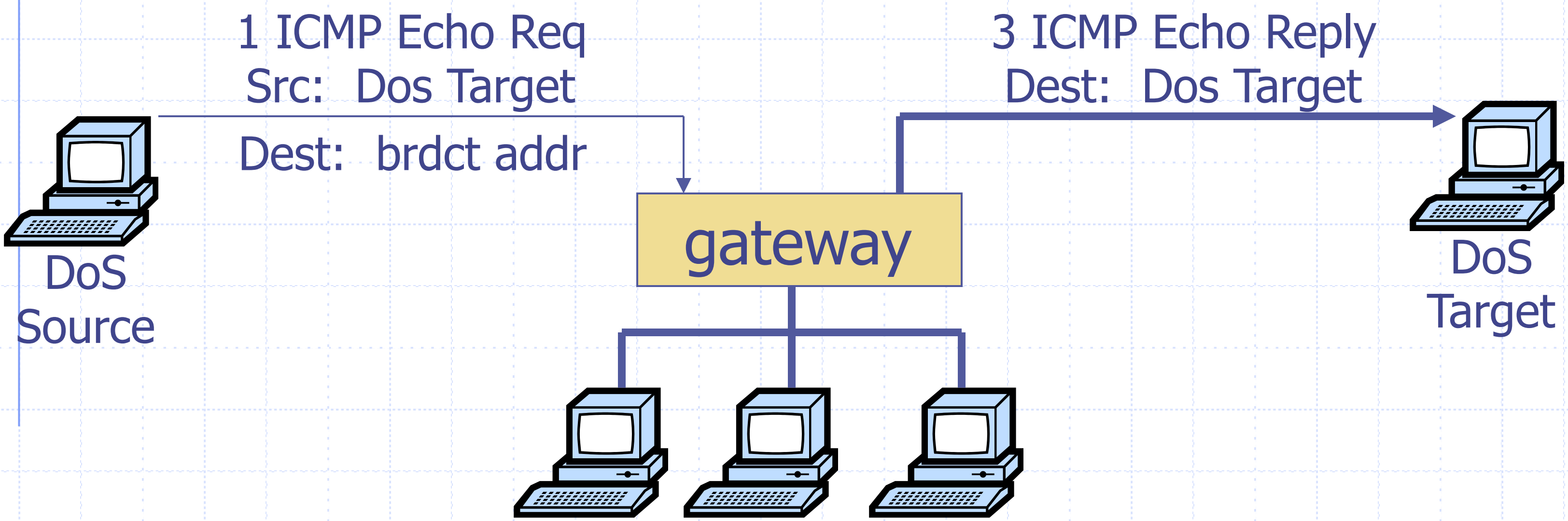
- This lecture:
  - Sample Dos at different layers (by order):
    - Link
    - TCP/UDP
    - Application
  - Generic DoS solutions
  - Network DoS solutions
- Sad truth:
  - Current Internet not designed to handle DDoS attacks

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
    - … attacker can repeatedly deauth anyone

Smurf amplification DoS attack

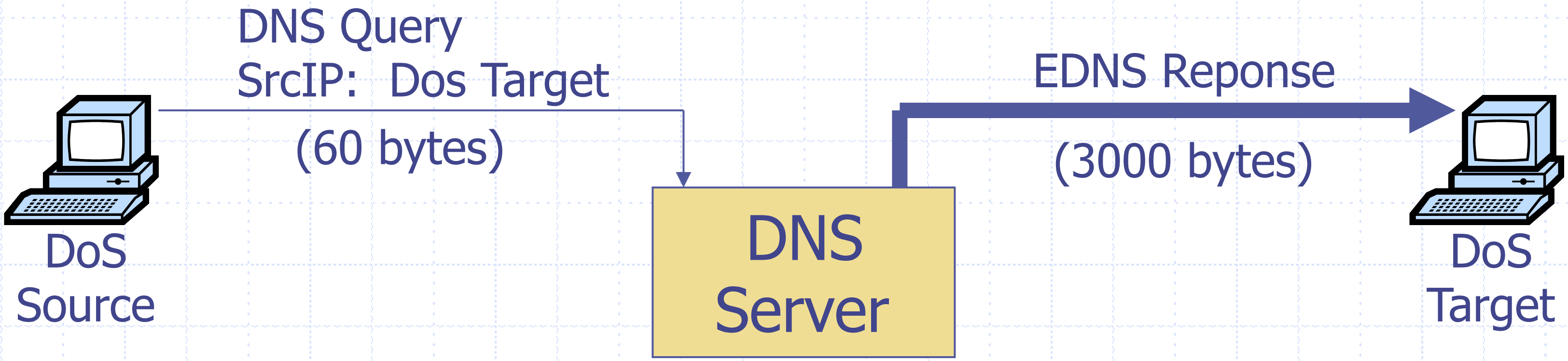


- Send ping request to broadcast addr (ICMP Echo Req)
- Lots of responses:
  - Every host on target network generates a ping reply (ICMP Echo Reply) to victim

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)

2014: 28M open resolvers (openresolverproject.org)

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

Scale, Targeting and Frequency of Attacks

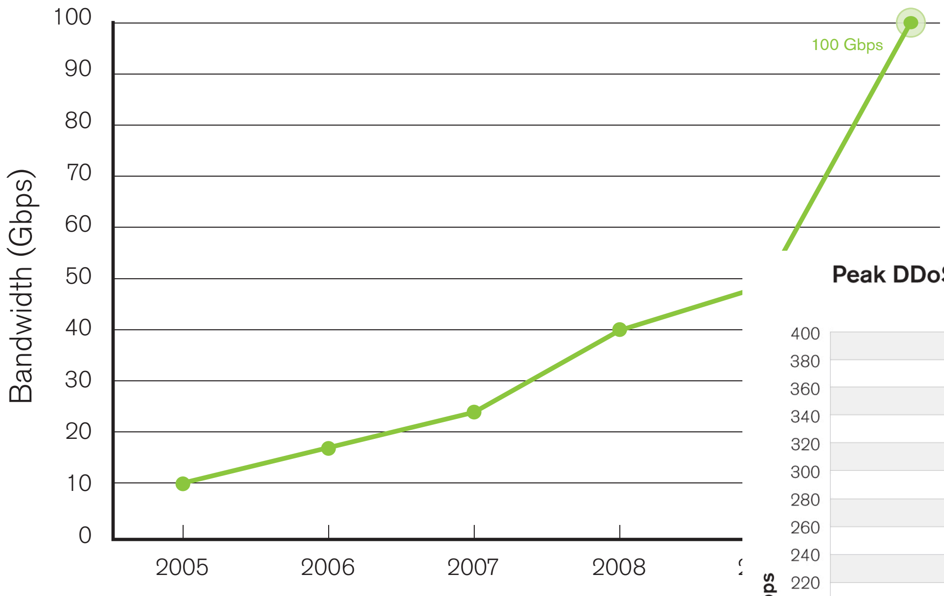
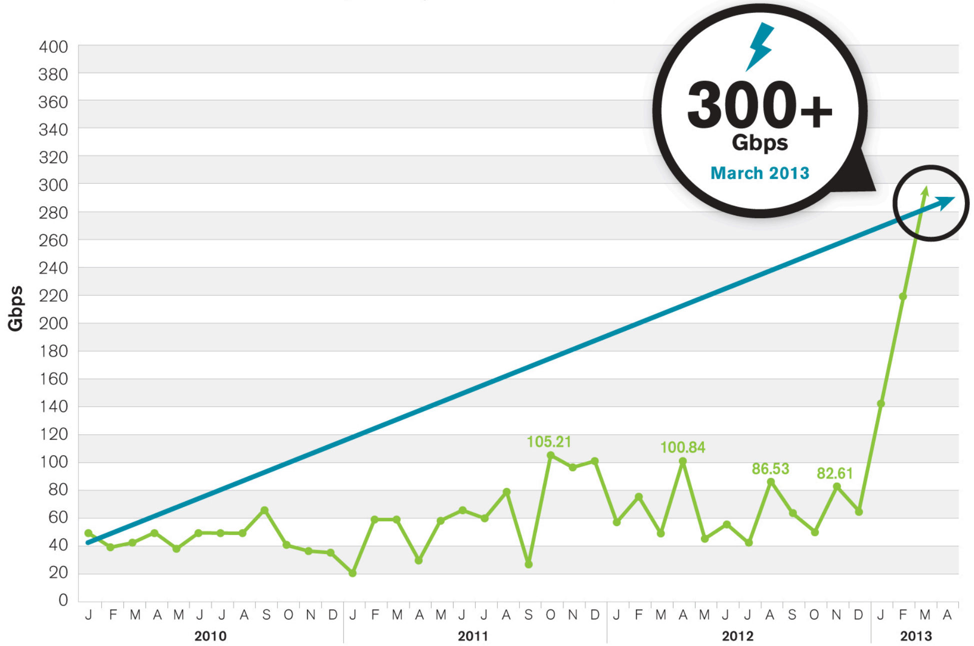


Figure 13

Source: Arbor Networks, Inc.

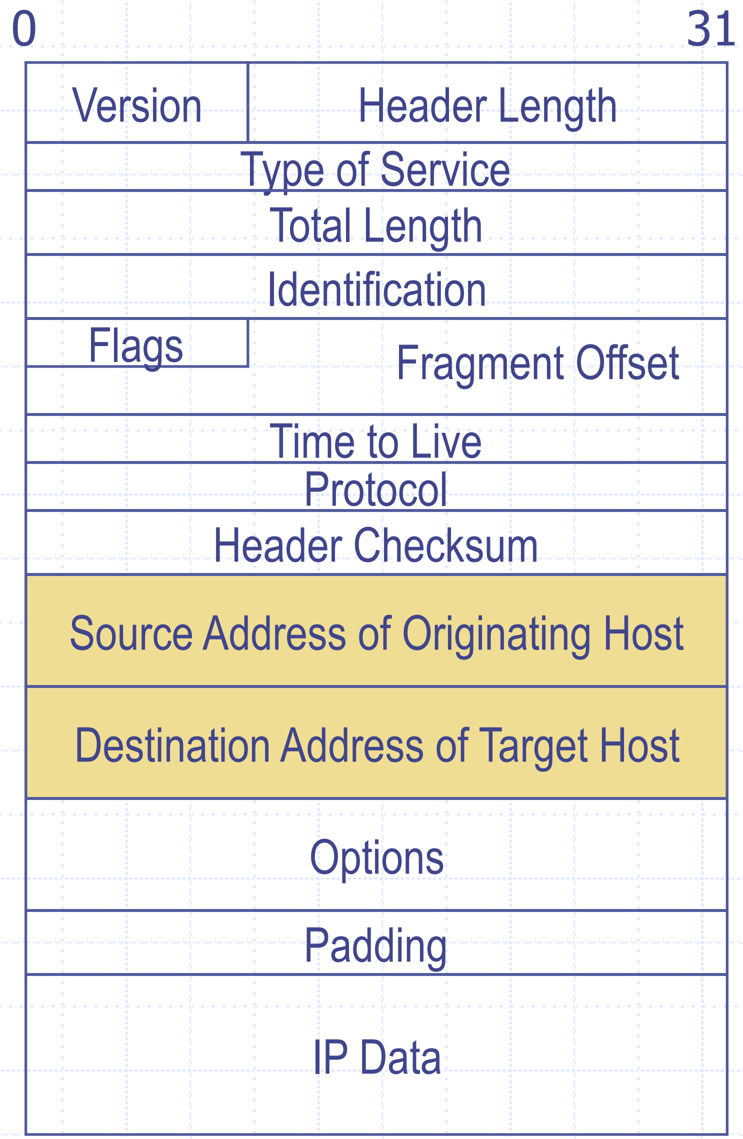
Peak DDoS Attack Size (January 2010 to Present)



Source: Arbor Networks, Inc.

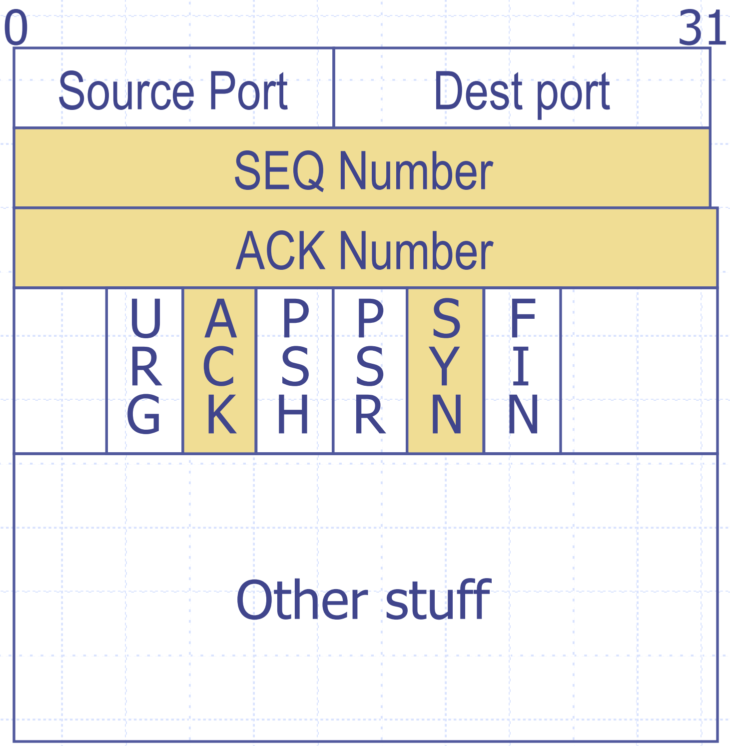
Review: IP Header format

- Connectionless
  - Unreliable
  - Best effort

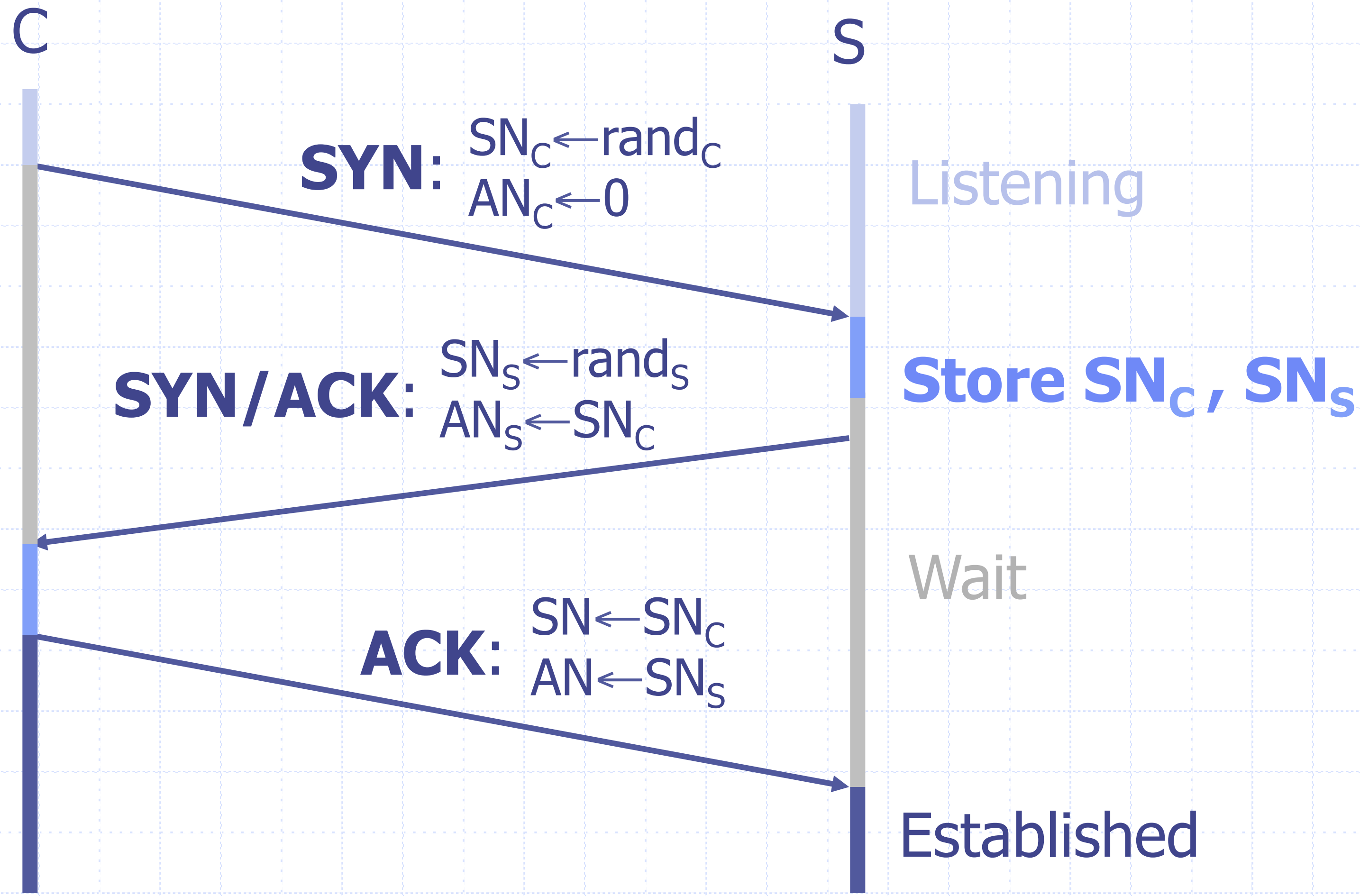


Review: TCP Header format

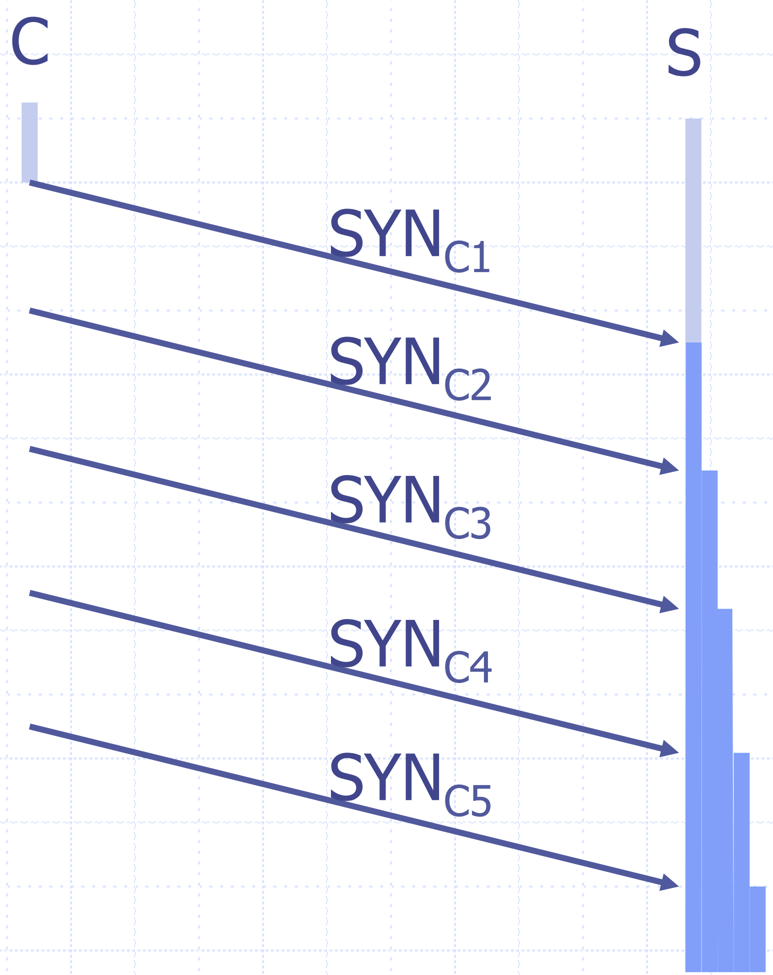
- TCP:
  - Session based
  - Congestion control
  - In order delivery



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 need only send 128 SYN packets every 3 minutes.

⇒ 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

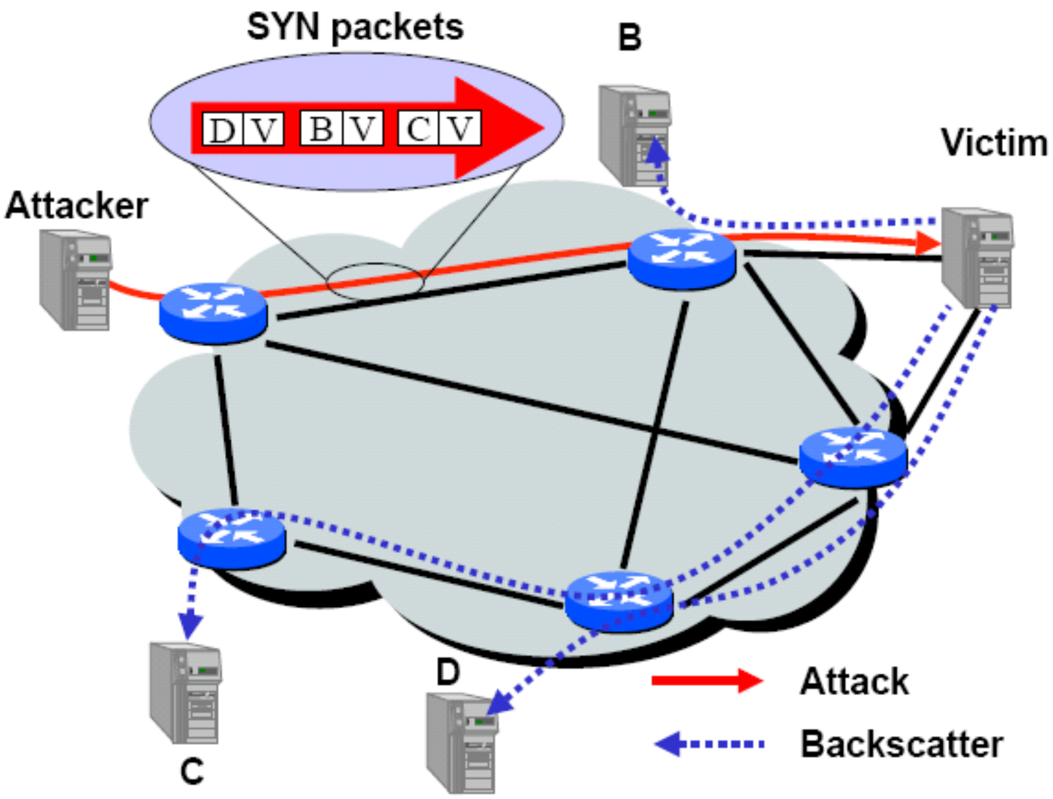
Syncookies

[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

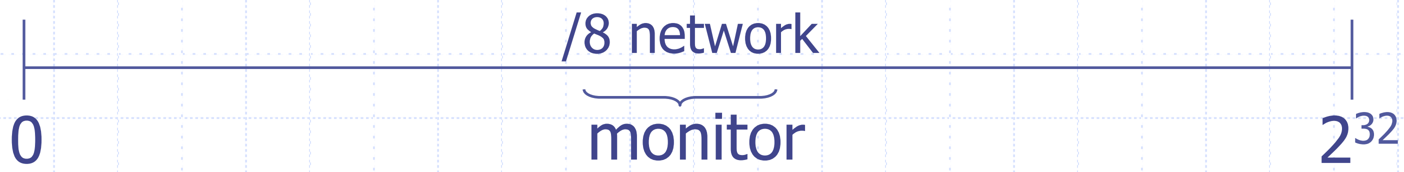
SYN floods: backscatter [MVS' 01]

- 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:
    - Estonian ISPs blocked all foreign traffic until attacks stopped

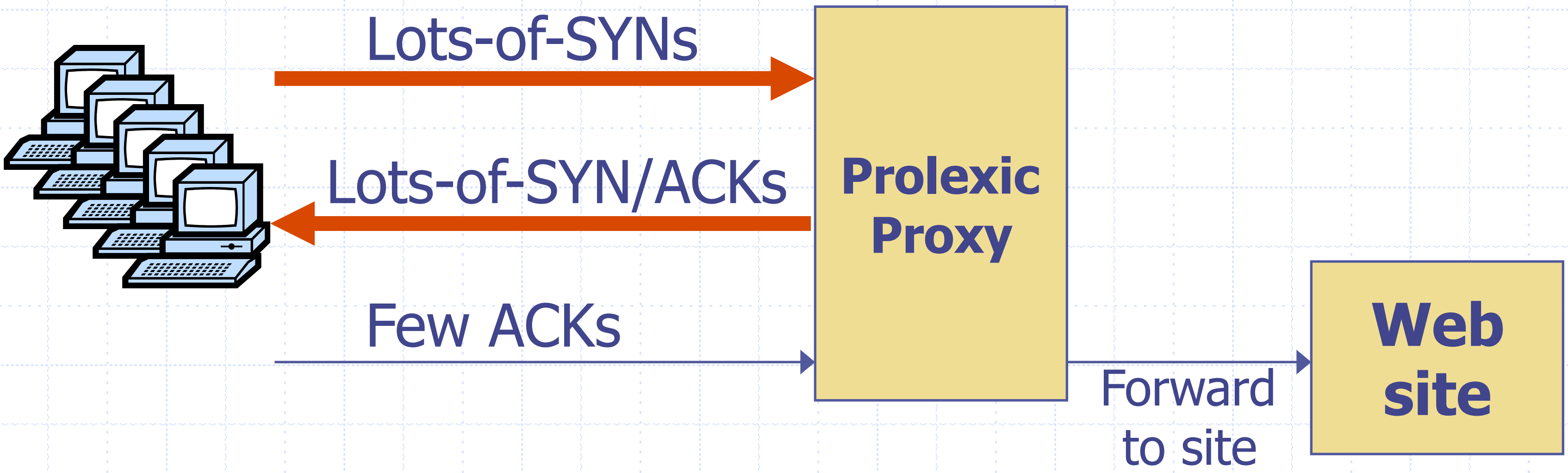
  => DoS attack had little impact inside Estonia

SYN Floods II: Massive flood
(e.g BetCris.com ‘03)

- Command bot army to flood specific target: (DDoS)
  - **20,000** bots can generate **2Gb/sec** of SYNs (2003)
  - At web site:
    - Saturates network uplink or network router
    - Random source IP ⇒
      attack SYNs look the same as real SYNs
  - What to do ???

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.

DNS DoS Attacks (e.g. bluesecurity ’06)

- DNS runs on UDP port 53
  - DNS entry for victim.com hosted at victim_isp.com
- DDoS attack:
  - flood victim_isp.com with requests for victim.com
  - **Random source IP address** in UDP packets
- Takes out entire DNS server: (collateral damage)
  - bluesecurity DNS hosted at Tucows DNS server
  - DNS DDoS took out Tucows hosting many many sites
- What to do ???

DNS DoS solutions

- Generic DDoS solutions:
  - Later on.   Require major changes to DNS.

- DoS resistant DNS design: (e.g. CloudFlare)

  - **CoDoNS**:   [Sirer' 04]
    - Cooperative Domain Name System

  - P2P design for DNS system:
    - DNS nodes share the load
    - Simple update of DNS entries
    - Backwards compatible with existing DNS

DoS via route hijacking

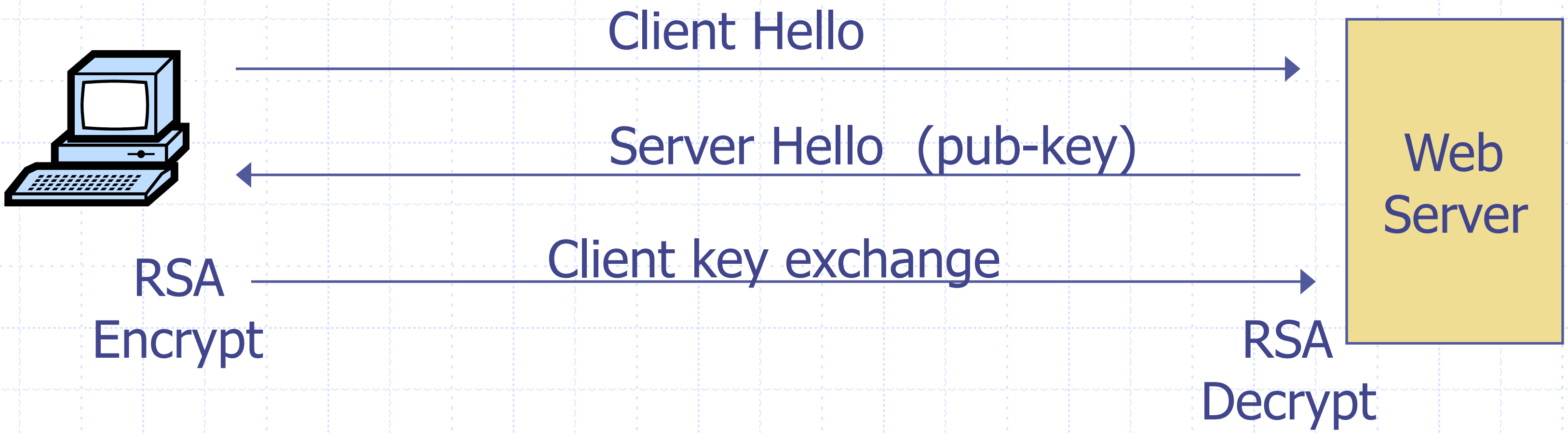
- YouTube is 208.65.152.0/**22** (includes 2^{10} IP addr)
  youtube.com is 208.65.153.238, …

- 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 at higher layers

- SSL/TLS handshake [SD'03]



  - RSA-encrypt speed ≈ 10× RSA-decrypt speed

  ⇒ Single machine can bring down ten web servers

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

  ⇒ 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

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

  - 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
  - ⇒ 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.

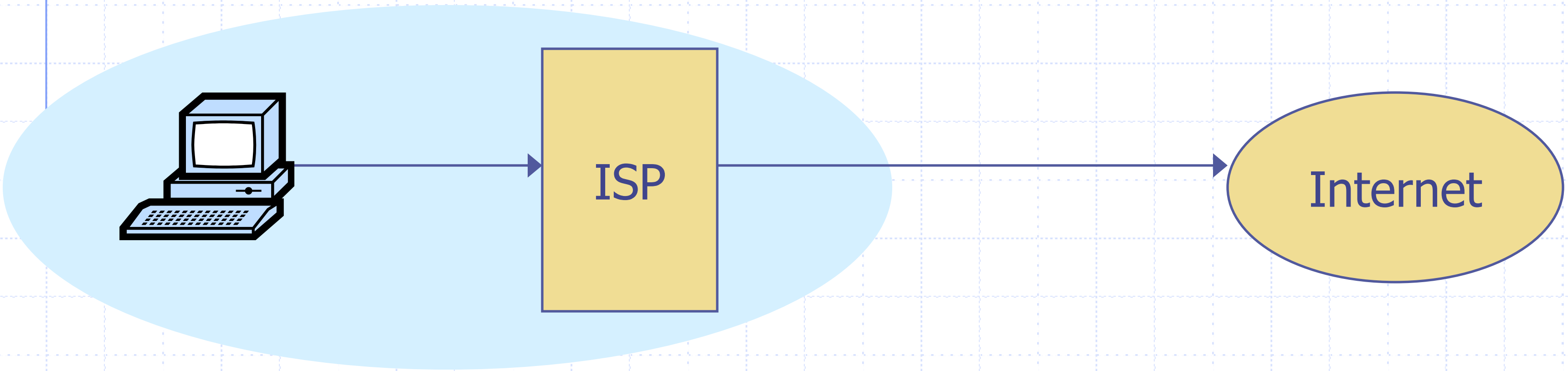
3. Source identification

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 (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

2014:

- 25% of Auto. Systems are fully spoofable (spoofer.cmand.org)
- 13% of announced IP address space is spoofable

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

2. Traceback [Savage et al. ’00]

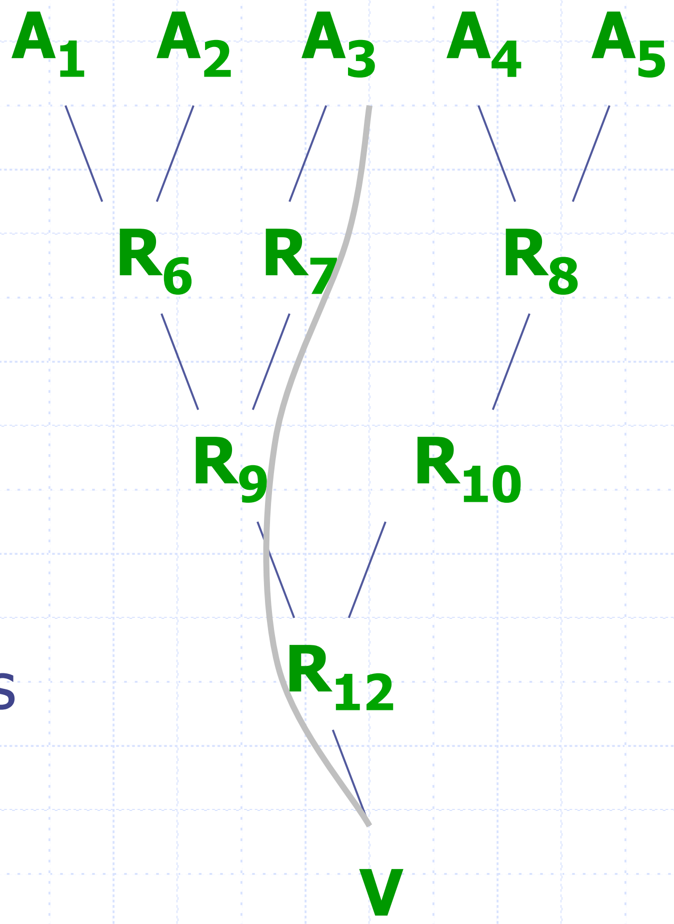
- Goal:
  - Given set of attack packets
  - Determine path to source
- How: change routers to record info in packets
- Assumptions:
  - Most routers remain uncompromised
  - Attacker sends many packets
  - Route from attacker to victim remains relatively stable

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

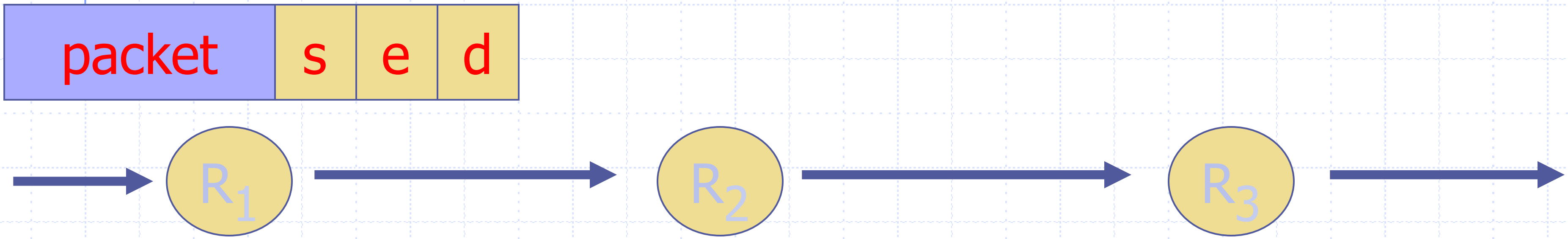
- Data fields written to packet:
  - Edge: *start* and *end* IP addresses
  - Distance: number of hops since edge stored

- 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
```

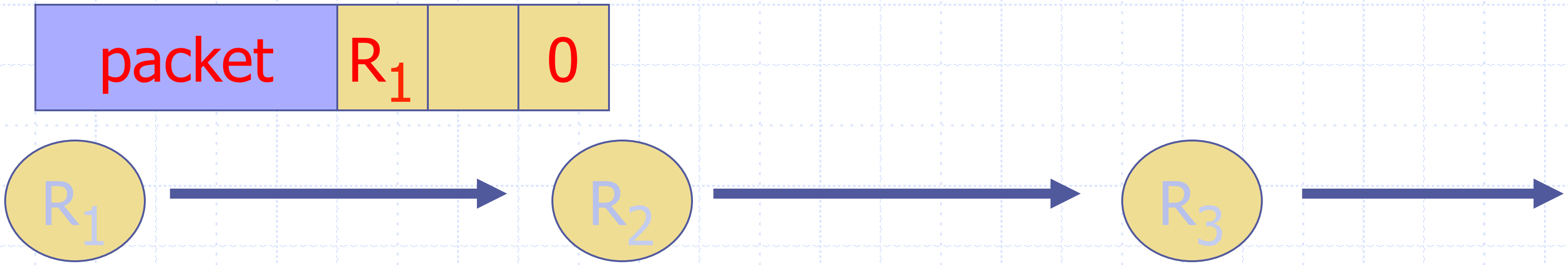
Edge Sampling: picture

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



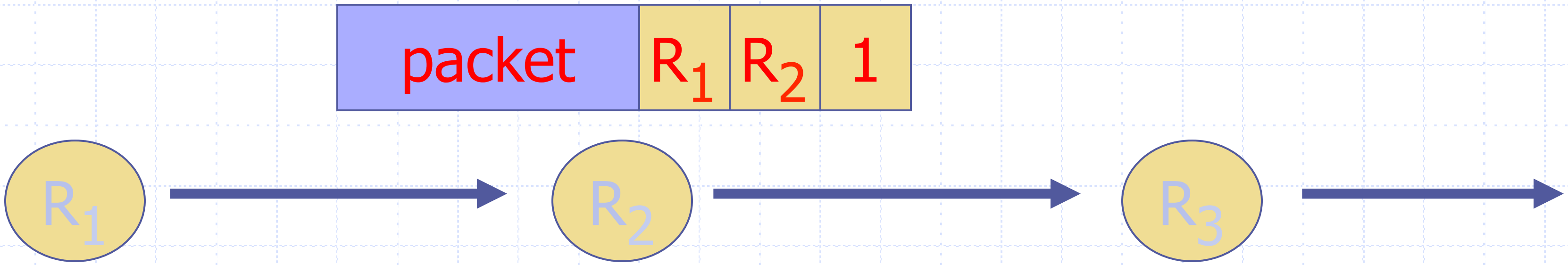
Edge Sampling: picture

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



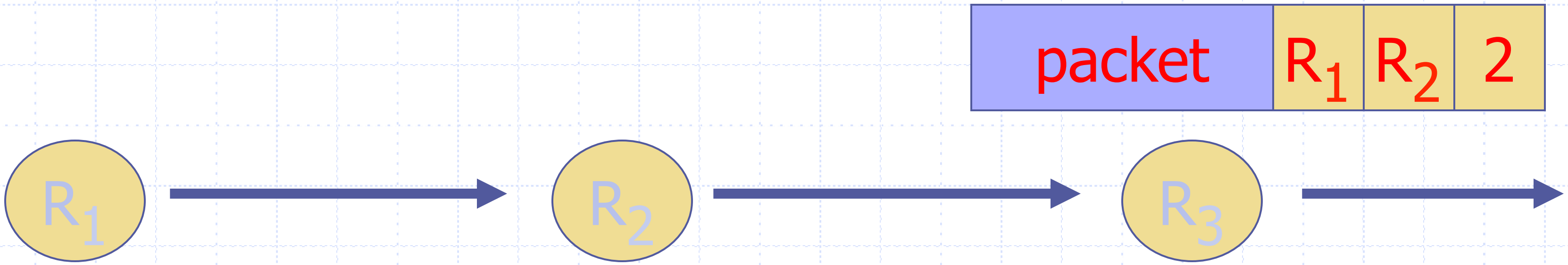
Edge Sampling

- 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

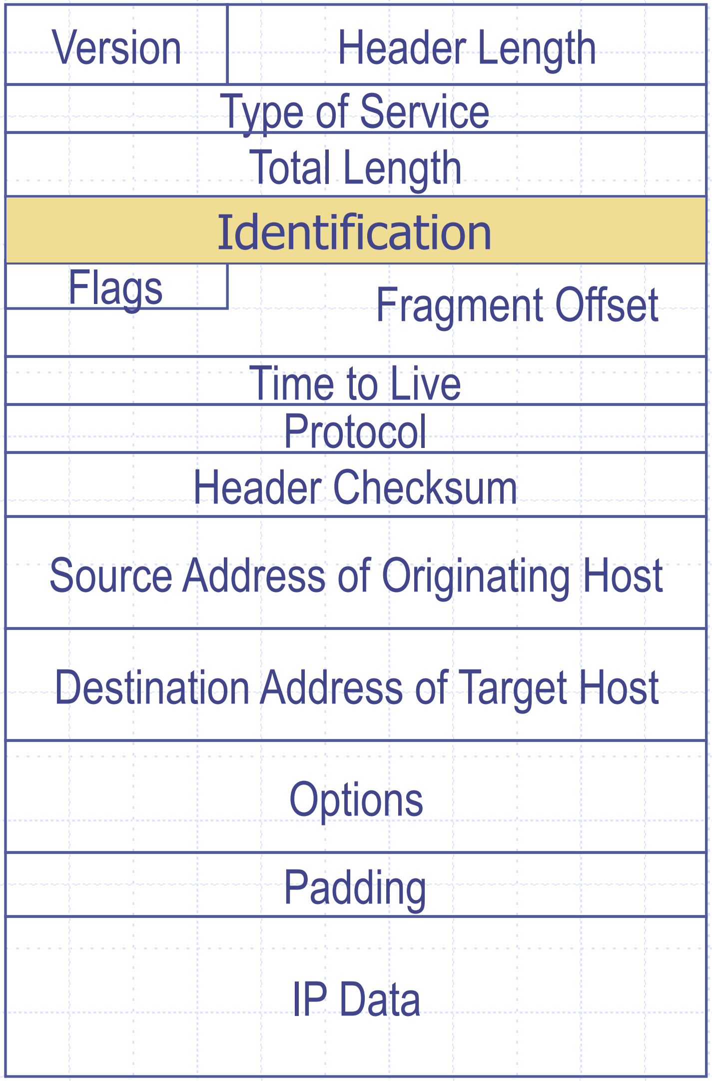
Details: where to store edge

- Identification field
  - Used for fragmentation
  - Fragmentation is rare
  - 16 bits

- Store edge in 16 bits?

offset	distance	edge chunk
0 2	3 7	8 15

  - Break into chunks
  - Store start ⊕ end



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

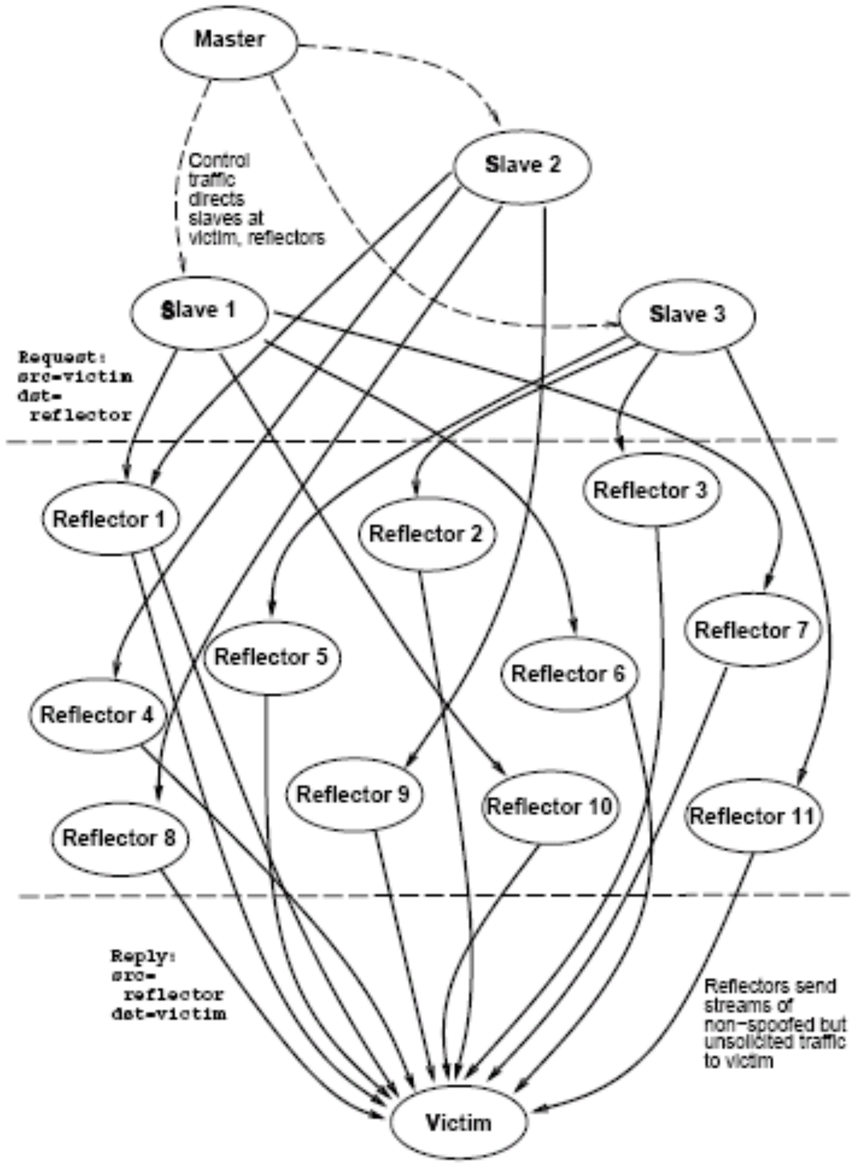
Problem: Reflector attacks [Paxson ’01]

- **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

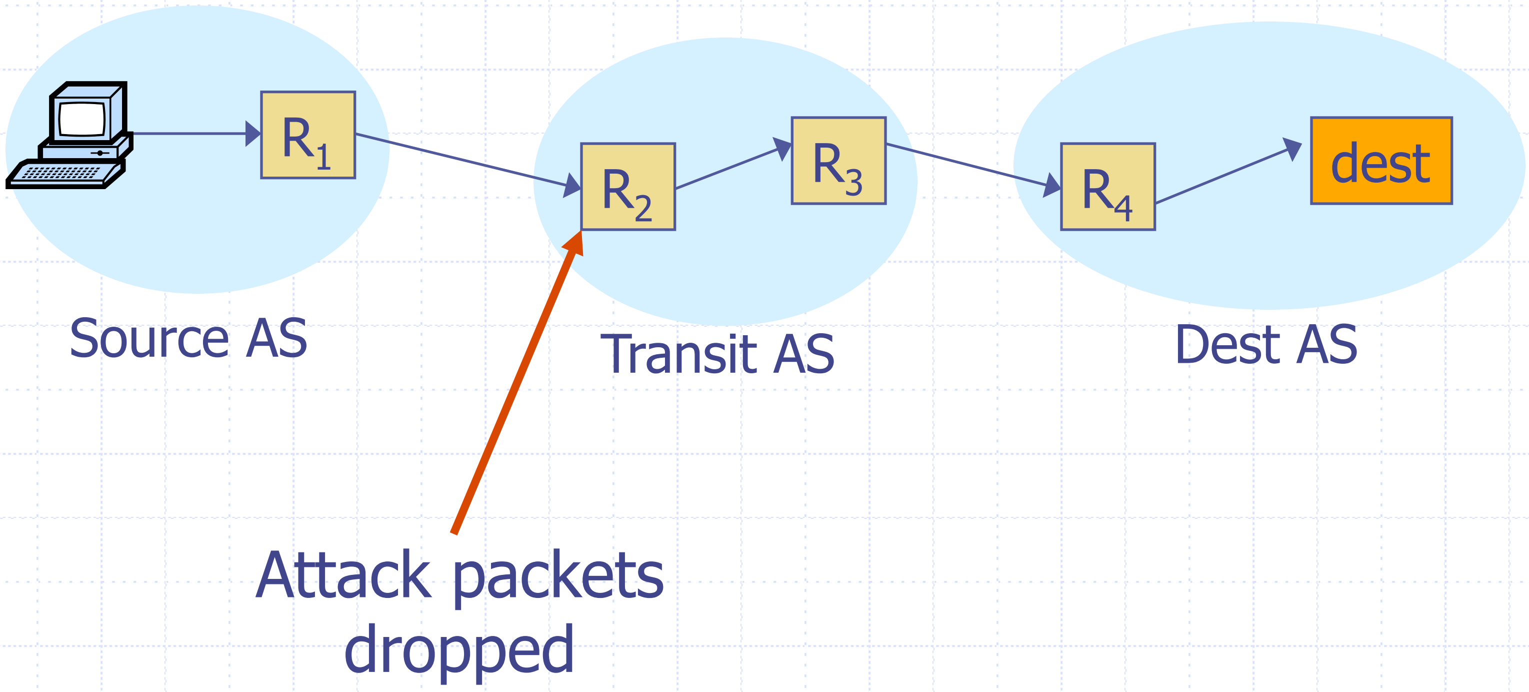
- Anderson, Roscoe, Wetherall.
  - Preventing internet denial-of-service with capabilities. SIGCOMM '04.
- Yaar, Perrig, and Song.
  - Siff: A stateless internet flow filter to mitigate DDoS flooding attacks. IEEE S&P '04.
- Yang, Wetherall, Anderson.
  - A DoS-limiting network architecture. SIGCOMM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



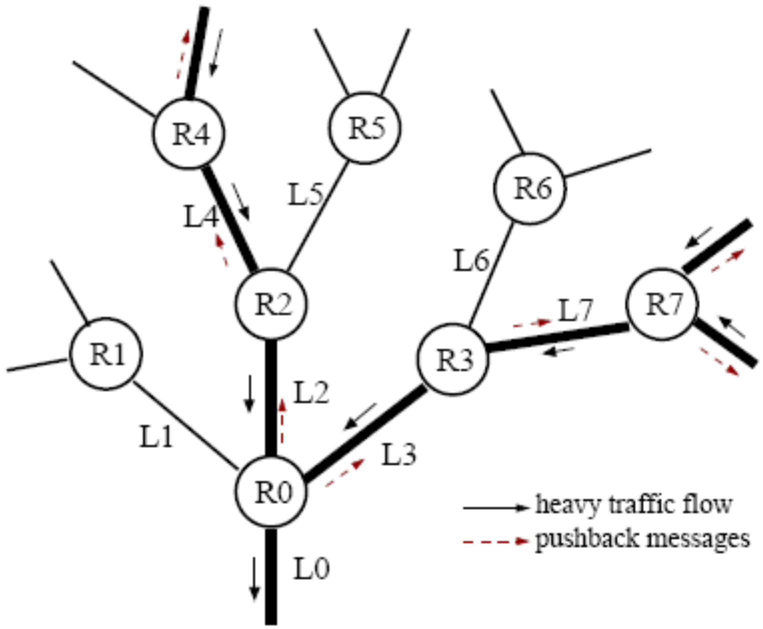
Pushback Traffic Filtering

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.

THE END