Announcements

- **No question session this week**

Stretch break

DoS attacks

- **In Feb. 2000, Yahoo's router kept crashing**
  - Engineers had problems with it before, but this was worse
  - Turned out they were being flooded with ICMP echo replies
  - Many DDoS attacks followed against high-profile sites
- **Basic Denial of Service attack**
  - Overload a server or network with too many packets
  - Mamize cost of each packet to server in CPU and memory
- **Distributed DoS (DDos) particularly effective:**
  - Penetrate many machines in semi-automatic fashion
  - Make hosts into "zombies" that will attack on command
  - Later start simultaneous widespread attacks on a victim

Smurf attack

- **Yahoo attack was smurf attack**
  - Penetrated hosts on well-connected networks
  - Flooded LAN with broadcast pings “from” yahoo
  - Every host on LAN then replied to Yahoo
  - Attack was *amplified* through uncompromised hosts
- **Can tolerate above by filtering packets**
  - Packets all ICMP echo replies from particular addresses
  - Attack still had to be traced to stop waste
  - But attack packets could be distinguished from most legitimate traffic

The SYN-bomb attack

- **Recall the TCP handshake:**
  - $C \to S$: SYN, $S \to C$: SYN-ACK, $C \to S$: ACK
- **How to implement:**
  - Server inserts connection state in a table
  - Waits for 3rd packet (times out after a minute)
  - Compares each new ack packet to existing connections
- **OS can't handle arbitrary # partial connections**
- **Attack: Send SYN packets from bogus addresses**
  - SYN-ACKs will go off into the void
  - Server's tables fill up, stops accepting connections
  - A few hundred pkts/sec completely disables most servers

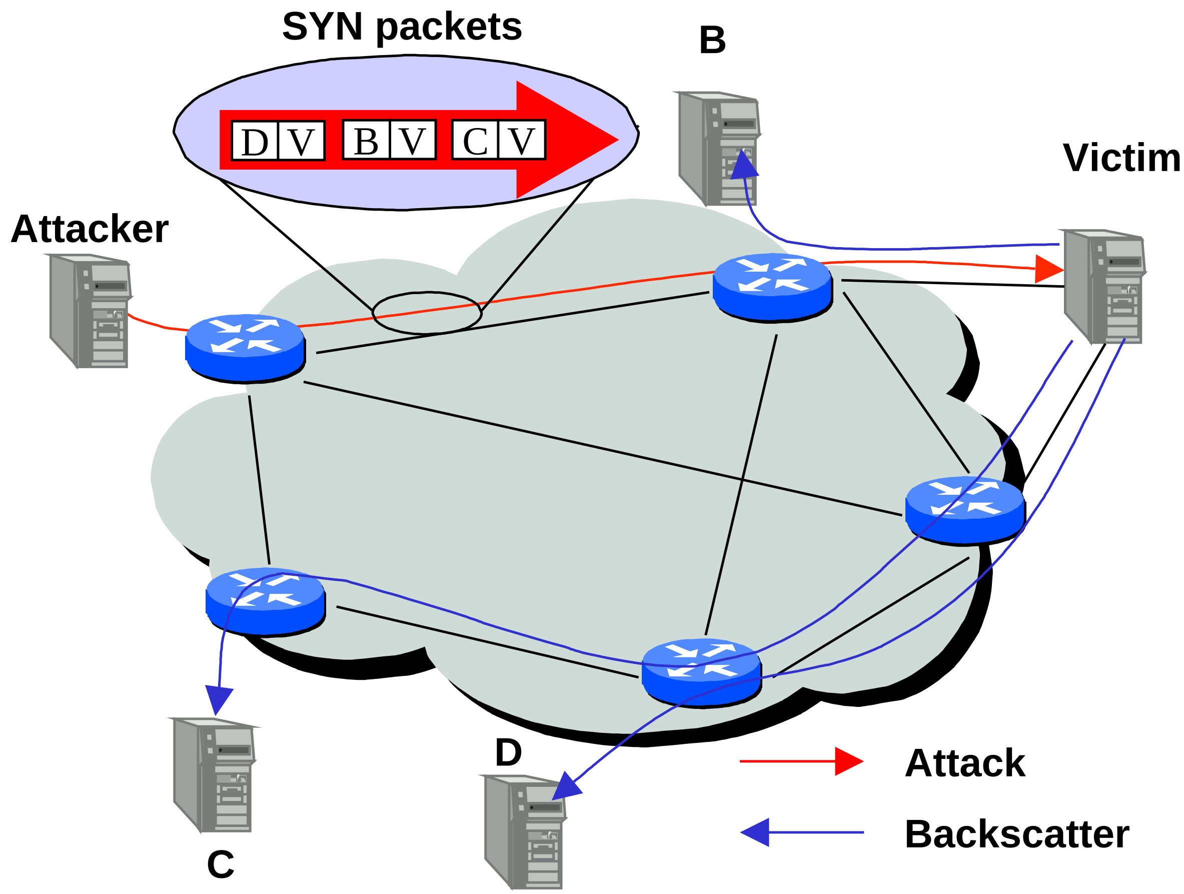
Other attacks

- **IP Fragment flooding**
  - Kernel must keep IP fragments around for partial packets
  - Flood it with bogus fragments, as with TCP SYN bomb
- **UDP echo port 7 replies to all packets**
  - Forge packet from port 7, two hosts echo each other
  - Has been fixed in most implementations
- **Standard flooding attacks**
  - Just flood-ping any site
  - Or bombard DNS server with requests

Making attacks hard to stop

- **Make DoS traffic indistinguishable from legit**
  - SYN-bomb ideal, DNS or any UDP service good
  - Flood-ping at least can be filtered anywhere upstream
- **Make source of attack hard to trace**
  - Victims need to trace attack and pull the plug
  - Can forge source IP address so packet origin not obvious
  - Most DoS tools use a random address for each packet
  - Can also use reflectors–bounce attack through 3rd parties

Backscatter



- **Premise: Many DoS attacks produce backscatter**
  - random IP source address gets reply

Measuring DoS activity

- **Measure backscatter to quantify DoS attacks**
  - If you m backscatter packets while monitoring n addresses, then $\sim nm/2^{32}$ attack packets were sent.
- **Researchers got lightly-loaded class-A network**
  - Represents 1/256 of all 32-bit IP addresses
  - Single workstation observed all traffic to class-A net
- **How worrisome are results?**
- **What are sources of error in experiments?**

Limitations of Technique

- **Factors that will cause underestimation**
  - Ingress filtering by ISPs
  - Packet loss
  - Reflector attacks
  - Attack packets that don't cause reply (TCP RST bomb)
- **Non-attack packets could cause overestimation**
- **Non-random source IP addresses could affect results either way**

Coping with denial of service

- **Engineering OSes to tolerate attacks**
  - Reduce state required for embryonic TCP connections
  - Increase size of hash table for protocol control blocks
- **Network monitoring box (schuba et al.)**
  - Passively monitors network (like Bro)
  - Uses heuristics to detect SYN bomb attacks
    (e.g., traffic paterns w. invalid source addresses)
  - Monitor engineered to keep little state
  - Send out forged RST packets to free resources on victim

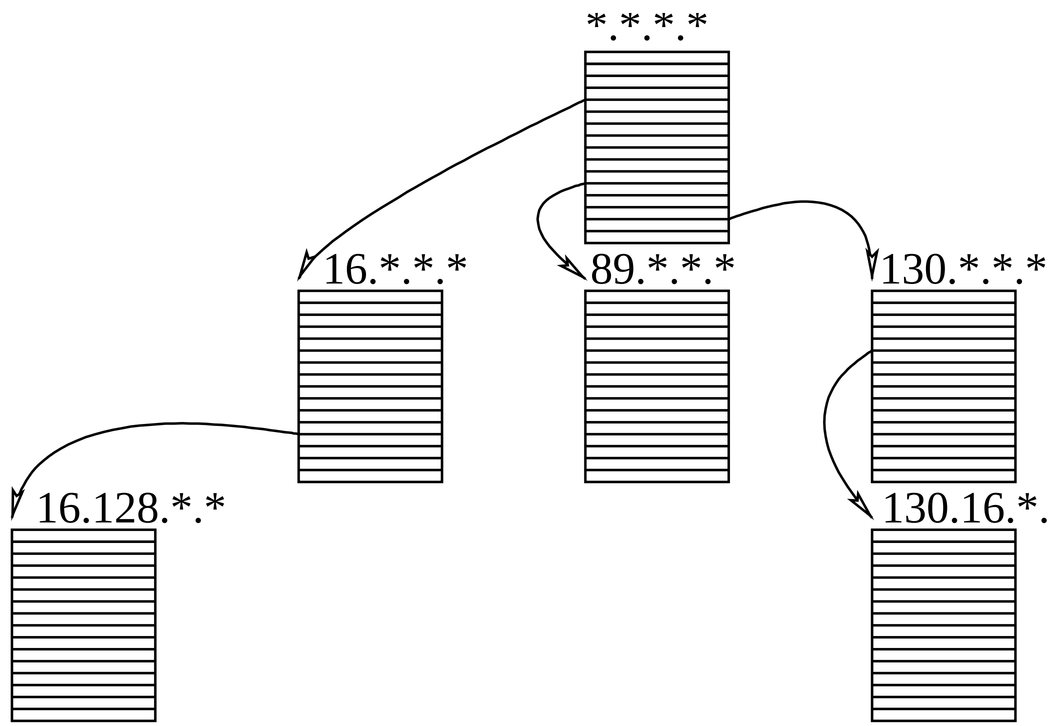
Egress filtering

- **Forged addresses complicate shutting off DoS**
  - Where is flood of packets coming from?
- **Filter forged outgoing packets**
  - Sites should block outgoing packets not from their network
  - ISPs should block packets not from customer's network
- **But still need to detect and shut down attacks**
- **And most attackers can find non-filtered networks anyway**

MULTOPS: Detecting DOS attacks

- **Observation: Many protocols bidirectional**
  - TCP: 0.5–1 ACKs for every data packet
  - DNS, ping: Reply for every request
  - Streaming media (not so easy, but can have heuristics)
- **Substantial imbalance means something is wrong**
  - Many SYNs not getting SYN ACKs (SYN bomb)
  - Many ICMP echo requests not getting replies (ping flood)
- **Attempt to detect problem and filter bad sources**
  - If attackers being egress filtered, will work
  - Can also be run in reverse to detect outgoing attacks
    (E.g., detect if NYU's network is being used for DoS attack)

Multops tree structure



- **Keep aggregate statistics for address prefixes**
  - Subdivide ranges in which an attack is detected
  - Keeps detailed statistics for attackers with limited space
  - Defend against attempts to exhaust memory

Tracing forged packets

- **MULTOPS not useful against forged packets**
  - Don't know which packets to fliter upstream
  - Can't find attacking machine to pull the plug
- **Need to trace attacks back link-by-link**
  - Goal: List of routers, where prefix is path to attacker
- **Many techniques for tracing, with trade-offs:**
  - Management, Bandwidth, Router CPU, Distributed attacks, Post-mortem capability, Preventative vs. Reactive capability

Input debugging

- **Some routers can trace output to input**
  - Develop attack signature to classify bad packets
  - Router tells you which input port they are from
- **Of course, only router administrator can do this**
- **Must continue on to upstream routers, in other realms**
- **Not all routers have this capability**

CenterTrack

- **Problem: ISPs want to trace attacks themselves**
  - Don't want to involve other administrators for each trace
- **CenterTrack: Employ overlay network**
  - Reroute all of victims traffic through an overlay network
  - Can do this by advertising different route with BGP
  - Send all traffic through central tracking router
  - Run input debugging on tracking router

Controlled flooding

- **Problem: Suppose you want to track attack w/o support from network operators**
- **Solution:** ***controlled flooding*** **[Burch&Cheswick]**
  - Exploit attacks that cause other hosts to flood you
  - Use knowledge of network to flood along various links
  - Infer source of real attack from interference with your attack
- **Ingenious, but somewhat evil (exploiting hosts)**

ICMP traceback

- **Goal: Let people trace attacks less destructively**
- **Have routers send tracing traffic**
  - Each router randomly chooses 1 in 20,000 packets to trace
  - Sends special ICMP traceback packet including packet and link that it came from
  - Victim can trace attack back from these packets
- **Unfortunatly, hard to implement**
  - Not all routers know input link when processing packet
- **Other weaknesses?**

ICMP traceback disadvantages

- **ICMP traffic sometimes differentiated from TCP**
  - More willing to drop them when under attack
- **Attacker can flood with forged traceback packets**
  - People will filter traceback packets to survive
  - How to tell real packets from forged ones?
- **Incremental deployment makes tracing hard**
  - Can't line up input link to previous node if previous node isn't generating tracebacks

Packet marking

- **Put tracing information in packets themselves**
- **Node append: The simplest solution**
  - Each router appends its address to every packet
  - Can get attack path from any packet
- **Problem: No room in packets**
  - E.g., with MTU discovery, TCP sends maximum sized segments
  - Would need to fragment, terrible overhead

Node sampling

- **Reserve a single fixed-size node field in header**
  - Just enough to hold IP address of one router—32 bits
- **Routers stamp their addr. in field w. probability** p
- **Eventually victim will get stamps from whole path**
  - Get stamp from d hops upstream with prob. $p(1-p)^{d-1}$
  - Can infer number of hops d from # of pkts. w. stamps
  - If $p > 0.5$, attacker cannot fake closer routers
- **Limitations**
  - Need many packets to trace away nodes. With $p = 0.5$, $\sim 300,000$ pkts. needed for 95% confidence in router order
  - Even 32 bits hard to find in all packets
  - Hard to separate paths from multiple attackers

Edge sampling

- **Add three fields to each packet: start, end, distance**
- **Router at address A marks packets as follows:**
  - With prob. p: start $\leftarrow A$, distance = 0
  - Else: distance$++$. If distance was 0, end $\leftarrow A$.
- **To reconstruct path, victim makes graph**
  - Starts with own address, inserts edge for each packet
  - Eliminate edges (start,end,d) if d not distance in graph
- **Works well with multiple attackers**
- **Incremental deployment works well, too**
  - An edge is closes two routers implementing system
- **Still requires non-existent space in IP headers**

Compressed edge sampling [Savage et al.]

- **Save a factor of two by XORing start & end**
  - Packet with $d = 0$ contains address of first router
  - XOR that with address in pkt with $d = 1$ to get next hop, etc.
- **Put only the fragment of an address in each packet**
- **Use checksum to add redundancy**
  - 32-bit checksum of IP address interleaved with address bits
  - Try all possible fragment reconstructions
  - Discarded ones in which checksum does not work out

Implementation

- **Use unused fragment ID in non-fragments**
- **You get 16 bits. Allocate as follows:**
  - 3 bit offset (which 1/8 of address is this)
  - 5 bit distance (32 hops is generally enough for internet)
  - 8 bit edge fragment
- **Distance aligned with TTL for checksum**
  - Makes implementation efficient—no change in IP checksum
- **Issue of fragmentation (though $< 0.25\%$ of traffic)**
  - Upstream fragments: If marked, frag IDs may then differ. So trash pkt & use full edge marking w. low probability
  - Downstream: Can get ugly if IDs reused. Could use DF bit.